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A comprehensive analysis of digitalisation in the agri-food supply chain - with a special focus on food safety issues

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A comprehensive analysis of digitalisation in the agri-food supply chain - with a special focus on food safety issues

Doctoral dissertation

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1. INTRODUCTION

My dissertation deals with a comprehensive analysis of digitalisation in the agri-food supply chain (AFSC). The focal research topic is the relationship between food safety issues and the opportunities offered by digitalisation. Technological tools for the 21st century have led to advances in within the field of traceability of products and processes in many areas of the manufacturing industry. In the agri-food industry, this is a key area for meeting quality assurance requirements. The collection, real-time transmission, analysis and interpretation of product and process data can support the fulfilment of food safety requirements. Digitalisation is a process that is more than just automating facilities. Regarding this topic, it is important to note how the concepts related to digitalisation can be understood as interdependent. Digitisation, "as the material process of transforming analogue information streams into digital bits", represents the first stage (Brennen and Kreiss, 2016, p. 1). The subsequent stage is represented by digitalisation itself, which is "the transformation of many aspects of social life around digital communication and media infrastructures" (Brennen and Kreiss, 2016, p. 1). Moreover, according to Demeter and Losonci's research (2020), digitalisation also includes the policy of operating paperless (Demeter and Losonci, 2020). The relevance of the topic is of key importance, since food safety has been endangered recently (Focus.de website, 2023), however digital solutions to empower it seem to be emerging (Menon and Jain, 2021, Cruz et al., 2018, Corallo et al., 2018). Therefore, there is a dedicated chapter (2.1. Relevance of the research scope) in my dissertation to state my point of view about the AFSC being analysed in the dissertation.

The thesis examines the impact of digitalisation on food safety from a management perspective while applying a three-pillar perspective conducted by me (decision-maker, funder, and technology provider), contributing to the not-isolated analysis of the implementation of technological solutions. The findings of the dissertation aim to contribute to the existing literature with its comprehensive attitude. Its aim is to raise awareness of the importance of this issue among both the academic community, internal (e.g., owners, managers) and external (e.g., customers, government) stakeholders of food production and processing companies. The initial research scope focuses on traceability, which is of paramount importance in quality assurance, especially in the food industry (Tian, 2018; Tse et al., 2017). The targeted areas of literature review in my thesis cover the questions a) which are the influencing studies regarding relationship of digitalisation and food safety? b) which areas of food safety are supported by digitalisation solution, and c) which digitalisation solutions contribute to ensuring traceability? The research questions of the theoretical background underpin the chosen methodologies applied in the three inserted papers which build the body of my dissertation.

Paper Nr. 1 focuses on answering PhD-RQ1: **How does the relationship between available technological investment in the agri-food industry and the willingness of decision makers look like?** To answer PhD-RQ1 a hybrid methodology was used. A systematic literature review was mixed with public data analysis to uncover the relationships between the goals of decision-makers and the tools (funding) used for fulfilling them. The research shows that interruptions of policy-makers while ongoing crisis situations have helped agri-food actors to adapt to the challenges of the pandemic. Available technological development opportunities such as process automation, sensor and control technologies and robotics have also contributed to the sector's competitiveness, however the findings show that the continuous challenges such as inflation or rapid change among the requirements can lead to lack of interest from the side of AFSC members. The research aims to fill a gap in the literature that has so far not investigated in an integrated way the relationship between technological investment and decision making.

Paper Nr 2. deals with the extension of the research scope, therefore it seeks to reflect not only to PhD-RQ1 but to the PhD-RQ2, too: **Which digitalisation tools are used by agri-food supply chain actors?** The aim of this paper is to answer the PhD-RQ2 with a comprehensive approach. Within the literature there is a lack of such comprehensive AFSC based analysis from the perspective of digitalisation, and the ones dealing with the topic (Barbosa, 2021) mainly target to describe the food safety relations of digitalisation. The second paper of my dissertation focuses on the effects of digitalisation on food safety which findings contribute to the existing literature. The methodology covers a bibliometric literature analysis which introduces the emerging trends and lets to build a cluster-based collection to show their characteristics. The findings of the study show that the examined tools can contribute to food safety operations, however there are challenges related to them. The effectiveness of AFSC technology solutions is highly dependent on the IT skills of the participants and the management of regulatory and standardisation issues, furthermore social, economic, and environmental limitations might have a huge impact on their application.

The role of Paper Nr 3. within the dissertation is to extend it with an empirical exploration of the applications of the previously analysed topics. PhD-RQ3: **How do food industry companies perceive the realisation of digitalisation and ICT based improvements in their operations and organisation?** The research identifies a gap in the literature on isolated operation of Industry 4.0 solutions, which can be observed in the analysis of available case studies. To answer this question a qualitative case study method was applied. Developing a research framework of analytical dimensions of strategy and organisation, data analysis, technology, employees, and corporate culture led to a broader analysis of the choses AFSC members. An important finding is that the impact of digitalisation goes far beyond production processes and significantly affects different levels of organisational functioning. The research showed that although the existence of Industry 4.0 strategies and conscious digitalisation actions are rare, companies are taking advantage of the opportunities offered by technology, often driven by labour shortages, the need to remain competitive and food safety regulations.

The aim of this doctoral research is to explore how to support the development of traceability of AFSCs through digitalisation tools, with a focus on decision making and strategy at the level of management. The thesis seeks to identify digital solutions and management practices that can facilitate effective traceability of agri-food products and services and contributes to enhance the transparency and security of supply chains. In this dissertation, digitalisation is understood not only in a technological context, but also in an organisational and strategic context, thus moving away from insular approaches. By focusing on the three key actors – decision-maker | funder | technology provider – that serve the members of the AFSC, the aim is to provide an integrated approach to digitalisation and to put management models into practice.

The structure of the thesis is divided into three major parts. First, I set out the scientific context of the topic. The focus of the literature analysis is on traceability, the rationale for which is that it is the most frequently identified area of digitalisation support in the literature review. The literature analysis presents the legal framework for food safety, the digitalisation solutions to support operations and the interrelationships between them. In addition, due to the high importance of the agri-food industry, I present an analysis about the impact of digitalisation affecting the industry during the research period (2019 to present).

The literature analysis is followed by a description of the methodological background, which includes the steps of the research design underlying the dissertation. I start with a description of the problem, highlighting the personal rationale for the choice of the topic, its topicality, and its socio-economic context. Then I illustrate the concepts related to the initial idea of the research using the research conceptual model. The formulation of the research objectives and questions serves as a prelude to a detailed presentation of the research methodology (choice of methodology). In the next step, in accordance with a classic research design, the thesis contains a conceptualisation, highlighting the most important concepts, and finally an operationalisation to illustrate the methodological coupling to answer the research questions. The third part of my article-based dissertation introduces the three chosen published papers which provide the body of my doctoral research, and at the end of the thesis the major findings, the limitations, and the further research steps are represented.

2. THEORETICAL BACKGROUND

2.1. Relevance of the research scope

The industry under research is one of the prominent economic sectors in Hungary (Kürthy et al., 2016), however the main focus of this dissertation is an area of major importance at national, regional and global level. When examining the food supply chain, agricultural actors are also included in the definition of producers, and the literature therefore typically refers to AFSCs. The thesis deals with AFSC members. In order to introduce the examined field, first I will conceptualize the most important terms regarding the food supply.

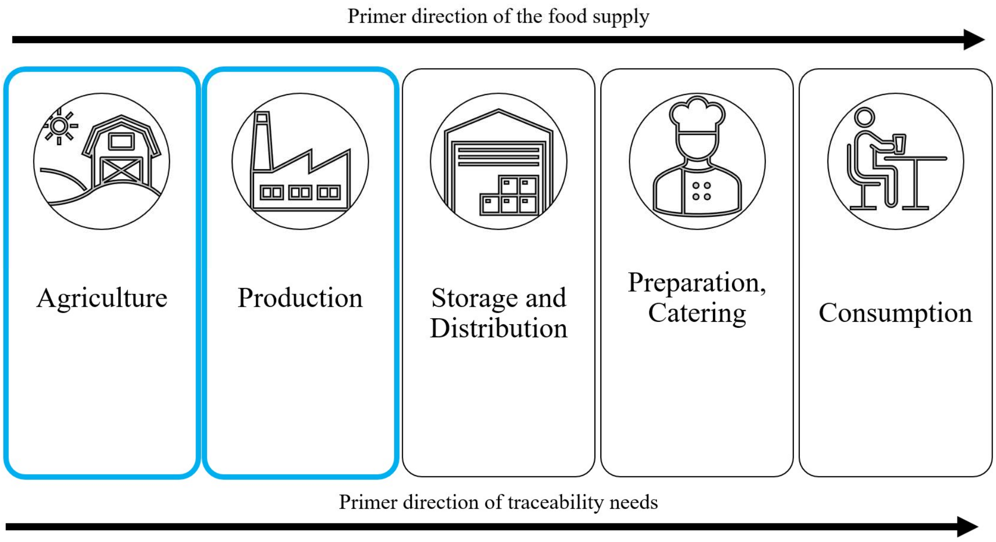

Figure 1: The schematic structure of the agri-food supply chain – positioning the research scope in the AFSC
Source: own editing, based on (Wu et al., 2010; Ganeshkumar et al., 2017)

According to experts agriculture is the starting point of the food supply (Barbosa, 2021; Dadi et al., 2021; Lezoche et al., 2020; Wu et al., 2010). This is where the process of food production starts, followed by primary and subsequent processing steps. Agriculture can be interpreted as "the most comprehensive word used to denote the many ways in which crop plants and domestic animals sustain the global human population by providing food and other products" (Harris and Fuller, 2014, p. 104). In my thesis I aimed to examine both the members from the agricultural and the food processor perspective. The reason for this choice can be traced back to the comprehensive study of Kürthy et al. (2016) about the status of the Hungarian food sector. They consider the food sector as the primary market of agricultural products (Kürthy et al., 2016). This approach confirms Wu's (2010) AFSC representation, thus I consider agriculture as part of the AFSC in the thesis. In this respect, the research will pay increased attention to both the areas affecting producers and manufacturers. Agriculture contributed 3.6% to the production of gross domestic product (GDP) in 2018 (KSH, 2020). This ratio changed until 2022, in 2022 the contribution of agriculture was 3.2% to the GDP. This reduction is mainly due to unfavourable weather conditions (low precipitation and extreme summer drought) compared to the previous years (KSH, 2022). In addition, the food industry accounted for 1.8% of GDP production and 2.2% of total gross value added in 2017. This ratio decreased until 2020, about the GDP value of the food industry the last available national statistics data (from the year 2020) is 2.0% (KSH, 2020). According to the Labour Force Survey, 215.000 people were employed in agriculture in 2018. The number of employees did not change a lot within the last years, it remained 214000 in 2020 (KSH, 2020). Besides this, 3.2% of the total workforce was employed in the food sector (KSH, 2018). On the other hand, demand plays an important role in the food supply question. While the world's population exceeded the number of 8 billion people in November 2022 (UN Statistics, 2023), the residential number of Hungary has decreased within the past years (it is 9,597,085 in 2023 which is a 1.13 % decrease to the year 2022 and a 7.5% decrease in contrast to 1990) (KSH, 2023). This reduction does not mean that the food supply in Hungary must be decreased.

From a regional perspective, it is worth noting that the regulatory framework for food supply within the EU has an impact on the functioning of member states, with quotas and export-import regulations characterising the region (European Comission, n.d.). Within the European Union food industry plays an important role, since it is the largest manufacturing industry regarding the value added and labour data (European Commission, 2023a). As the importance both of agriculture and the food industry, from this on the agri-food sector, is also highlighted by the EU, it also keeps this sector among critical infrastructures (CI). Nowadays, in the era of various disruptive events, such as the pandemics caused by the Covid-19 virus and the military conflict between Russia and Ukraine, it is crucial to pay attention for the sectors having significant effects on the entire society. The EU defines Cis as "physical assets, services, information technology facilities, networks and property, the disruption or destruction of which would have a serious impact on the health, peace, security or economic well-being of Europeans or on the effective functioning of the EU and its Member States' governments" (EUR LEX Green Book, 2005). Food sector stays on the fifth place on EU's CI sector list (I. Energy, II. Information and communication technologies, III. Transport, IV. Water, **V. Food**, VI. Health, VII. Finance, VIII. Industry and IX. Legal order – Government, X. Public security – Defence) (Hungarian government decree 2080/2008 (30.VI.). The products produced within the food industry typically fall into the FMCG (fast moving consumer goods) product group. FMCG producers face fierce competition in their submarkets due to the scale of consumption and the volatility of demand.

At the global level, we can think beyond this to the level of interconnected supply chains, which – for reasons of cost efficiency and economies of scale – take the form of long chains rather than short ones. This raises issues of both sustainability and traceability.

At this point, the question arises: which impact does the high pressure to quick reaction time have on product quality and traceability? AFSC members have to respond to rapidly changing customer demand not only at a national level, but also regionally and globally, because of a constant desire for new product variations. The aim of this research is to explore the relationship between traceability tools used by companies (hopefully now supported by digitalisation) and food safety regulations and their coexistence in order to supply healthy, sustainable and safe food for consumers. In this respect, the research will pay increased attention to both the areas affecting producers and manufacturers, where the first steps of traceability are set.

In the first part of the literature review, the findings of the literature on the quality process and food safety regulations are presented. The next step of the literature review is to present the digitalisation solutions applied in the food industry, with a special focus on the issue of traceability, which is the focus of the research.

The literature review aims to examine the context in which actors in the AFSC operate, including public authorities. The analysis will provide a picture of the complex expectations that AFSC members in the industry need to meet, in order to be able to cope with the emerging technological developments. National, regional, and global expectations are addressed, as well as options for digital support for traceability. The aim of this part of the doctoral research is to explore these options and to find the links between the available digitalisation solutions, the regulations, and standardisations, which will provide the link between the papers presented in the thesis and the further orientation of the research.

The theoretical background begins with the description of the legal framework and its relation to quality management and the focus area of food safety "traceability".

As it was highlighted in the introduction, the agri-food sector is of paramount importance. Governments can influence the management and functioning of the agri-food sector, both at a national and an international level. To achieve strategic goals, authorities can make use of their power to create regulations and directives. These authorities (e.g., EU, or governments) are considered as decision makers. By developing strategies and using tendering processes through which they can influence developments at the level of AFSC members. Call for tender proposals are the tools which can connect investments with sustainable and digitalised technological solutions in accordance with AFSC members. In order to provide a detailed account of the relationship between the strategies of decision makers, the background of financial support, and the available technological solutions, I examined the topic in the first paper introduced in the thesis.

Drawing on the literature review of the thesis, prominent technologies are introduced which appeared in the systematic search (the second paper of the dissertation serves with a deeper analysis for this part (Freund, 2023)). In addition, it appears that the identified technological elements mainly serve the primary activities of the value chain activities (Porter, 1985). To provide a comprehensive view about the evolution and the emerging topics related to the research topic, I extended the research direction, in order to investigate how and with which tools can digitally support the value chain processes managed by AFSC members. The second paper examines this question, too.

The third paper of the thesis presents an exploratory research which we conducted in order to have a detailed overview of Hungarian companies from the agri-food sector, applying emerging technologies. This paper consists of a framework built by the Food Supply Chain Research Group and case studies from four important sub-sectors of the AFSC. Stakeholders, such as farmers and processors were interviewed to answer the research questions raised by our research team. The interviewees came from the sub-sectors of pasta manufacturing, dairy production, dairy processing, and meat processing.

2.2. Theoretical framework

The literature analysis model aims to examine the three key roles of the decision-maker – the facilitator/funder – and the technology provider, together with the opportunities, policies and tools provided by them, focusing on the management-level decisions of the AFSC members using them, in order to explore the directions of empirical research.

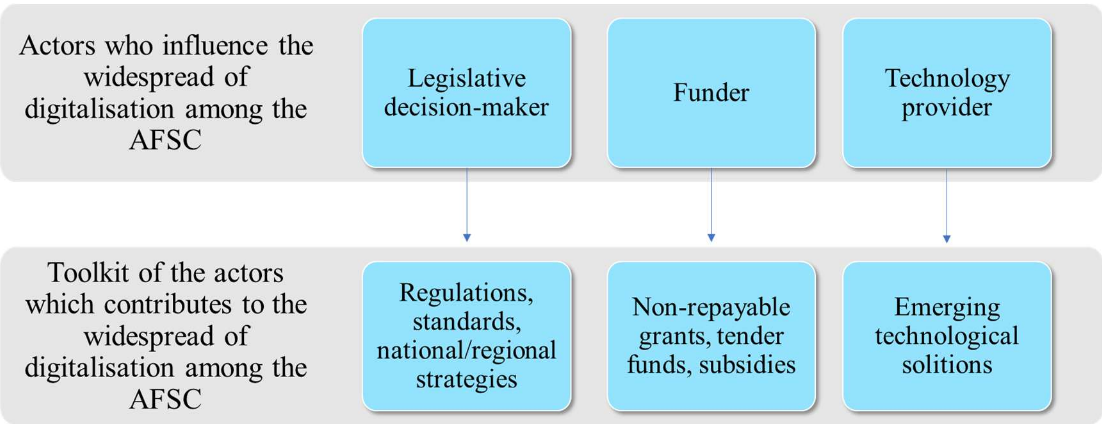

Figure 2: The concept of the analysis of the theoretical background
Source: own compilation

Figure 2 represents the body of the preliminary literature review which underpins the three chosen papers of the dissertation. The starting point of the literature analysis is the assumption that digitalisation is based on data collection, while quality management is mainly related to the adequacy of specific data. Technological developments in the era of Industry 4.0 (I 4.0) build on digitalisation which can be interpreted as the basis for I 4.0 (Nagy, 2019, Nagy et al. 2020b, Oláh et al., 2019) and is considered in my thesis as a preliminary step done by AFSC members in direction of developments. From the beginning of the dissertation, digitalisation is an umbrella term (Losonci et al., 2023, Lőrincz et al., 2024) serving for technological developments which are consequences of development processes combining digital tools to achieve a state where their integration boosts effectivity (Losonci et al., 2023, Demeter et al., 2024) and from the perspective of this thesis digitalisation is a broader term as I 4.0 as this is a basis of I 4.0 solutions. The importance of data is therefore paramount in the field of the agri-food sector. When quality or even food safety requirements are discussed, they can be considered as expectations of the conformity of products or processes (Veress et al., 2010). Besides by the relevant authorities required quality expectations, nowadays customers tend to raise their needs regarding food quality (e.g., origin of food, or less preservative supplements). The agri-food industry is based on a complex set of quality requirements (Hungarian Food Codex, HACCP guidelines, GMP (Good Manufacturing Practice) regulations). These requirements are widely applicable to the production of the equipment used (raw materials, processing procedures... etc.), as well as their operation (pressure maintenance, closed systems, material flow, mixing, self-cleaning... etc.), in addition to the quality requirements of the products manufactured (Food Chain Website, 2021; FDA Website, 2021; Njt.hu, 2021).

The actual laws in force in Hungary include both national and adopted international regulations. This is partly due to globalisation, as the Hungarian food market is characterised by a number of foreign-owned large companies which, in addition to Hungarian laws, are also forced to comply with the requirements of their home country or other requirements imposed by the parent company. Additionally, Hungarian companies also tend to produce for foreign markets. An overview of the main governing regulations is provided below.

The role of financial support is crucial nowadays, therefore the available opportunities are introduced in this thesis. The theoretical background analysis reveals the main areas where funding manifests, meanwhile the first paper of the dissertation provides deeper insights about the manifestation of funding opportunities.

2.2.1. Introduction of the role of the legislative "decision-maker"

As a result of the expansion of the range of regulations due to globalisation, besides national regulations, international ones have appeared on the Hungarian food market, which companies are starting to apply voluntarily or under pressure from their parent companies.

The European Union develops foundations for another mandatory regulations which must be in focus of EU member states. Therefore, the Green Deal serves as a well-prepared guideline for governments in order to build strategies using the power of regulations and other actions (e.g., tendering, funding directions). The agri-food sector is important for the EU since there are many initiatives dealing with this sector. First of all, the "Farm to Fork" strategy synchronized with the EU Green Deal addresses the sustainable operation of the AFSC. Establishing food systems (from farms, through processors, distributors, retailers, and caterers until the customers) with the objective of creating sustainability – both regarding production and food safety – is an important goal of the "Farm to Fork" strategy. Besides this, sustainable and healthy guidelines for consumption should be prioritized in order to achieve the reduction of food loss and waste and the avoidance of food fraud (EU Green deal, 2020). In addition, the CAP (Common Agricultural Policy) formulates directions for governments to strengthen their agri-food systems (European Comission CAP, 2021).

At national level, the co-existence of two decrees (Act LXXXII of 2003 on Food and in Hungary the Act XCI of 1995 on Animal Health (Law Gazette-A, 2023, Law Gazette-B, 2023)) complementing each other, shows that agriculture is considered as an equal partner to the food sector. While Act LXXXII of 2003 on Food sets the standards for the operation of food related companies regarding food safety, Act XCI of 1995 on Animal Health regulates the keeping of animals and the production of food of animal origin (Law Gazette-A, 2023, Law Gazette-B, 2023). Furthermore, the three-volume Hungarian Food Codex plays a prominent role. The Hungarian Food Codex, as defined in the Ministry of Rural Development (MRD) Decree 152/2009 (12.XI.), encompasses obligatory stipulations directed towards participants within the AFSC (Njt.hu, 2021). Among these provisions, the international HACCP principles hold particular significance, exerting a unifying impact on the entire agri-food sector (Njt.hu, 2021). The international importance of HACCP principles is paramount, this paper discusses the relevant aspects derived from the Hungarian Food Codex (HACCP Website, 2020). HACCP "is a system that identifies, assesses and controls hazards that are significant to food safety" (Food Chain website, 2021). This definition shows that in addition to situation assessment, there is also feedback in form of value judgement and regulation in relation to HACCP principles. Adherence to HACCP guidelines is obligatory for all stakeholders within the agri-food business sphere, thereby accentuating the potential advantages of embracing these guidelines digitally, transcending conventional technological approaches, for the cultivation of prosperous operations and even competitive advantage amongst corporate entities (Food Chain website, 2021).

Another prevalent example of guidelines involves the multi-volume GMP (Good Manufacturing Practice) regulations. This comprehensive document delineates prerequisites pertinent to both the food and pharmaceutical sectors, encompassing all actors within the supply chain (FDA Website, 2021).

GMP aims to set and enforce standards to ensure that products do not harm consumers. GMP includes requirements from the specification of the manufacturing process to the sterilisation of the manufacturing environment, to the storage conditions, and the partial documentation of activities. Furthermore, GMP encapsulates guidelines for the entire supply chain, as it also provides guidance to the user on how to assess suppliers and identify the appropriate risks (HACCP website, 2020).

Targeting the whole supply chain, the GxP definition summarises the indicators of "good practice". GxP is an umbrella term that includes requirements from 'farm to fork'. This feature contributes to the "Farm to Fork Strategy" coming from the previously introduced EU directive (EU Green deal, 2020). The first stage is Good Agricultural Practice (GAP), followed by Good Manufacturing Practice (GMP), Good Retail Practice (GRP) or Good Hygiene Practice (GHP), which can form a comprehensive picture when linked into a harmonised system (Raspor, 2008; Wu et al., 2010, p. 45).

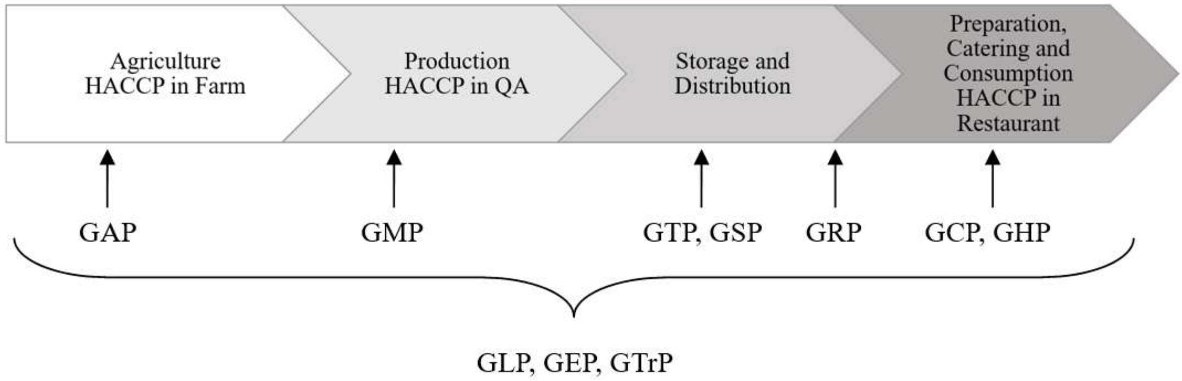

Figure 3: Illustration of food GxP "good practice" through the supply chain
Source: (Wu et al., 2010, p. 45)

Figure 3 illustrates the process of building up the GxP standard evolution along the chain. It is important to highlight that the GxP good practices are in line with the HACCP guidelines and support the requirements formulated there during the entire AFSC.

The ISO 9000 standard is another internationally accepted but not mandatory system in the food industry, but it is also used by many companies in Hungary, too (TUV-A, 2021). The ISO 9001 standard, which supports quality assurance in the food industry, also provides a framework for operations that can help with documentation and monitoring processes. ISO systems can essentially be understood as a framework for operations. The ISO 9001 standard supporting quality assurance in the highly complex industry under consideration (food industry), but also in the pharmaceutical industry, can help the processes of documentation, including monitoring. The ISO:22000 family of standards specialises in food safety, with specifications designed to ensure the quality and safety of food from farm to fork throughout the supply chain (TUV-B, 2021).

Another global standardisation contributing to food safety is the FAO/WHO Codex Alimentarius, which is a joint development of the Food and Agriculture Organisation of the United Nations (FAO) and the World Health Organisation (WHO). The Codex Alimentarius encompasses globally applicable benchmarks, hygiene and technology directives, and criteria for consumable products, alongside established thresholds for admissible levels of pesticide residues within edibles (FAO Website, 2021).

The predominance of regulations that are not explicitly mandatory to use suggests that international practice is also widespread. One reason for this is that there are a number of internationally owned food companies operating in Hungary in a Central-East European (CEE) country. On the other hand, CEE-owned enterprises (in focus of this dissertation) also export their -typically- low-processed products abroad, where compliance with these rules may be expected of supply chain operators.

2.2.1.1 AFSC challenges within the EU

At EU level, the food supply challenges in recent years can be attributed to several factors. On one hand, there is the concept of food fraud, which is nowadays an increasingly serious problem that not only causes economic damage but also poses a serious risk to food safety and consumer confidence (Brooks et al., 2021). Cases such as the Kinder scandal, where products had to be recalled because of salmonella contamination (Focus.de website, 2023), or the tractor protests by French and German farmers (Matthews, 2024a, 2024b, Tagesschau 2024a, 2024b) against non-transparent imports and unfair competition, all highlight the fact that transparency and traceability in the AFSC are key to the current challenges (Majdalawieh et al., 2021). Further aggravating these, grain supply difficulties have emerged as a major challenge in recent years, especially in the light of the global political and economic crises (Zhang et al., 2023). The Russian-Ukrainian war has drastically affected grain supply in Europe and on the world market, as Ukraine is one of the world's largest grain producers and exporters (Reidy, 2024). The disruption of the supply chain, export restrictions and the inflow of cheap Ukrainian grain into the European market led to a severe competitive pressure, which particularly affected farmers in Central and Eastern European countries (Zhang et al., 2023). All these problems have raised the issue of food safety and highlighted the importance of traceability. Transparent systems supported by digitalisation can help to authenticate origin, ensure quality, and avoid unwanted competition. The absence of such systems, however, just adds to uncertainty and supply risks.

2.2.2 Introduction of the role of the "funder"

The role of the funder includes the opportunity to continuously modernise the regulatory environment to facilitate faster and wider adoption of digital technologies in the agri-food industry. Since funding institutions are typically policy makers or public actors, such as the European Commission or national governments, they have the power to use regulatory instruments to stimulate the diffusion of technological innovation. In contrast, the involvement of private capital is less common, as digitalisation-related improvements can have longer return periods and do not always offer immediate business benefits. Another priority for funders is the creation of accessible programmes for small and medium-sized enterprises (SMEs) to help them adapt and integrate new technologies. They also have a key role to play in supporting education and knowledge sharing to ensure that different actors, including producers, processors, and traders, are well prepared for the challenges and opportunities of digitalisation.

The European Commission has provided funding opportunities for the digitalisation of the agri-food industry, mainly through Horizon 2020 (European Commission, 2023b) and the Common Agricultural Policy (CAP) (European Comission CAP., 2021). The Horizon 2020 programme has allocated more than €200 million for the development of precision agriculture and smart farming systems, as well as for increasing the efficiency of food production. As part of the Common Agricultural Policy, €8 billion is dedicated to the digitalisation of rural farms under the Next Generation EU. Projects launched to deploy IoT technologies, such as IoF2020, ATLAS, DEMETER and SmartAgriHubs, play a key role in building data-driven agricultural ecosystems and improving food security (European Commission, 2023b). These projects create systems that ensure interoperability, optimise data and support sustainable farming practices. At the agri-food level, the funding aims to ensure the integration of digital technologies along the entire supply chain, from production to processing and consumption, thus improving traceability, transparency, and food safety. The first paper (Paper Nr. 1) of this dissertation (Freund, 2022) discusses the importance of the relationship between the goals of decision-makers, the provided funding opportunities, and their relevance to applicable digitalisation by AFSC members in detail.

2.2.3 Introduction of the role of the "technology providers"

The conclusion from the previous chapter is that the food industry needs reliable, real-time, and traceable data about the products and their production process in total to comply with the regulations described above. The thesis from here on presents how digitalisation can facilitate this requirement.

The requirements described above apply to food products as well as to their production processes. In this respect, it is worth looking at digitalisation solutions that support real-time feedback and product traceability through appropriate data collection. I 4.0 tools can help to comply with national and international systems. I 4.0 solutions can contribute to compliance with national regulations such as FDA, GMP (Good Manufacturing Practice) or FAO/WHO Codex Alimentarius.

My research focuses on upstream actors, such as producers and processors, in the supply chain of the highlighted food sub-sectors. The thesis presents the technological solutions used by producers and processors in this regard. The primary provision of tracking takes place at these points of the AFSC. Although, the downstream (close to the end user) supply chain actors (distribution, retail, service (restaurant)) continue to apply traceability solutions and collaborate with other AFSC members, they are indirectly involved in the production of food (Wu et al., 2010). Hence, the thesis will explore digitalisation and I 4.0 technologies that are applied in the production of raw materials on the one hand and in processing on the other.

Since, the term of supply chain can be interpreted as "a cross-company process of value creation" (Chikán, 2017), AFSC activities contribute to value creation. Based on Nagy's 2017 collection, it is conspicuous that both those primarily involved in value creation and those supporting activities show up as solutions specific to Industry 4.0 (Nagy, 2017). There are functional areas which link AFSC members together and should be equally supported by digitalisation. These areas can be logistics, where both information provision and identification systems should be harmonized within an AFSC to operate efficient. These are fields, where sensors, or RFID (radio frequency identification) can provide information for all AFSC members and contribute to cooperate (Wang et al., 2016)

For supportive activities linking AFSC members (procurement, technology development, human resource management and corporate infrastructure), the efficient processing of data collected in primary activities in particular can be a key link to I 4.0 solutions. Controlling at a supply chain level can be one of the prominent functions that can harness the large amount of data generated from primary activities. Monitoring the performance of the AFSC can also be effectively supported by digitalisation tools (Deloitte, 2017). An electronic network is essential for this, which can be built either by the concepts of CPS (cyber-physical systems) or IoT (Internet of Things) or Big Data (Heynitz et al., 2016).

The aim of my research is to connect the topic of available technological developments with the strategies and directives coming from authorities and examine how do they affect the AFSC. It seems to be important to harmonize the directions between the mandatory requirements and the available technological solutions. By applying the systematic literature analysis method described in the methodology section, I seek answers to three questions (see chapter 3.1.2.2). First, I am interested in the question, how do the available technologies and the strategies and requirements of decision makers harmonize. The second question deals with the digitalisation tools suitable for AFSC members. At last, the third research question wants to explore how agri-food industry actors interpret the effects of digitalisation related improvements in their operations among the supply chain and in their own organisation. In the following, I discuss solutions related to I 4.0 and digitalisation that support the traceability process.

2.2.3.1 Traceability

Digitalisation is beneficial to the agri-food industry in many ways (e.g., milking robots in dairy farms, monitoring weather or animal health conditions) (Driessen and Heutinck, 2015, Nagy et al. 2020b), but I focus on traceability in my thesis. Based on Kittipanya Ngam and Tan (2020), who developed a framework for detecting the key challenges of digitalisation on the AFSC, traceability has a prominent role related to factors in connection with digitalisation. According to them, digitalisation can contribute to sustainable operations of supply chains along the following dimensions: efficiency improvement, transparency and traceability, environmental and social impacts, legal culpability, and e-market/supply accessibility. Moreover, Kittipanya-ngam and Tan (2020) presents in their results that based on the cases examined by them traceability has a heavy impact on the AFSCs (Kittipanya-ngam and Tan, 2020). Another reason for my decision focusing on traceability, is that traceability requirements accompany the product from the start of production through the entire supply chain to the end consumer. This feature makes traceability an important element in the digital support of the farm to fork strategy which is in line with the EU directives (EU Green deal, 2020). There are hardware and software solutions to support traceability in general. The most common, however, is a combination of the two, e.g., the communication of digitalisation tools without human intervention.

Traceability has an important feature, its demand is mainly formulated by downstream members of the AFSC such as customers and authorities, meanwhile the real action of traceability is started to be supplied by downstream members such as farmers or processors. The demand can be incorporated in form of food safety regulations (Khan et al., 2020) or customer requirements, while the supply is ensured by a mechanism of continuously tracking the data flow during the entire lead time within the AFSC. Traceability fundamentally serves as a tool for retrospectively monitoring and validating events and facilitating timely interventions when necessary. It effectively functions as an input (data collection) for decision making enablers (data processing), conducive to predictive modelling and eventual preventive actions (Bianchi et al., 2018).

Highlighting the importance of traceability, the definitions in Table 1 show, that widely used standards emphasize the term "traceability" and provide their own interpretation for this term (Olsen and Borit, 2013, p. 143).

Name of standard	**Definition**	**Release details**
ISO 8402: 1994	*"The ability to trace the history, application or location of an entity by means of recorded identifications*."	ISO, 1994
ISO 9000	"*The ability to trace the history, application or location of that which is under consideration.*"	ISO, 2000
ISO 22005	In addition to the ISO 9000 definition, it adds: "*Terms such as 'document traceability', 'computer traceability', or 'commercial traceability' should be avoided.*"	ISO, 2005
EU General Food Law	"*The ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution*"	EU 2002
Codex Alimentarius Commission Manual of Procedures	"*The ability to follow the movement of a food through specified stage(s) of production, processing and distribution.*"	FAO/WHO, 1997

Table 1.: Definitions of tracking and tracing
Source: own editing based on (Olsen and Borit, 2013, p. 143)

Table 1 introduces definitions where traceability is jointly defined as an ability to monitor, save, and validate data about the path of a product (food, feed, document, substance), information, or human actions from "farm to fork". The ISO standard definitions introduced in Table 1 contain generalised statements about traceability which are applicable in any industries, while the Codex Alimentarius Commission and the EU Regulation are the basis for a strong approach to food safety. The following paragraph illustrates how traceability can be supported by digitalisation solutions.

2.2.3.2. Digitalisation solutions supporting compliance with standards

The further development of IT tools, if consistently improved, can contribute significantly to the success of agri-food sector participants, especially in the engineering area, which includes new product development, optimization of operational processes and plant maintenance (Kayikci et al, 2020). Furthermore, researchers argue that the application of digitalisation offers potential benefits for supply chain actors that are not limited to operational aspects within engineering alone, but also extend to financial efficiency, overall process transparency and commercial functions (Kittipanya-ngam and Tan, 2020). In addition, the potential benefits from the opportunities of I 4.0 need to be considered from a strategic and organisational perspective, going beyond mere technological improvements (Demeter et al, 2020). The current literature proposes a dichotomous framework for the tools discussed, depending on the availability of hardware on the one hand, and software-driven developments that facilitate their operation and the medium that enables them to work together with each other (Nagy et al., 2020a).

Figure 4 presents the characteristics of concepts that emerged in the literature related to the term "Industry 4.0"and its relation to traceability (Carpenter and Wyman, 2016; Casino et al., 2019; Dadi et al., 2021, Demeter et al., 2020; Geissbauer et al., 2018, Hermannet al., 2016, Tian, 2018; Tse et al., 2017; Wang et al., 2016, Yu et al., 2016).

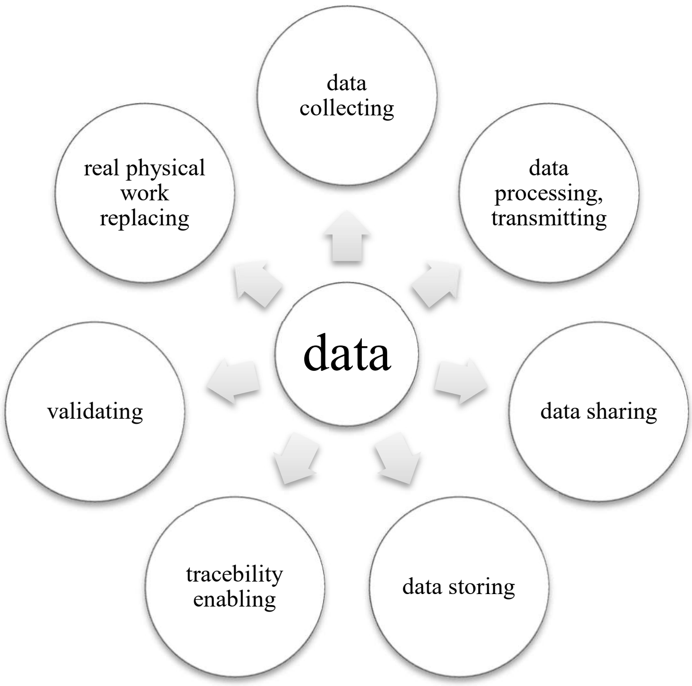

Figure 4: Sources highlighted in the systematic literature review
Source: own editing, 2023

Figure 4 shows that the basics of industrial digitalisation is data, and it is at the centre of all concepts that appeared in the findings. The intersection of the triad of the agri-food industry (1), digitalisation (2), and quality (3) is primarily dependent on the level of the quality of the data available and the analysis derived from it. As Figure 4 demonstrates the effects of technological solutions introduced in the followings are built on data availability. They play dual role: either in direct connection to data analytics (collecting, processing, storing, sharing) which contributes to decision making processes, or data can indirectly affect traceability processes as enabler and validator. Furthermore, data is the basis of hardware supported solutions as well, so the replacement of human workforce and physical work is also linked back to data.

Obviously, regulatory and compliance expectations are based on data availability. However, the collection of real-time data will be greatly simplified by digitalisation technologies, including those related to I 4.0. From a holistic supply chain perspective, the adoption of digitalisation technologies depends on the use of tools such as IoT, Big Data and cloud-based communications (Geissbauer et al., 2018). Successful implementation requires hardware for data collection and software for data transmission, which dichotomy is reflected in the role of traceability (Bianchi et al., 2018). Data sharing and storing are enabled by cloud storage offering abundant data storage underscores a common feature of cloud services, where the interconnection of infrastructural technological solutions contributes to wireless operations (Nagy, 2019). In contrast, the Internet of Things (IoT) refers to the interconnection of devices and computers capable of autonomous communication, free of human intervention (Hermann et al., 2016). The IoT is a network of global scale based on the seamless interaction of physical and virtual entities (Yu et al., 2016). This feature of IoT makes it responsible for data sharing. Real-time data transmission (Dadi et al., 2021) relies on hardware components such as sensors, radio frequency identifiers (RFID) or chips that can collect data on animals, plants, or production equipment. Data processing and transmitting is supported by the term of "Big Data". Big Data refers to the abundant amount of rapidly generated data from various devices, which must be analysed with a software support because traditional data processing methods are not suitable due to the inherently complex characteristics of Big Data (Dadi et al., 2021). Blockchain is one of the most prominent technological developments which has a huge impact on food traceability as well (Casino et al., 2019). Blockchain represents both the role of traceability enabling and validating. As the final category of the findings (real physical work replacing) shown in Figure 3, robotics, drone technology, or as data collectors, sensors can appear (Hasnan and Yusoff, 2018; Oztemel and Gursev, 2020; Smetana et al, 2020).

According to a preliminary systematic literature review, the following digitalisation solutions contribute most to ensuring traceability (Alladi et al., 2019; Bougdira et al., 2020; Casino et al., 2019; Casino et al., 2021; Creydt and Fischer, 2019; Corallo et al., 2018; Durrant et al., 2021; Hasnan and Yusoff, 2018; Hassoun et al., 2023;

Kayikci et al., 2020; Khan et al., 2020; Lahane et al., 2023; Lin et al., 2019; Majerník et al. 2023; Menon & Jain, 2021; Nurgazina et al., 2021; Oztemel and Gursev, 2020; Pakseresht et al., 2022; Prause et al., 2020; Sadiq and Anal, 2023; Savina et al., 2020; Smetana et al., 2020; Yadav et al., 2020, Yogarajan et al., 2023; Zhao et al., 2019).

2.2.3.2.1. Blockchain

Blockchain, emerging as a focal point in the literature, emerges as a potent I 4.0 solution facilitating food safety (Alladi et al., 2019; Creydt and Fischer, 2019; Kayikci et al., 2020; Khan et al., 2020; Lin et al., 2019). The contribution of blockchain to traceability, efficiency, and data storage is seen in its feature being decentralised (Pakseresht et al.;2022, Sadiq and Anal, 2023). Blockchain incorporates a distributed ledger for recording transaction data, shared across network nodes (Alladi et al., 2019). The mechanism assures transaction transparency and is lauded for its efficacy in overseeing the food supply chain (Creydt and Fischer, 2019, Hassoun et al., 2023; Menon and Jain, 2021; Yogarajan et al., 2023). This transparency can emerge trust both in upstream and downstream AFSC members but parallel to this, doubts can be raised as well (Durrant et al., 2021; Nurgazina et al., 2021). While ensuring validated data service during the entire AFSC, less educated (meaning not technologically developed) members may withstand applying blockchain and related technologies. That is why also managerial skills are required to implement developed solutions (Casino et al., 2021). Strengthen the positive effects of blockchain, its potential extends to averting food waste and fraud (Kayikci et al., 2020), thereby bolstering trust within business transactions. Casino et al. (2019) adds that blockchain can provide a proof for customers and authorities requiring food safety data.

2.2.3.2.2. IoT (Internet of Things)

The Internet of Things (IoT) raised as another dominant technological solution supporting traceability. IoT operates through sensors capturing data from processes and equipment, channelling the information to a cloud-based enterprise data centre (Prause et al., 2020; Yadav et al., 2020). IoT's significance is underscored by its role in addressing regulatory mandates within food and pharmaceutical domains, fostering the sharing of resources and intelligence across a spectrum of devices and technologies (Bougdira et al., 2020). It emerges as a collaborative solution, facilitating data aggregation among supply chain stakeholders (Khan et al., 2020), thus enabling data collection, analysis, and product management (Corallo et al., 2018).

2.2.3.3. Sinergy between technologies

Quality management and traceability across all stages of production, distribution and consumption can be supported by the cooperation of technological solutions (Savina et al., 2020). Combining advanced solutions such as blockchain, ICT (information communication technology) and IoT can contribute besides traceability to information technology or even manufacturing processes (Zhao et al., 2019). Hasnan and Yusoff (2018) state that automation, cost reduction, systematic management, adherence to standards and resource efficiency are also important field where the combination of advanced technologies can affect positively (Hasnan and Yusoff, 2018). The importance of synergies between technologies lies in the fact that different technologies can work together to achieve effects that could not be achieved by a single technology alone (Demeter et al., 2024). These synergies occur when the benefits of different technologies complement and reinforce each other (Demeter et al., 2020). Synergies also play a role in increasing transparency and efficiency. The creation of synergies creates the opportunity to create a new kind of digital ecosystem (Nagy, 2019) that not only improves traceability, but also promotes sustainability and food safety.

According to Lahane et al. (2023) barriers of implementation and maintenance of combined solutions are also the lack of top-management commitment and support. To resolve this, withstand, clarification of regulations and their relations to available technological solutions can be an appropriate starting point (Majerník et al. 2023). Collaborative potential is evident as IoT and blockchain technologies synergistically address areas like origin proof, payments, and process management (Khan et al., 2020). Collectively, the integration of diverse I 4.0 solutions amplifies their efficiency in facilitating traceability and fostering transparency (Kayikci et al., 2020; Khan et al., 2020; Lee et al., 2019; Oztemel and Gursev, 2020; Prause et al., 2020; Smetana et al., 2020).

2.2.3.4. Concerns arising connected to digitalisation

However, it is seen that digitalisation and the related technologies are warmly welcomed both by academics (Casino et al., 2020, Kittipanya-ngam and Tan, 2020, Barbosa, 2021, Baksa et al, 2021, Erdei et al., 2021) and practitioners (Siemens AG, n.d., Breuer, 2018, Industr.com website, 2023), there are concerns arising from the implementation of digital solutions.

The digitalisation of the agri-food industry raises a series of concerns that pose significant challenges for operators in the sector. In the current economic climate, the costs involved, and the availability of technologies are of key importance (Baksa et al., 2021). The high investment and sometimes operational costs of digitalisation and the lack of access to the necessary technological tools can be a serious barrier (Demeter et al., 2020, Baksa et al., 2021). Some actors in the sector may find it difficult to adapt to new digital solutions, especially those who are still attached to traditional methods, which may also be a major concern for their uptake (Nagy et al., 2020b). In addition to company-specific concerns, it is worth reviewing the supply chain level concerns that technology brings. Difficulties in technology integration for data security may be the starting point for concerns. Ensuring that different digital systems work together can be a challenge, especially when different technologies are used at different points in the supply chain (Zeb et al., 2021). The issue of data security is particularly important as both smaller businesses, which often lack adequate protection solutions, and large enterprises, such as subsidiaries of multinational companies, fear that their data could fall into the wrong hands or be the victim of data theft by competitors (Baksa et al., 2021). A related point is the legal aspects of data management. The rules on data ownership, management and sharing are not always clear, which can create uncertainty between actors (Atik, 2022). Moreover, it goes as far as raising ethical issues. The combination of digital solutions can also raise ethical concerns, especially when human decision-making is completely replaced by machine-based systems (Kosior, 2020). The problem of data fraud also poses a serious risk, as deceiving consumers and customers can not only lead to a crisis of confidence, but also to significant economic losses (Brooks et al., 2021, European Comission, 2021). In addition, the threat of cyber-attacks is nowadays becoming increasingly significant, especially for critical infrastructures such as food supply, where a well-targeted attack can cause serious disruptions (Khursheed et al., 2016, Kulkarni et al., 2024).

The synergies and the application of the relevant digital solutions, and the concerns appearing related to them are analysed in the first paper of the dissertation (Freund, 2023) to provide a deeper understanding of their effects on the AFSC.

2.3. Concluding considerations of the literature review

The aim of the literature review at the beginning of the thesis was to highlight food traceability and to present the advanced technological solutions that can contribute to efficient operations and can be analysed detailed in the thesis. An overview of the regulations governing food safety is essential to understand the context of the research topic. In the following step, I try to examine the research questions that emerged during the systematic literature review which focused on traceability and I 4.0 /digitalisation links in the first round. Question 1 of the literature review in the thesis (see Question 1, 2, and 3 of the literature review in the thesis in 3.1.2.2 chapter) is, what are the influencing studies regarding the relationship of digitalisation and food safety.

Regarding food safety, besides traceability, food loss and food fraud appear in the literature as highlighted areas (Kayikci et al., 2020, Yogarajan et al. 2023). Important elements of this issue are the will of the decision-makers themselves (economic policy dimension) and the financing context that acts as a barrier or sometimes a driver for investment. Paper Nr. 1. of the thesis introduces the question of the national and international tendering schemes that support this, with a view to explaining the link between the funding context and the directions taken.

Broadening the systematic analysis, I found literature reviews that show that different I 4.0 solutions are available for AFSC members. It appeared also that blockchain and IoT are terms which can be found in the literature on their own and combined with other technological solutions as well. Based on these findings it was worth continuing the research in direction to explore the coherence and cooperations between technological solution suitable for supporting traceability. As a result, Paper Nr. 2. of my dissertation presents a detailed bibliometric literature analysis to effectively illustrate the impact of digitalisation. The second research question of the theoretical background analysis aims to investigate the area of food safety where the researched I 4.0 and digitalisation solutions can be supportive. Question 2 of this literature review in the thesis is, which areas of food safety are supported by digitalisation solutions?

Examining the answers to the third question of the literature review in the thesis (Question 3: which digitalisation solutions contribute to ensuring traceability) two main I 4.0 solutions emerged as specific enablers of food traceability (Pakseresht et al., 2022; Sadiq and Anal, 2023; Yu et al., 2016). Blockchain and IoT and the combined version of advanced solutions were the most frequently mentioned in the reviewed literature. Blockchain has a paramount importance, and this fact leads to further research steps in direction to analyse the literature. As a result of this study, it can be stated that traceability needs two main supporting elements: hardware and software which can enable the so-called "farm-to-fork", whole AFSC long durable traceability. It can also be seen that the I 4.0 solutions listed above can make this possible. There are, of course, some difficulties that may affect the success of the implementation of these technological solutions. On the one hand, they are significantly expensive investments. Agri-food industry actors must have the financial and technical skills to apply them. On the other hand, traceability plays a prominent role within ensuring food safety. Traceability is vital for all members of the AFSC (because of e.g., mandatory requirements of authorities, financial decisions, performance, or quality management) and must be ensured throughout the supply chain process. I 4.0 solutions would work effectively, if all participants invested in them. However, this requirement may cause difficulties.

The methodology (described in part II detailed) has certain limitations. Due to the strong national and international legal framework regarding traceability in the AFSC, instead of only focusing on the discussion of purely academic studies and literature reviews, my doctoral dissertation starts with a mixed methodology supported paper (Paper Nr. 1.) which examines the circumstances coming from the practical application. A broader theoretical background of the available technological solutions is examined in Paper Nr. 2. in order to unlock this limitation. Since the ratio of standards to legal requirements dominates the exploration, I aimed to develop the introductory articles (Paper Nr.1. and Paper Nr.2.) of this article-based dissertation as a response to the need for a broad and comprehensive presentation of the literature on the impact of digitalisation on food safety and its facilitation. Meanwhile, Pape Nr. 3 deals with the manifestation of the examined topic among the AFSC members.

2.4. Research gaps in the literature

A review of the literature shows that there is a large literature on digitalisation and traceability (Creydt and Fischer, 2019, Dadi et al., 2021, Majdalawieh et al., 2021, Menon and Jain, 2021), but it is typically technology-driven and less focused on the integration of agri-food actors at the management level. In relation to the framework developed for the analysis of the literature, a particular gap can be identified in the research direction focusing on the availability of digital solutions for AFSC members and the potential for collaboration (synergy) between multiple technologies. An isolated approach is noticeable, whereby the tools of the decision-maker are the first to be explored (e.g., EU Green Deal and the Farm2Fork Strategy (EU Green deal, 2020), or even Hungary's Digital Agricultural Strategy (DAS, 2019), at the level of classical strategy formulation. In addition, I believe there is a major gap in the study of conscious fund allocation, as the academy has so far placed less emphasis on the joint study of purpose and instrument.

Finally, there would be a need to integrate the study of the technological side directly linked to these in order to clarify the possibilities in the AFSC field.

The research gap found in the literature review of the thesis is that a comprehensive analysis, linking the available technological solutions with regulations and standardisation solutions is missing from the literature. These identified gaps clearly indicate the need for research that comprehensively analyses the management side of digitalisation in the AFSC.

3. INTRODUCTION OF THE METHODOLOGY

The research aims to explore the practices of I 4.0 and digitalisation in different sectors of the agri-food industry. The research focuses on the actors in the AFSC. The exploratory study deals with digitalisation solutions emerging in the production and processing of food raw materials. In particular, this doctoral research examines methods that support the improvement of product traceability and food safety. My doctoral research involves exploring and interpreting the foundations of the relationship between food safety and the digitalisation and I 4.0 toolbox. With its practical focus, the research can contribute to the work of both academia and practice. The methodology introduced in the followings, aims to analyse the AFSC from a perspective of decision makers, available technologies, and the implementation processes. The study examines the practices of I 4.0 and digitalisation processes that underpin them in different sectors of the agri-food industry.

I planned to use a mixed methodology (described in detail starting in section 3.1.2) to explore the research field. Based on the literature review conducted in the thesis, I aimed to collect and interpret comprehensive national and international data using systematic literature review methods, which can be considered as the theoretical and practical background of qualitative methods. The chosen qualitative methodology is case study based on semi-structured interviews for mapping the practices of the actors under study.

3.1. Research characteristics and methodology

To build the framework of my research, I used the methodologies acquired in my PhD training (Horváth and Mitev, 2015; Sajtos and Mitev, 2007; Szüle, 2016). Based on

Malhotra (2002), I prepared the methodological design of my research on more levels. My choice of topic was based on an internship at a supplier of mainly pharmaceutical products. During my internship, I was able to learn about strict quality requirements. Based on these requirements, the company had made the manufacturing equipment (including the components to be incorporated) traceable in order to meet them. This company had a low level of orders from the agri-food industry and, as food is also a human consumption product, I was interested in this area of research. After that, in my MSc thesis, I examined dairy producers and processors, as representatives of the actors in the agri-food industry. In my study about the digitalisation of the dairy industry, I conducted exploratory research on two main actors in the dairy supply chain. Already at that time, the prominent role of traceability in food safety due to strict food industry requirements was highlighted. When I enrolled in the doctoral programme, I set myself the goal of researching digitalisation supporting food safety.

Since food safety issues, including traceability, track food along the supply chain, the focus of my research is its relations to digitalisation. Due to the breadth of the topic, I have narrowed the scope of the research. Figure 5 shows the conceptual model of the research which forms the basis for the concrete implementation of the doctoral research.

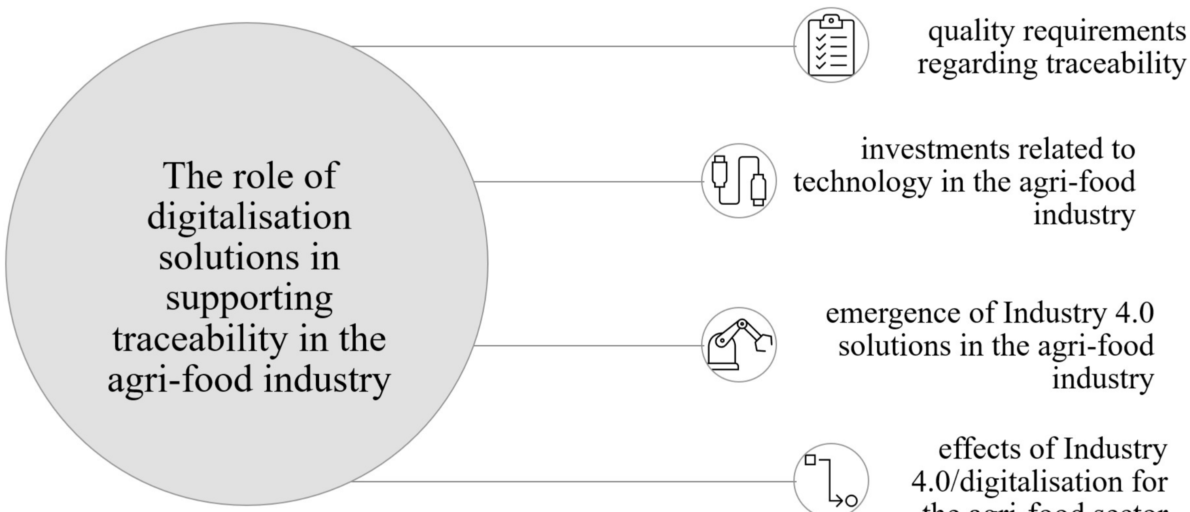

Figure 5: Conceptual model of the research
Source: own editing

First of all, a comprehensive literature analysis is presented about the AFSC, food industry investments and traceability in the context of I 4.0 technologies. The first paper deals with the manifestation of available funding opportunities, the willingness of decision-makers and the appropriate and available technological solutions.

The second paper deals with a more comprehensive review of the evolution of the AFSC literature regarding digitalisation and emerging topics. A bibliometric literature review was conducted to gain relevant results representing the effects of digitalisation on the AFSC.

The third paper aims to refine the results coming from the broad review of the literature. Through case studies, we intended to illustrate the practices already in use, in order to formulate a "good practice" that is of value to both academics and practitioners as a result of this dissertation.

3.1.1. Explanation of methodologies applied in the thesis and the papers

When preparing the thesis, I turned to qualitative methods based on my research history, a decision justified by the exploratory nature of the research. Qualitative data collection can typically take two forms: primary and secondary data. Primary and secondary data are essentially complementary. While primary qualitative data are collected by the researcher (e.g., in the context of this study, factors influencing the relationship between digitalisation and food safety according to the actors in the supply chain of the food sectors under study), secondary data are defined as the search for and collection of existing data (documents, literature analysis) (Sajtos and Mitev, 2007).

As an initial step, I decided to use preliminary conducted in-depth interviews, in order to assess the problems on the professional side. On the basis of the information obtained from the interviews, I moved towards the analysis of secondary data. The theoretical and practical background of the research field must be analysed after having explored the main areas raising the interest of the author. Throughout the dissertation I planned to assess the current literature context through a systematic literature analysis. I consider it important that the results of the exploratory research serve as a starting point for the next step, the planning of the practical application of the findings through semi-structured interviews with actors in the four food sub-sectors that are in the focus of the research and analyse what I explore through case studies.

The characteristics of qualitative research are meant to show the problem in depth (Horváth and Mitev, 2015). Based on the collection of Cresswell (2007) and Rossman and Rallis (1998), I interpret the characteristics of qualitative research as follows when I design my own research: a qualitative researcher collects data to answer the question in the natural setting of the problem, typically in the field. The advantage of face-to-face interviewing can be that while the questions are being asked the researcher can see the respondent's reactions, possibly accompanied by a visual illustration during a site visit to concretise the problem. However, it is important to point out that in qualitative research the researcher plays a key role. The personality of the researcher influences the process of data collection and interpretation. In order to overcome this bias, it is worthwhile to formulate a self-reflection to make the framework in which the researcher places the findings transparent. The experts also noted that qualitative research is characterised by the use of multiple data sources and methods. This is the reason why my research relies on the examination of documents and literature in addition to the conducted interviews.

Qualitative research also includes inductive data analysis. Thus, in my PhD research I approach the issue of digitalisation in the food industry from the bottom up (Cresswell, 2007; Rossman and Rallis, 1998). I started exploring patterns in the data, which seemed to be categorizable. After the categorisations, the analysis was carried out. Qualitative researchers try to paint a more complex picture of the problem as an output of the analysis. Indeed, a holistic picture can serve as an input when synthesizing the results of the research (Horváth and Mitev, 2015).

3.1.2. Introduction of applied methodologies

The methodological structure described earlier is detailed below. The framework of my research consists of three steps, and I built my dissertation based on them.

3.1.2.1. Preliminary interviews - Step 1: qualitative basics

Following Malhotra (2002), it is worthwhile to conduct interviews with potential stakeholders of the research (decision makers, experts... etc.) to delimit the problem. The grounding information has two important roles. On the one hand it helps the researcher to formulate the research problem precisely and, on the other hand, they provide feedback on whether the research is worth being conducted (Sajtos and Mitev, 2007). For these reasons, I considered it important to conduct interviews as a basis for my doctoral research. During 2018-2019, I had the opportunity to conduct interviews in three of the four industries that I wanted to investigate as a member of the research team of EFOP-3.6.2-16-2017-00007 "Aspects of the development of a smart, sustainable, and inclusive society: social, technological and innovation networks in employment and the digital economy" project. The input gathered here confirmed that the topic is worthy of further research. This research project also included other industries, thus bringing into view the contrast that appeared in the food industry, as well as other industries such as automotive, SSC (shared service centre), retail, or even logistics services (Baksa, et al., 2021; Demeter et al., 2020; Nagy et al., 2020a). The limitations of the exploratory interviews might be due to the fact that semi-structured interviews were the first step of the exploratory research within the research project. The semi-structured interviews were carried out in the same way across all the industries concerned by the researchers for the sake of comparability in the future. However, I interpret this limitation as an advantage for my doctoral research. Observing the work of co-authors, it stood out that digitalisation and I 4.0 are present in traces in the food industry actors studied, but their adoption is mainly due to necessity and practical constraints. There are two main ways in which those constraints can be overcome, either by meeting food safety standards or to overcome the difficulties of labour shortages by investing in digital solutions. From the exploratory interviews (Horváth and Mitev, 2015), I concluded that my research is indeed relevant and that the possible findings could also contribute to facilitate the everyday decisions of practitioners. Systematic thinking and the integration of tools that support functioning in systems would support effective working. Based on the interviews, traceability was highlighted as an important area for improvement when complying with strict food regulations. In addition, the interviewees wanted to implement "smart" solutions to increase productivity.

3.1.2.2. Systematic literature analysis - Step 2: collecting and analysing secondary data

The literature review of the research is structured on three different levels, which build on each other to ensure a thorough exploration of the topic under. The first level consists of a comprehensive literature analysis, which serves as a starting point for the research. The second level presents the methodological choices resulting from the identification of gaps in the literature, which led to a hybrid analytical approach. The third level details a bibliometric literature review incorporated into the third paper of the dissertation, reflecting on the research questions addressed based on the first two levels.

In the first phase of my PhD research, I conducted an extensive literature review in order to map the impact of digitalisation and I 4.0 on the agri-food industry which is seen in the first chapter of my dissertation "2. Theoretical background". This review helped me to understand the academic discourse within the topic, existing research and identify gaps in the literature which could lead to the research structure building process. Simultaneously, the research also aimed to identify key areas where digitalisation can contribute to food safety, supply chain transparency and efficiency improvements. In the introductory part of the thesis, I used the systematic literature review methodology developed by Brereton and colleagues (Brereton et al., 2007) to complement my existing knowledge of the literature. The methodology describes a scientific validation mechanism that, due to its comprehensive approach, can be applied to almost any field. The steps of the method are: *formulating questions; identifying data collection sources; selecting keywords; running the search; describing the search results; selecting primary studies; finally, analysing and synthesising the results*. The reason why I took this choice was that the systematic literature analysis seen in previous supply chain researches (Corallo, et al., 2020; Cruz et al., 2018; Seuring and Müller, 2008) seemed to be suitable for the study of traceability trends in the case of AFSCs. I also consider it important to use a well-described, consistent methodology, which gives both the researcher and the reader a good starting point for getting to grips with the subject.

In the followings, according to Breteton et al. (2007), I show the direction of my investigation in the systematic literature review of the introductory part of the thesis.

<u>Questions</u>

Question 1: What are the influencing studies regarding relationship of digitalisation and food safety?

Question 2: Which areas of food safety are supported by digitalisation solutions?

Question 3: Which digitalisation solutions contribute to ensuring traceability?

<u>Sources</u>

- Scopus
- Web of Science
- SpringerLink
- Google Scholar (specifically for keywords in Hungarian)

According to Brereton et al. (2007) using more searching engines contributes to reach appropriate results. It is also useful to search consequently, which means that the same keyword combination must be applied. Sometimes, (e.g., in the case of WoS) the marking of keyword cannot be identical with the marking of keywords at other searching engines. To unlock this disadvantage using merging opportunities can be a preferable choice (Apriliyanti and Alon, 2017) Language variety is also a positive extension, especially regarding geographical boundaries, e.g., researching Chinese regions is worth examining not only in English but also in the native language, using the native language speaking searching engines.

For the purposes of my doctoral research, I conducted the literature review using keywords in Hungarian and English. Web of Science, Scopus and SpringerLink search engines were used in the case of international keyword search, and the Hungarian literature and the Hungarian specific regulations were searched using Google Scholar and Google.

Keywords

One of the main objectives of the research is to find the supporting role of the currently widespread phenomenon I 4.0 and digitalisation in the different processes of the food safety, taking best practices from industries such as automotive or logistics where applying technological developments related to I 4.0 has started for a while (Demeter et al. 2020).
In order to detect the relationship between digitalisation and its supporting role to food safety I highly focused on traceability within the searching process. I also wanted to uncover the connections to regulations and standardisation. That is why I applied in the preliminary search the following keywords, as an exploratory step of Paper Nr. 1. and Paper Nr. 2, in order detect the research gaps and set the research directions.

traceability	food safety	Industry 4.0 or digitalisation
standards		

Table 2: Keywords
Source: own editing, 2025

The main search terms were as follows:

("traceability" OR "tracking" OR "tracing" OR "quality assurance" OR "standards") AND "food safety" AND ("Industry 4.0" or "digitalisation")

Before presenting search results, it is worth mentioning additional information if other filtering parameters are set. In addition to keywords, I also set a specific range for each platform as a filter (availability from 2015), in order to complement existing literature knowledge (used in previous literature searches) with the latest contemporary literature. The selection of primary studies is the next step, followed by the synthesis of the literature database, which are introduced in the theoretical background part of the thesis.

Based on the results of the comprehensive review, it became clear that the literature addresses the issue of digitalisation in the agri-food industry in an isolated way.

Some research focuses on the technical aspects of technological developments, while others examine the role of digital solutions from the perspective of food safety regulations, rarely dealing with the willingness of decision-makers. It was therefore necessary to adopt a hybrid methodological approach that combines both perspectives. Accordingly, two methodological tools were used by me in my dissertation to be able to answer the first comprehensive research question, PhD-Q1: How does the relationship between available technological investment in the agri-food industry and the willingness of decision makers look like? Among the papers introduced, there are 2 literature review articles, and their characteristics is detailed in Table 3. The first one is a mixture of the bibliometric literature review and a content analysis. This hybrid methodology is suitable for analysing both academic literature and white papers (mandatory regulations set by authorities e.g., governments, EU, chambers… etc.). The detailed description is presented in Paper Nr. 1. (Freund, 2022), presented in my doctoral dissertation.

The second review paper deals with the topic of bibliometric literature reviews. Bibliometric literature reviews belong to the group of systematic reviews focusing on scientific data about publications. Here, a quantitative methodology was used to select and analyse relevant literature on the examined field. Bibliometric reviews also contribute to relevance and validity (Donthu et al., 2021). My goal was to carry out a literature analysis which characterises the current situation of the research topic and highlights the emerging parts coming in the followings. Paper Nr. 2. (Freund, 2023) introduces this methodology in detail.

	Hybrid LR	Bibliometric LR
Title of the paper	*"Investigating the food digitalisation tenders for small and medium-sized enterprises in the wake of pandemic Covid-19"*	*"Effects of digitalisation on food safety"*
Aim of applied methodology	The aim is to combine the advantages of systematic and content analysis methods to provide a deeper and more comprehensive picture of the researched topic, which is dynamically evolving, and relevant knowledge is not only drawn from academic publications but also from practical sources.	The aim is to identify research gaps and new opportunities. This methodology helps to identify under-researched areas or topics that need scientific attention. It also allows for the detection of scientific trends and new topics. Keyword analysis and trend analysis can be used to predict emerging research directions.
Characteristics of methodology	This method also uses a structured search strategy (e.g., databases, keywords, search intervals).	This method also increases the reliability of the research by using a structured search strategy (e.g., databases, keywords, search intervals).

	It is based on a scientifically valid methodology that makes the results reproducible. However, it has the advantage of allowing research to draw directly applicable conclusions by analysing sectoral reports, white papers, regulatory documents in addition to purely academic literature. The extent to which and how academic findings are incorporated into industry practice can be understood.	It is based on a scientifically valid methodology that makes the results reproducible. Bibliometric analysis (e.g., citation networks, trends) can be used to reveal the evolution of scientific discourse.

Table 3: Comparison of the two applied literature review methods
Source: own editing, 2025

The three-level structure of the literature review ensures that the research is structured, comprehensive and well-founded. The comprehensive literature review helped to identify relevant research questions and gaps in the literature. The hybrid methodological approach allowed for a deeper understanding of the subject area, while the bibliometric literature review built into the studies ensured that the research was not only theoretically relevant but also provided practical implications which contributed to the interpretation of the third study of the dissertation.

3.1.2.3. Case studies - Step 3: synthesis of results

The third step of the applied methodology was carried out by the Food Supply Chain Research Group and published in form of Paper Nr. 3. (Nagy et al., 2020a). With my colleagues, Judit Nagy, PhD and Zsófia Jámbor, PhD we chose the case study methodology as the tool for qualitative analysis. The primary reason for this choice was that it is a multipurpose method for exploratory research (Szokolszky, 2004). Kvale (1996) describes qualitative interviewing in 7 steps: thematization, planning, interviewing, interview design, data analysis, reliability and validity verification, verification, and reporting of research findings. The case study design steps set out by Dooley (2002) and Klenke (2008) also provide further confirmation of Kvale’s (1996) approach extending it with an 8. step, including the declaration of quality criteria. We considered these guide instructions before conducting the interviews with the selected AFSC members. In the following, I present the case study design along these steps.

1. Defining the research question

The case study is intended to answer “how” and “why” questions (Horváth & Mitev, 2015). Based on these, the second and the third research question of the thesis match this method.

PhD-RQ-2 of the thesis: Which digitalisation tools are used by agri-food supply chain actors? → HOW processes work.
PhD-RQ-3 of the thesis: How do food industry companies perceive the realisation of digitalisation and ICT based improvements in their operations and organisation?

In order to answer RQ-2 and RQ-3, it is important to pay attention to selecting the right cases.

2. Selection of cases

We intended to write case studies based on several cases. One reason for this choice was to get a more comprehensive picture of the research following the principle “more eyes…”. I believe that, if authors research the situation of actors in the food supply chain, it may be particularly useful to approach more actors. In addition, this method seems to withstand methodological criticisms due to its structured nature (Horváth and Mitev, 2015). Selecting the interviewees, we took the following aspects into account:

We have an interviewee from each of the two main groups in the food supply network in each sector under study. I consider the two main actors as those directly involved in the value creation process (production and processing). The enterprises should preferably be small and large, Hungarian, and foreign-owned.

In order to find potential interviewees, we initially used the contact capital gained during the pre-interviews. In addition, contacting industry stakeholders (e.g., the Responsible Food Producers Association) could be a useful step for future research directions, as they could act as 'gatekeepers' to help establish further contacts. We could offer the participating companies the results of the research so that they can use them in their daily operations in the future. The contacted subjects might suspect that we would disclose insider information and business secrets and therefore refuse the interview. In order to avoid this, we informed potential interviewees thoroughly about data management, confidentiality, storage and disclosure of information, and data obtained.

3. Definition of data collection and analysis techniques

The case study has the potential to use a variety of mixed methods (Horváth and Mitev, 2015). In addition to collecting secondary data, it is also worthwhile to use a primary data collection method. The use of systematic analysis techniques can help to provide transparency for the researcher. In light of this, we opted for qualitative interviews, which were conducted after the transcription of the transcribed audio.

4. Preparation of data collection, reflection

During the data collection process, it is essential to focus on the researcher's personality. During the interviewing process, we strived for active listening, and we considered it important to follow a pre-planned schedule without overly influencing the subject's reactions. In addition, we all took notes for self-reflection, which helped to minimise subjectivity in subsequent analysis.

5. Data collection: qualitative interview

We conducted this part of the thesis using primary data collection. We chose qualitative interviews because of the exploratory, descriptive nature of the research topic, which has two basic forms, the individual interview, and the focus group interview (Horváth & Mitev, 2015). For our research, we chose thematic-qualitative interviews that we conducted with the actors of the AFSCs under study. Conducting the interviews, we collected data in a personal tone, if possible, on the viewpoints and lived experiences of digitalisation in the food industry (Szokolszky, 2004). We were interested in how the business professionals perceive the impact of digitalisation on their productivity and what are the reason for them to embark on technological improvements.

We conducted semi-structured interviews (see Annex 1 in Paper Nr. 3. for the interview outline). It was important for us to think in a systematic way, therefore semi-structured gave us enough security to have a consistent overview of the topics, while at the same time being flexible enough to deal with the questions on each topic. The guideline we followed contributed to the comparability of the information obtained in other cases. However, the semi-structured nature may be the reason why some topics are left untouched during the interview. To minimise this risk, we considered it appropriate to listen actively to non-explicit verbal signals given by the interviewee (silence, changed tone of voice, clearing throat ...etc.) since this gave us the opportunity to ask for additional information.

Conducting the interviews

The consent of the subjects is necessary for the recording of the interviews which is of paramount importance for the subsequent steps. We made the audio recordings with our smartphones in the case of face-to-face interviews. In the case of online interviews, we used Microsoft Teams.

Four interviews are presented in Paper Nr.3. Based on relevance and the availability of interviewees, we chose three agri-food sub-sectors among the largest ones in Hungary (Kürthy et al, 2016). According to Denzin and Lincoln (2011), the aim of these four interviews was not to obtain generalizable or representative results (Denzin and Lincoln, 2011). Based on the theory of Yin (2011), these results can provide a more detailed understanding about the motivation of companies analysed. The participating and chosen sub-sectors were dairy production, dairy processing, pasta industry, and meat processing.

We expected interviews to last 1-1,5 hours (adapted to the tight time schedule of the professionals). After a short introduction (general position of the company in question on digitalisation, I 4.0 concepts), we asked the interviewee to present digitalisation projects along the lines of company projects, with regard to motivation, implementation (whether there is a dedicated digital department, responsibilities, competences), nature of investment, return on investment, and links with productivity. In addition, we asked about the economic environment, how supportive they see the economic situation of the sector, tendering opportunities, and the competitive situation.

6. Analysis and interpretation of data

The analysis of the interviews started at the interview stage since we also took manual notes while recording the audio material. This was useful because it makes it easier to ask for clarifications, to see what the subject means in more detail and whether we have interpreted his or her statement correctly. This is followed by typing the audio material. The transcriptions allow for a deeper analysis of the interviews.

The method of analysis we chose is content analysis, which is "a systematic quantitative analytical procedure in order to draw some conclusion about the intentions, motivations or tendencies of the writer of a text" (Szokolszky, 2004, p. 293). Content analysis seeks to uncover hidden patterns after a quantitative examination of interrelated content.

In order to assist in the coding and interpretation of codes within content analysis, we took the following steps (Horváth and Mitev, 2015; Mitev, 2012; Szokolszky, 2004):

1. reading texts one by one,
2. page-by-page coding after first impressions,

3. the creation of categories from each theme,
4. sorting the codes.

We chose the "open" encoding technique. This method can help to understand the content without restrictions, but it also presents a limitation. If one manages to formulate multiple codes per line, it makes interpretation more difficult. In the case of open codes, the raw data is not distorted, it constitutes the subsequent conceptual categories. The latter can be used to build a multidimensional framework in a descriptive way. This is the path we took when we were working on Paper Nr. 3. Codes derived directly from raw data can also help to ensure the validity of the work done (Khandkar, 1998). Although this method of analysis is time and energy consuming, it is a good starting point for implementing a systematic analytical process and ultimately, for answering research questions.

7. Preparing a research report

The purpose of the report is to answer the research questions in a way which is understandable to a readership other than the researcher. Writing the report, we used an analytical style which is structured as follows: introduction, summary of literature, methodology, results and discussion (Gall, Borg, & Gall, 1996). We considered it important to keep the classical structure, as this makes the case study systematically compatible for both the academic community and practitioners, as well as other target audiences, such as students in education.

8. Definition of quality criteria

Based on the positivist approach of Klenke (2008) and Paré (2002), we distinguished four quality criteria: conceptual, internal validity, external validity, and reliability. Conceptual validity refers to the suitability of the instrument used for the study. To ensure this, we used a variety of sources and qualitative methods in the analysis.
In the case of internal validity, we had to prove the basis on which we drew our conclusions. Constructing a logical chain of evidence, linking the propositions to the literature, can help to achieve internal validity.

By external validity, we refer to the question whether the results can be generalised beyond the studied subjects. In qualitative research, we consider external validity to be one of the most difficult steps, and in order to achieve it, we formulated proposals linked to the relevant literature, which also allowed us to apply an analytical approach. Voss et al. (2009) also confirms that multiple case studies are useful to avoid researchers' bias (Voss, 2009) they also contribute to increase external validity. For supporting this aim, we interviewed the major sub-sectors (dairy production and processing, meat production, and pasta manufacturing) within the agri-food industry.

Reliability refers to the reproducibility of the processes, e.g., whether the research can be reproduced after documentation. We tried to address this through the recording of the coding system and continuous reflection.

In general terms, we focused on the followings to enhance validity and reliability in Paper Nr. 3. and - also in this part of my thesis (Horváth and Mitev, 2015).

• Data diversity: we aimed to reach a wide range of interviewees. This was difficult because of limited contact capital, as well as the uncertainty caused by the coronavirus epidemic and the reluctance of companies to work with outsiders. One way to overcome these difficulties was to conduct interviews online. It can also increase the interviewee's confidence and interest in the topic by giving him or her an insight into the framework of the interview beforehand. Our aim was to interview relevant subjects (with a comprehensive knowledge of the company's digitalisation processes) until saturation is achieved in terms of the number of interviews.

• Data recording: systematic documentation is needed for transparency and in order to keep track of the research phases. We have already detailed at the beginning of the interviews that we plan to take notes on the spot, and typed interview transcripts, audio recordings and codes are also part of the documentation. As a good practice, we have also adopted from previous research that after the interview (preferably on the same day, which helps to organise the thoughts and to remember what happened later in the interview), we write down the main ideas in the interview outline.

• Triangulation: as part of a qualitative research strategy, triangulation refers to the validation of research from multiple sources by converging information (Lather, 1991). The different types of triangulation are defined by Denzin (1978) and Patton (1999). There are four types: data, theory, method, or personal triangulation. We implemented in our research by going through a validation process with the interviewee, e.g., by sharing with him/her the interpretation and analysis of the information from the data collection phase, in order to detect anomalies.

• Self-reflection: the researcher's self-critical attitude is essential in qualitative research. Avoid bias and strive for objectivity in the interpretation of the information collected missing verb. As one of the ways of doing this, we planned to write a few paragraphs of reflection after each step in the process, in order to use them as a reference point for analysis. In addition, our own insight and reflection could have been hindered when we discussed the topic in the Food Supply Chain Research Group. We regularly consulted with each other of the Food Supply Chain Research Group on the topic.

3.1.3. Conceptualisation

The basic concepts that are relevant to my research are conceptualized below. Table 4 shows the identified conceptual framework of the dissertation.

Term to be conceptualised	Interpretation of the term within the dissertation
Food sector	The food sector plays a prominent role in Hungary as it is "one of the main markets for agricultural raw materials and its performance has an impact on the entire food supply chain" (Kürthy et al., 2016, p. 7). The research conducted by Kürthy and colleagues (2016) between 2003 and 2013 showed that "the deteriorating profitability of the sector led to a halt in development and technological innovation, which further worsened the competitiveness of enterprises, making it difficult to recover from the crisis" (Kürthy et al, 2016, p. 45). As a consequence, Industry 4.0/digitalisation developments are much needed to reduce the technological and efficiency gap in the industry.
Supply chain	"A vertically interconnected sequence of economic activities across corporate boundaries to satisfy a given consumer demand" (Chikán, 2017, p. 179).
Agri-food supply chain	The agri-food supply chain lists stakeholders both from the upstream and downstream side of supply chains. Stakeholders, farmers, processors, distributors, retailers, caterers, and consumers build the agri-food supply chain (Ganeshkumar et al., 2017).
Industry 4.0	Industry 4.0 is a phenomenon that "builds on technological tools, integrates a set of activities and exploits the opportunities offered by digitalisation to raise process transparency to a high level, integrates the corporate value chain and supply network, and brings customer value creation to a new level by making customised and smart products available" (Nagy, 2019, p. 15).
Agriculture 4.0	Based on Hungary's Digital Agriculture Strategy (DAS), Agriculture 4.0 is "is the umbrella term for the digital agricultural economy, or in a narrower sense, precision agriculture, information and communication technologies (ICT), decision support based on the collection and processing of large-scale data, and technological and management reform resulting in the ever closer integration of automation and robotisation, as well as changes in production, farm management and business models for product chains" (DAS, 2019, p5).
Digitalisation	Digitalisation is a process that "can be understood as the transformation of many areas of social life around digital communication and media infrastructures" (Brennen & Kreiss, 2016, p. 1). According to Demeter and Losonci (2020), digitalisation also includes the policy of going paperless (Demeter & Losonci, 2020).
Food safety	Borchers and colleagues (2010) define food safety as "reasonable certainty of safety". By this they mean the degree to which food is regulated, which indicates the extent to which additives and unavoidable contaminants may be present in products (Borchers, Teuber, Keen, & Gershwin, 2010, p. 96).

Traceability	Traceability is defined in ISO 8402:1994 as "the ability to trace the history, application or location of an entity by means of recorded identifications" (Olsen & Borit, 2013, p. 143).

Table 4: Conceptualisation
Source: own editing, 2025

The conceptualisation also serves to clarify the basics of the relevant literature and the consequent application of the terms appearing in my dissertation.

3.1.4. Operationalisation

Ques-tions	Description	Prelimi-nary as-sump-tions	Description	Methodology	Paper, which deals with the PhD-RQ	Characteristics and the role of paper in the dissertation
PhD-RQ-1	How does the relationship between available technological investment in the agri-food industry and the willingness of decision makers look like?	PA1	There are investments in food technology which can contribute to the sustainable and efficient operations of AFSC members, and the directions and the financial background how to apply them is partly formulated by authorities.	Systematic literature review methodologies, both a hybrid (literature+ secondary data analysis) and bibliometric literature review	Paper Nr. 1. (hybrid) and Paper Nr. 2. (bibliometric)	The role of Paper Nr. 1. in the thesis: review of the current status of the agri-food sector, identification of opportunities, assessment of needs
PhD-RQ-2	Which digitalisation tools are used by agri-food supply chain actors?	PA2	The agri-food supply chain actors are mainly using digitalisation tools to support value-creating processes.	Bibliometric literature review and case study, semi-structured interview questions	Paper Nr. 2. and Paper Nr. 3.	The role of Paper Nr. 2. in the thesis: review of available technological solutions for the agri-food sector (as a following research direction of Paper Nr. 1.), analysing their effects on the AFSC

PhD-RQ-3	How do food industry companies perceive the realisation of digitalisation and ICT based improvements in their operations and organisation?	PA3	Companies are adopting digitalisation mainly because of regulatory compliance, partly because of economic competition and partly because of their own convictions.	Case study, semi-structured interview questions	Paper Nr. 3.	The role of Paper Nr. 3. in the thesis: exploratory research of the manifestation of I4.0/digitalisation solutions contributing to the operations of AFSC members

Table 5: Operationalisation
Source: own editing, 2025

The operationalisation step is designed to provide a transparent way of linking analytical methods to answer research questions. Table 5 shows that I used systematic methods to answer the first two research questions of the dissertation, and qualitative methods mixed with systematic reviews to answer the second and the third research question of my PhD research.

Table 6 further introduces the methodologies applied in the three chosen publications.

Nr. of publication in the dissertation	**Description of the applied methodology**
Paper Nr. 1	I analysed secondary data sources in this exploratory research. Both the literature and the data on tenders for small and medium-sized enterprises and Hungary's Digital Agricultural Strategy were part of the analysis. The scope of the research covers digital solutions for stakeholders across the food sector, from farmers to processors and caterers (Kürthy et al., 2016). For a targeted exploration of the literature, I conducted a bibliometric analysis. <u>Data characterisation</u> A SCOPUS database was used as the search engine for this research. I checked the results manually to see if they met the previously defined requirements. After the validity check, 181 papers remained in the SCOPUS list. The publications used include scientific articles, early access articles and conference papers regarding literature reviews. For the studies published between 2005 and 2022, I applied a filter to answer the research question, so that the final list includes publications published between 2019 and 2022. The final number of elements used for the bibliometric analysis is 115 papers. <u>Data analysis</u> I used the Biblioshiny software (the bibliometrix package of the R studio) to analyse and interpret the literature results. Biblioshiny generated outputs in visual and textual formats to answer the thematic evaluation of the topic under study.
Paper Nr. 2	This publication used the methodology of a systematic bibliometric literature review.

	The observed dataset contained data from two important databases. Web of Science (WoS) and SCOPUS served as searching engines for this bibliometric literature review. Data characterisation After having checked the validity of the searched paper, 466 articles remained on the SCOPUS list and 78 articles on the WoS list. To reach an appropriate database without duplications, the merging function of R Studio's bibliometrics package was used. As a result of the merging process, 499 documents form the dataset of the current literature review. Data analysis Thematic evolution and bibliographic coupling were used as methods to analyse the collected secondary data. Biblioshiny and VosViewer served as tools for data analysis.
Paper Nr. 3	Data characterisation Data were collected from four food companies in Hungary, covering pasta manufacturing, dairy production, dairy processing, and meat processing using the analytical framework we developed. Among the interviewees there were a plant manager, a farm manager, another plant manager, and a CEO whom with we made 1.5-2 hours long structured interviews. Data analysis There were five analytical dimensions along which the interviewed the companies. We interviewed them about the company's I4.0 approach, the digitalisation solutions used, the projects and the directions of development. As all interviewees were top executives of a given company, they were aware of both production and strategic issues and were considered relevant sources of information. The reliability of our research is enhanced by the fact that although the number of interviews is low, they were conducted with the three largest subsectors of the Hungarian food industry, the meat industry, the dairy industry and the bakery and pasta industry.

Table 6: Data and methods applied in the three publications of the article-based dissertation
Source: own compilation, 2025

4. OVERVIEW OF THE INTRODUCTION OF THE DOCTORAL DISSERTATION

In the introductory part I presented the basics of my doctoral research which led to conduct the research that concluded in my three targeted papers in this dissertation. In the following chapters (5.-10.), the three papers that were chosen for the thesis are introduced.

Beforehand, I summarize the main goals of the introductory part of my dissertation. The structure of the three papers presented in my dissertation is built on the *concept* of first examining the opportunities from a governmental, technological and industry perspective, then explore the real-life manifestations of the results gained by the first two papers.

Paper Nr. 1. aims to present the current situation of the agri-food sector in Hungary, showing the development opportunities available for AFSC members, highlighting the directions set by the EU and the Hungarian Government. This paper also deals with the willingness of the decision makers, which means mainly the motivation behind the implementation of directives.

Paper Nr. 2. is an extension of the first article. My aim was to explore the theoretical background of the effects of digitalisation on the AFSC. The goal was to collect valid and valuable knowledge about the pros and risks of digitalisation in the examined industry. The tool for the research was the methodology of the bibliometric literature review. This systematic method allows us to search for the relevant literature within the scope and analyse them with software support (relying on quantitative bibliometric data).

Paper Nr. 3. uses a qualitative methodology, in order to gain a comprehensive understanding of the operations of the examined AFSC members. According to Kürthy et al. (2016), we aimed to conduct exploratory research reaching prominent interviewees of the largest AFSC actors. The upstream side of the supply chain was represented by AFSC members from the sub-sectors dairy, meat, and pasta. It was an advantage that we could conduct interviews with AFSC member who belong to the prior steps of production (farming) and to the processor group.

I wrote two papers on my own, in order to widen my own deep understanding about the examined industry. I wanted to gain as much knowledge as possible about the recent technological advancements and the drivers of economic policy which directly or sometimes indirectly affect the AFSC. The first two papers present the results of this research goal. The third one was written by me and my colleagues from the Food Supply Chain Research Group. We have been working on topics related to managerial questions about the operation of AFSCs since 2018. Our main driver in research is I 4.0 and digitalisation, as well as their effects on the sector under study. In Paper Nr. 3., we aimed to explore opportunities for the integration of digitalisation solutions and the motivation behind the decisions. We were also interested in the financial background of these technological investments, whether their return rata is acceptable or how difficult it is to obtain funding for these improvements.

5. BRIEF INTRODUCTION OF PAPER NR. 1

5.1 Bibliometrics

Freund, A. (2022). A Covid-19 világjárvány következményeként kis-és középvállalkozások számára hirdetett élelmiszeripari digitalizációt célzó pályázatok vizsgálata. [Investigating the food digitalisation tenders for small and medium-sized enterprises in the wake of pandemic Covid-19]. *Marketing & Menedzsment*, *56*(3), 69-79. doi: 10.15170/MM.2022.56.03.06.

Ranking of journal in year of publishing:
Hungarian Academy of Science – IX. Section of Economics and Law: C.

5.2 Targeted research question

The original research question (PhD-Q1) of my PhD research deals with the fundamental relationships of the targeted stakeholders of my research. The thesis aims to answer the question "*How does the relationship between available technological investment in the agri-food industry and the willingness of decision makers look like?*" with conduction a hybrid literature review with the following sub-research question.

RQ-Paper nr.1: Which are the targeted funding frameworks supporting SMEs that have come to the fore in recent years in relation to the Covid-19 virus?

5.3 Research gap

During the analysis of the literature, I discovered a gap in that the literature tends to be descriptive, either only on the technology side or at most on the decision-making side (Tse et al., 2017, Lin et al., 2019, Wang et al., 2016). The aim of this study was to provide a comprehensive foundation on whether targeted support is feasible after decisions have been taken at EU or even regional (state) level, and whether the tools and technology development are available, and how they relate to decisions taken at higher levels.

5.4 Key findings

The results of the first paper show that the impact of the Covid-19 pandemic has led to the alignment of food digitalisation support frameworks for small and medium-sized enterprises (SMEs) with national and EU strategies, such as the Digital Agricultural Strategy (DAS, 2019). The research shows that rapid responses by policy makers, such as the modification of the GINOP operational programme deadline, have helped agri-food actors to adapt to the challenges of the pandemic. Available technological development opportunities such as process automation, sensor and control technologies and robotics have also contributed to the sector's competitiveness. In addition, the results highlight that the targeted alignment of support frameworks and technological solutions is not only an option but a necessary tool for crisis management and technological development in the agri-food sector. The research aims to fill a gap in the literature that has so far not investigated in an integrated way the relationship between technological investment and decision making.

5.5 Author contribution

I conducted every phase of this publication process on my own.

6. THE ORIGINAL TEXT OF PAPER NR. 1

Investigating the food digitalisation tenders for small and medium-sized enterprises in the wake of pandemic Covid-19

Freund Anna

DOI: 10.15170/MM.2022.56.03.06

THE AIM OF THE PAPER

Due to the Covid-19 virus outbreak in early 2020, the importance of the food industry in our country has also been highlighted. The importance of the country's self-sufficiency, with small and medium-sized enterprises being important players, was demonstrated. As a result, from 2021 onwards, entrepreneurs have had access to a wide range of funding for development. The aim of the study is to examine whether the Covid situation will accelerate investment in digitalisation tools through the resulting calls for proposals and to see which directions firms will take being encouraged by funding opportunities.

METHODOLOGY

The exploratory research is based on a hybrid analysis of secondary sources, which includes both literature and tender data. The literature is processed in the form of a bibliometric analysis, while the tenders and policy objectives are analysed through a manual content analysis.

MOST IMPORTANT RESULTS

The results of the research show that the support of domestic food industry is pushed towards digitalisation by tendering opportunities. In the case of eligible activities, development directions for automated production systems, manufacturing technologies, sensor and control technologies are the main focus, as well as investments in robotics and smart manufacturing solutions (GINOP call for proposals 1.2.12-21, 2021). In addition, in response to the Covid-19 wave, calls for proposals to support further development and survival of Hungarian operators have been launched in 2021 (GINOP-PLUSZ-1.2.1-21 call for proposals, 2021).

RECOMMENDATIONS

The study aims to provide practitioners an overview of the relationship between economic policy objectives and implementation options, raising their awareness of the benefits of digital-enabled operations.

Keywords: digitalisation of the food industry, Covid-19, tender resources

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Introduction

Due to the technological toolkit of the 21st century, many areas of the manufacturing industry have developed in terms of digital support for products and processes (Baksa et al.., 2021; Demeter et al.., 2020; Demeter & Losonci, 2020). The research is carried out in the food industry, one of the most important industries in Hungary (Kürthy et al., 2016). The importance of the chosen industry for digitalisation developments is internationally prominent (Casino et al., 2020; Kayikci et al., 2020; Lin et al., 2019).

This study, a hybrid of systematic and traditional (narrative) literature analysis, investigates whether the Covid situation for food supply chain actors is driving food businesses in a direction that accelerates the adoption of coordinated digitalisation solutions by companies. In Hungary, as in all other EU countries, there are opportunities to target different sources of funding. The Government of Hungary has taken advantage of these opportunities, and as a result, the tender databases open to Hungarian SMEs are publicly available on palyazat.gov.hu. The study will show the link between the policy objectives (Hungarian Digital Agricultural Strategy), the funding opportunities (tender resources) and the possible technological solutions (literature review). In the paper, the author seeks to answer the question of how to motivate Hungarian entrepreneurs to invest in digital solutions and whether the objectives set by the European Union can be implemented in the Hungarian reality. These investments are typically very cost-intensive for various stakeholders, which raises the question of the financing options available to them. The aim of the paper, which presents a review of the calls for tenders, is to provide practitioners a transparent structure of the opportunities available to Hungarian SMEs, in order to enhance their farms and businesses.

Literature review

In the following, the paper presents a hybrid literature review based on two pillars. On one hand, the analysis of national and regional level economic policy making documents will be examined, including the national level Digital Agricultural Strategy and the calls for tenders issued by the European Union. In addition, the author has applied systematic methods to achieve reproducibility and reliability. The author applies a bibliometric literature review to the topic of digitalisation solutions, which is mainly covered in the international literature. The bibliometric approach ensures the identification of relevant literature, and the traditional method of analysis allows for synthesis. In terms of systematic literature reviews, the source discovery methodology is of paramount importance for validity as well as credibility and is therefore presented at the beginning of the paper.

Methodology

The author has analysed secondary data sources in the present exploratory research. Both the literature and the data on tenders for small and medium-sized enterprises and Hungary's Digital Agricultural Strategy were part of the analysis.

The scope of the research covers digital solutions for stakeholders across the food sector, from farmers to processors and caterers (Kürthy et al., 2016). For a targeted exploration of the literature, the author conducted a bibliometric analysis.

	Keywords	Findings (piece)
From SCOPUS database – version[1]	TITLE-ABS-KEY (("covid*" OR "pandemic*") AND ("agr* food supply chain") AND ("digitali*" OR (*ndustry AND 4*) OR "blockchain" OR "big data" OR "internet of things" OR "robot*" OR "machine learning" OR "sensor" OR "cloud" OR "network"))	9
From SCOPUS database – version[2]	TITLE-ABS-KEY (("tender*") AND ("covid*" OR "pandemic*") AND ("agr* food supply chain") AND ("digitali*" OR (*ndustry AND 4*) OR "blockchain" OR "big data" OR "internet of things" OR "robot*" OR "machine	0

	learning” OR “sensor” OR “cloud” OR “network”))	
From SCOPUS database – version3	TITLE-ABS-KEY ((“agr* food supply chain”) AND (“digitali*” OR (*ndustry AND 4*) OR “blockchain” OR “big data” OR “internet of things” OR “robot*” OR “machine learning” OR “sensor” OR “cloud” OR “network”))	181

Table 1: Differences in keyword searches
Source: own editing, based on SCOPUS database results, 2022

In this paper, the author presents the keyword search in the SCOPUS database, as the search on the Web Of Science (WOS) search engine with the same keywords did not yield any additional results (131 results for WOS version 3, of which almost 60% match the SCOPUS results). The decision is further supported by the fact that the WOS search engine does not allow all search operators (see (*ndustry AND 4*) for the left operator) so the results of the extended find list are analysed in this study.

In version 1, studies on digitalisation tools for the food supply chain in the context of the Covid-19 pandemic were filtered. It can be seen that there are very few direct links between the Covid-19 epidemic and digitalisation -based technology solutions. In addition, the author applied a search on the SCOPUS database to complement the tender opportunities. In the version 2 search, no study was included in the set of studies matching the filtering criteria. This may suggest that this aspect of the topic has not yet been addressed at the literature level. The filtering, called version 3, covers the digital opportunities offered to actors in the food supply chain. Here, the result is a list of 181 items. The bibliometric analysis combines the advantages of statistical and qualitative analysis, so that an in-depth interpretation can be presented in a literature review alongside the presentation of statistical data (Maditati et al., 2018). The bibliometric literature review is based on statistical findings on the relationships and performance of researchers. This method can lead to more relevant results while searching for the most influential publications (Zupic & Čater, 2015).

Along the main research question, the author was interested in the targeted funding frameworks supporting SMEs that have come to the fore in recent years in relation to the Covid-19 virus. To investigate this, she focused on the national database of palyazat.gov.hu and the Hungarian Digital Agricultural Strategy (DAS) announced in 2019 (DAS, 2019; Tender website1, 2022).

Data characterisation

The SCOPUS database was used as the search engine for this research. The author checked the results manually to see if they met the previously defined requirements. After the validity check, 181 papers remained in the SCOPUS list. The publications used include scientific articles, early access articles and conference papers regarding literature reviews. For the studies published between 2005 and 2022, the author applied a filter to answer the research question, so that the final list includes publications published between 2019 and 2022. The final number of elements used for the bibliometric analysis is 115 papers.

Data analysis

The author used the Biblioshiny software (the bibliometrix package of the R studio) to analyse and interpret the literature results. Biblioshiny generated outputs in visual and textual formats to answer the thematic evaluation of the topic under study. The applications and the content of the Digital Agricultural Strategy are presented along the lines of a qualitative content analysis.

Analysis of the literature through hybrid review methods

The logic of the literature review is based on the fact that the study first presents the directions considered important by policy makers at national level through the Digital Agricultural Strategy. Based on the content published there, it is possible to see what objectives the Hungarian Government has set for the coming period for the operation of the Hungarian food sector. The content of these objectives can be a guide for the Hungarian food sector, since, if we assume that the agricultural economy is the starting point for the rest of the food sector, it is worth paying attention to what basic expectations are set at the beginning. The national objectives can be achieved through tendering resources that mediate regional economic policy. Tendering opportunities are also open to food sector stakeholders. From farms to processors, issues affecting the whole food sector are addressed in this sub-chapter. It is clear that they do not necessarily target food SMEs directly. However, they share the common objective of supporting the development of smaller Hungarian enterprises, in order to stabilise their operational security and to establish and maintain competitiveness. Finally, due to the relevance of the topic, technologies based on digital solutions from the international literature will be presented. The aim of the author has been to present digital solutions that seem to be already widespread in the international literature, thus providing practitioners a structured overview of the triad of the Hungarian economic policy *objective* (DAS) and the *support options* and technological *solutions* for digitalisation.

Requirements of the Digital Strategy for Agriculture

To link technological solutions with farming characteristics, it is worth looking at Hungary's current strategy for agriculture. The Digital Agricultural Strategy (DAS) was announced by the Hungarian Government in August 2019. The DAS actively addresses the digital issues of Hungarian agriculture, focusing on facilitating the digital transition of farmers (Erős, 2019).

The list of DAS Initiatives can be seen as a positive development in terms of difficulties (Kürthy et al., 2016). The DAS aims to further develop precision farming and promote "Agriculture 4.0". Agriculture 4.0 is understood as "the name of the information and communication technology (ICT), decision support based on big data collection and processing, automation and robotics, technology and management summary reform" (DAS, 2019, p. 5) whose objectives are to increase the technological development of stakeholders. Its main objective is to support precision farming at national level by providing an adequate asset base that can finance its investments through the application framework presented below.

Tendering opportunities for small and medium-sized enterprises

Even before the emergence of the Covid-19 virus, EU support programmes were already being developed in line with the Hungarian institutions. Several agricultural and food industry support programmes have been launched (Dairy Interbranch Organisation and Product Council, 2013), which may provide a stable basis for the launch of tenders in the wake of the outbreak of the coronavirus. Since the emergence of the Covid-19 virus in 2019 there are basically two types of EU funding opportunities available for SMEs in the food industry (Tender website1, 2022).

Within the framework of the Széchenyi 2020 development programme, different funding opportunities were available for the period 2014-2020. During the period of the Covid-19 virus pandemic, only the Economic Development Operational Programme (called GINOP in the Hungarian tender structure) 2021 call for proposals package was extended, so that it will be available until 2023.

In addition to the procurement of equipment, GINOP supports the development of new technological systems and capacities, including the improvement of production systems through the procurement of manufacturing technologies, process automation tools, sensor and control technologies, robotics, and smart manufacturing solutions.

The Competitive Central Hungary Operational Programme (called VEKOP in the Hungarian tender structure) offers capacity-building development funding for small and medium-sized enterprises engaged in productive activities with the aim of creating state-of-the-art product and service development capabilities.

The Rural Development Programme (called VP in the Hungarian tender structure) aims to make agriculture competitive and to support sustainable management of natural resources and activities to create/maintain a workforce.

The Hungarian Operational Programme for Fisheries (called MAHOP in the Hungarian tender structure) offers specific funding to increase the competitiveness of fisheries.

For small and medium-sized enterprises, a second source of funds is the Norway Fund. Within the Business Development, Innovation and SMEs 2014-2021 programme, the aim is to promote increased value creation and sustainable growth (Tender website1, 2022).

Technology solutions based on digitalisation

In the present paper, local and global citations were the basis for the bibliometric analysis. The leading study is from Kamble et al. (2020), which dealt mainly with the topic of production (Kamble et al., 2020). In addition, the Institute of Electrical and Electronics Engineers (IEEE) journal, and thus the field of electrical engineering and information technology, dominates this list. The studies that stand out in terms of citations in the literature analysis are predominantly on the topic of blockchain. There also appears the topic of traceability. The term “blockchain” dominates the literature analysis (17% of the results, while the other terms appear in isolated cases). However, it is also worth considering the preconditions for the feasibility of blockchain in food supply chains.

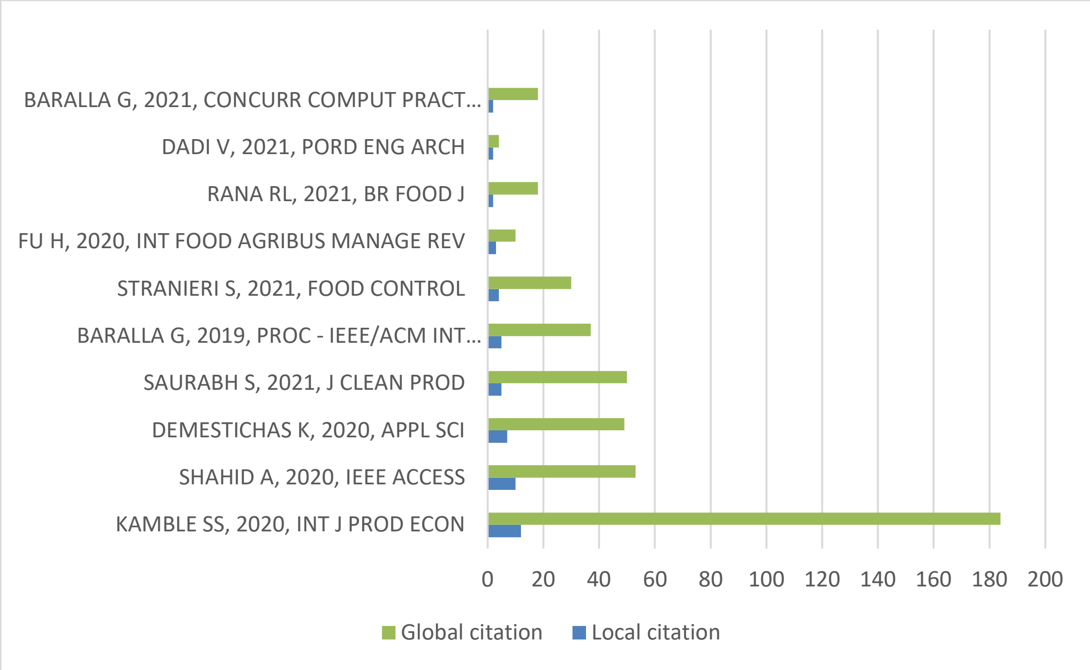

Figure 1: Citation trends for the sample at local and global level
Source: own editing, based on data from Biblioshiny, 2022

An interesting trend in the evolution of local and global citation data is illustrated in Figure 1. While the citation figures at the local level decrease proportionally for the first 10 studies, a more significant difference in the global citation figures can be observed.

Technological solutions

Technological term	Approach to Technology	Sources
Blockchain 9	software (cooperation with hardware data collectors)	Oguntegbe et al., 2022; Varavallo et al., 2022
IoT (Internet of Things)	software (cooperation with hardware data collectors)	Awan et al., 2021; Fu et al., 2020
AI (Artifical intelligence)	software (cooperation with hardware data collectors)	Ahamed & Vignesh, 2022; Kollia et al., 2021
Big data analytics	software	Kamble et al., 2020; Lassoued et al., 2021
Cloud-based technology	software	Coppolino et al., 2021
Smart contracts	software	Dos Santos et al., 2021; Wang et al., 2021

Precision farming	software (cooperation with hardware data collectors)	D’Agaro et al., 2021; Lassoued et al., 2021
Robotisation	hardware	Viet et al., 2021

Table 2: Technology solutions found in papers published during the Covid-19 pandemic
Source: own editing, based on SCOPUS database and Biblioshiny software, 2022

Table 2 lists the terms that appeared in publications along the filtering criteria during the Covid-19 outbreak.

The blockchain is a technological solution that provides efficient tracking along the entire pathway of the product (Varavallo et al., 2022). On the other hand, it can also be conceived as a tool for information storage, where none of the stored data can be changed afterwards (Oguntegbe et al., 2022).

According to experts, IoT can be understood as a set of tools and technologies that enable resource sharing (Awan et al., 2021; Fu et al., 2020).

In addition, robotisation, as a mainly hardware-based solution to productivity issues, can play a useful role in replacing labour, and can even support the management of labour shortages, food safety, maintaining and improving food quality, and avoiding food waste (Duong et al., 2020).

According to Kollia and colleagues (2021), artificial intelligence (AI) is a tool for enabling safe food supply chains. AI can contribute to the realisation of the farm-to-fork concept, for example by optimising energy consumption (reducing costs and environmental impacts) or ensuring food safety and human health by optimising optical recognition and monitoring the expiry date of food consumption (Kollia et al., 2021).
Smart contracts can track and manage all communications and transactions within the food supply chain network (Dos Santos et al., 2021). All actors in the supply chain can be insured with these contracts.

Cloud-based technology is a software solution that allows data to be shared in real time in addition to being stored. The cloud solution also allows for more efficient communication and the ability to simultaneously access and modify data from separate locations, as required for the Covid-19 virus, thus helping employees to work together (Coppolino et al., 2021).

Big Data refers to the accumulated data from various data collections (e.g., IoT, RFID or sensors). Usually, additional steps are needed to analyse this data in a quantitative way, the results of which can contribute to companies' decision-making (Lassoued et al., 2021).

Precision farming can be understood as a set of different management solutions. It covers management solutions ranging from animal nutrition, through cost management, to various animal diseases and environmental issues. In addition, it is a farm management solution for animal and crop productivity issues (D'Agaro et al., 2021).

Only 4.3 percent of the identified studies deal directly with the situation caused by Covid-19 virus, whereas the studies published so far in 2019-2022 are in line with the policy objectives described earlier. An analysis of this link is presented in the results chapter.

Results

The analysis of the three approaches (Digital Agricultural Strategy, tender calls, literature) shows that there is a link between the objectives of policy makers and the support offered as a means of implementation, as well as the technological solutions for digitalisation that can be found in the literature.

Title of development programme	**Funding period**	**Name of OP (Operational Programme)**	**OP Objective**	**Is the application for digitalisation development**	**Appearance of DAS target**	**Responding to the appearance of Covid-19**	**Eligible technology solution**
Széchenyi 2020	2014-2020	GINOP	automation, robotisation, information technology development, intelligent manufacturing solutions, creating a modern business infrastructure	yes	explicit	yes	Blockchain, AI, IoT, cloud, Big Data analysis, robotisation
	2014-2020	VEKOP	Capacity expansion, technological renewal technological improvement	yes	explicit	no	precision farming, Big Data analysis, cloud

			s, promotion of R&D&I (research & development & innovation) activities				
	2014-2020	VP	improving the development of equipment and technology, economic performance and facilitating the restructuring and modernisation of agricultural holdings, increasing R&D activity	yes	explicit	no	precision farming, direction of Agriculture 4.0
	2014-2020	MAHOP	increase the competitiveness of fisheries	yes	non-explicit	no	N/D
Norway Fund	2014-2021	Business Development, Innovation and SMEs	Enhanced value creation and sustainable growth	yes	non-explicit	no	Decision support solutions: Big Data, IoT

Table 3: Relationship between digitalisation objectives and tendering opportunities
Source: own edits, (DAS, 2019; Tender website1, 2022) and based on literature analysis, 2022

The GINOP programme is the only one that has been extended due to the emergence of Covid-19. The relatively "late" addition, at least in relation to the EU plan for the 2014-2020 timeframe, shows that decision-makers, both at national and EU level, are aiming to apply digitalisation-related solutions. The application orientation of GINOP-1.2.12-21 turns to be in line with the objectives of the Digital Agricultural Strategy, which can be supported by the digital technology solutions for the food supply chain identified in the literature analysis.

Table 3 also shows the intersection between the objectives of the Digital Agricultural Strategy of the Government of Hungary, the existing funding opportunities, and the available digital technology. The results of the analysis show that the objectives set out in the Digital Agricultural Strategy are in line with the eligible projects announced as a response by national and international decision-makers. The digitalisation technologies identified in the literature can contribute to the achievement of these objectives, but their availability can be a major challenge for SMEs. However, solutions related to Industry 4.0 can also contribute to increasing customer satisfaction in the long term (Ejaz, 2021), which makes it worthwhile to embark on this path.

Research limitations

Limitations of the research include the fact that the level of technological development within the food industry may differ between Hungary and the international food industry. Therefore, a literature analysis using the SCOPUS database may show a different picture of the relationship between Hungarian reality and international examples. A further limitation of the research is that the administrative processes for handling application materials (tendering, winning contracts) are considered to be relatively slow. Their accessibility limits the availability of data, despite the fact that full transparency is expected for the use of EU-funded resources (Tender website1, 2022). Finally, regarding the content analysis of the applications and the Digital Agricultural Strategy, it is worth mentioning that the manual analysis method may be a limitation, and that the analysis of the Digital Food Sector Strategy (ed. the study was written before the approval of the Hungarian Official Gazette of 11 October 2022), which has not yet been officially launched by the Government, is also necessary to get the full picture.

Conclusion

In conclusion, it can be clearly stated that the Digital Agenda for Agriculture is reflected both in the calls for proposals and indirectly in the digital technology solutions identified. Stakeholders should focus on their harmonisation. Stakeholders in this context are the food sector operators (e.g., farmers, processors, traders, etc.), the producers of digital technology as suppliers, and other stakeholders that influence economic policy, such as the Hungarian State and the European Union through the provision of tender funds. This also means that both decision-makers and food sector operators must invest in ensuring that they can work in harmony and create a competitive position in the Hungarian market in cooperation with the technology producers. The analysis also showed that the process improvement targeted by the economic policy (Digital Agricultural Strategy) is necessary. Public intervention seems to be justified in this case, as it supports both social and economic objectives. Targeted support for market processes (through tenders) could favour small and medium-sized enterprises in the food sector, provided that the right conditions are created. However, the question of whether the nature of targeted support goes beyond necessity and reaches the level of effectiveness will be explored in a future study. The next step of this study remains exploratory. The author has set out to contact the winning applicants, in order to examine their perceptions of the winning tenders in terms of their contribution to their development.

Summary

In conclusion, the eligible projects are clearly in line with the Digital Agricultural Strategy (DAS) in the context of digitalisation, which was formulated before the spread of the Covid-19 virus. These include, among other things, the implementation of automation to boost production technology, while the various project descriptions also include systems for robotisation and even sensor-based and RFID-based solutions for monitoring. This clearly shows that the drive from the government and the European Union is to encourage SMEs to use digitalisation solutions to become or remain competitive. Consequently, these operators are in great need of investment, as investments in technologies offering digital solutions also impose a significant burden on food operators. These difficulties may be caused by the fact that the ratio between co-financing and tender funding may be uneven. In addition, the economic crisis caused by the pandemic, which has led to daily price fluctuations for technologies, may mean that the amount awarded today under a tender may not be able to make a significant contribution tomorrow.

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7. BRIEF INTRODUCTION OF PAPER NR. 2

7.1 Bibliometrics

Freund, A. (2023). Effects of digitalisation on food safety. *Studies in Agricultural Economics*, *125*(3). https://doi.org/10.7896/j.2498

Ranking of journal in year of publishing: SJR Q2.

7.2 Targeted research question

The second original research question (PhD-RQ2) of my PhD research dealt with the applied technological solution in order to investigate the available solutions which might match the targeted directions of decision makers. PhD-RQ2: *Which digitalisation tools are used by agri-food supply chain actors?*
To answer this question Paper nr. 2. sets two sub-questions:

RQ1-Paper nr.2 focused on the area: “Which are the emerging topics of AFSCM regarding food safety?” and

RQ1-Paper nr.2 dealt with the question: “How has the topic of food safety in AFSCM evolved during the last 10 years?”

7.3 Research gap

This study aims to fill the research gap that exists for a comprehensive study of agri-food supply chains. Previously, studies have typically approached either only from the agriculture or the processing industry side, with less research targeting chain-level integrated solutions. The last such comprehensive AFSC based analysis from the perspective of digitalisation was published in 2021 (Barbosa, 2021); but it does not focus on the effects on digitalisation on food safety rather on their descriptive introduction. This is the gap that this study aims to cover in order to achieve a full AFSC-wide detection of traceability. To this aim, a bibliometric literature analysis is carried out to identify research trends across the entire chain.

7.4 Key findings

The results of the second paper show that there is a wide range of digitalisation tools available for actors in the agri-food supply chain (AFSC), including innovative solutions such as Artificial Intelligence, Big Data, Blockchain, IoT, precision farming and autonomous systems. These tools have significant potential to improve food safety, but their application poses complex social, environmental and economic challenges. The research has highlighted that the effectiveness of AFSC technology solutions is highly dependent on the IT skills of the participants and the management of regulatory and standardisation issues.

The results underline that the digital transformation of AFSC is not limited to the implementation of technological innovations but requires an integrated approach that takes into account food safety regulations, corporate culture and sustainability. The study aims to fill a gap in the literature that has not yet comprehensively examined the effects of technological solutions on the AFSC, while offering new perspectives on the future development of digitalisation.

7.5 Author contribution

I conducted every phase of this publication process on my own.

8. THE ORIGINAL TEXT OF PAPER NR. 2

Effects of digitalisation on food safety

Anna Freund

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Abstract

This paper reviews food safety within the agri-food supply chain (AFSC) literature and presents a comprehensive framework for understanding how digitalisation has reshaped food safety practices within the AFSC. Its significant contribution lies in its identification of novel research streams in food safety that are underpinned by digitalisation techniques, a focus that can be expected to benefit both academic researchers and practitioners who are seeking solutions to pressing challenges related to the efficient achievement of food safety goals. In this paper, the powerful bibliometric analysis capabilities of Biblioshiny and VosViewer were utilised to conduct a comprehensive review of the relevant literature. Biblioshiny's strengths in data visualisation and network analysis were instrumental in identifying key trends and patterns in the research, while VosViewer's ability to create insightful maps of collaboration networks provided valuable insights into the relationships between researchers and institutions. The evolution of the published reviews from the past 10 years and the trending AFSC articles were thus revealed. The used databases were Web of Science and SCOPUS. Based on bibliometric coupling, the identified seven underlying research streams are (a) traceability challenges in AFSC, (b) quality management in AFSC, (c) Agri-food 4.0, (d) future trends of AFSC, (e) impact of the Blockchain, (f) smart packaging, and (g) circular economy. Results show that besides contributing to the efficiency and profitability of companies, digital developments also help to promote sustainable practices and mitigate environmental impacts, while ensuring traceability, proactive risk management and incident prevention.

Keywords: agri-food supply chain, food safety, digitalisation, bibliometric review

Introduction

In November 2022, the world's population reached 8 billion people. Research highlights that this figure – albeit at a slowing pace – continues to grow and the current expectation is that the global population will exceed 8.5 billion in 2030 and 9.7 billion people by 2050 (UN Statistics, 2023). In this context, the issue of world food supply represents an ongoing challenge, and it must be a unified goal for agri-food supply chain members to work on serving the increasing demand efficiently. This paper aims to provide a comprehensive review and identify recent research streams in the field of food safety, including the connection of food safety and digital solutions. The paper examines the manifestations of Industry 4.0 and digitalisation in a sector that is not typically considered high-tech when viewed as a whole. Although automation has been present in many sub-sectors of the food industry for many decades, the changes being wrought by the Fourth Industrial Revolution tend most often to be studied by researchers and professionals whose interests lie in the automotive and electronics industries (Demeter and Losonci, 2020; Szász et al., 2020). This paper points out that Industry 4.0 is also present in the food industry and offers a number of opportunities in two areas that are the particular focus of this sector: traceability and food safety (Luo et al., 2018). In addition, the automation of manufacturing processes, intern, and extern logistics and even finances can be supported by Industry 4.0 solutions, which can be indirectly connected to traceability and food safety (Beltrami et al., 2021). The goal of this study is to uncover the research streams in connection with the triad of "industry 4.0" – "agri-food supply chain" – "food safety" solutions. This paper makes an original contribution to the literature by describing the emerging topics from a holistic perspective regarding their positive and risky effects for the AFSC members. The two research questions are as follows: (1) What are the emerging topics of AFSCM regarding food safety?; and (2) How has the topic of food safety in AFSCM worldwide evolved during the last 10 years? There are literature reviews (Barbosa, 2021; da Silveira et al., 2021) dealing with the topics above, but this paper aims to complement them in two important ways. On the one hand, the focus has been widened from the previously examined food supply chain to the agri-food supply chain because the author assumes this term is the most comprehensive research scope possible. The term "food" sometimes does not cover the total agri-food supply chain, because agriculture and similarly zootechnics, forestry and fishing are considered as primary activities (Manzini and Accorsi, 2013). On the other hand, this paper seeks to uncover the links between distinct technological concepts and offers a comprehensive framework for both academics and practitioners. The results of the paper provide an overview of both the positive and the risk-signifying effects of the technologies highlighted here. The paper initially introduces a brief review of the theoretical background. Next, it introduces the review methodology used to analyse the literature. Outputs from the analysis based on software-generated data then follow, after which the results are presented, and a discussion of the findings closes the review. The last section concludes.

Theoretical background

This paper aims to analyse the effects of digitalisation from the perspective of food safety solutions within the agri-food supply chain (AFSC). The AFSC sector remains a priority even now; it plays a major role in supplying food. In the previous decades, research in the food sector has tended to focus more on manufacturing and services, while the agricultural sector has been less prominent (Ganeshkumar et al., 2017). Food safety contributes significantly to the resilience of AFSC. Suppliers may require information about the origin and quality of the products (to validate their originality and quality and to be financially accountable in the trading processes) and consumers receive trustworthy information thereby (Xiang, 2015). Food safety can be defined as an approach controlled and regulated by official authorities. The tools used to ensure these two functions can be nationally and internationally valid laws, but mostly international standards such as GHP (Good Hygiene Practices), GMP (Good Manufacturing Practices), ISO9001, ISO22000, or the HACCP (Hazard Analysis and Critical Control Point) system (Gomes-Neves et al., 2007, Wu et al., 2010, Xiang, 2015, Kittipanya-ngam and Tan, 2020). Food safety includes aspects such as preventing food fraud, foodborne outbreaks, and traceability processes to ensure quality assurance compliance (Ehuwa et al., 2021). Recent studies have found that digitalisation can contribute to ensure food safety in various ways: digital solutions or complex management solutions, such as applications for farm management, can decrease risks, increase transparency, and avoid food waste (Jagtap and Rahimifard, 2019, Prause et al., 2020, Barbosa, 2021). The term traceability can be interpreted as a trade link between stakeholders of various agri-food supply chains (Dabbene et al., 2014) and is a highlighted part of food safety which can be supported by digitalisation. Key stakeholders of the AFSC, like representatives of governments, corporations, and customers must be involved in implementing traceability to ensure its effectiveness (Qian et al., 2020). Traceability as a trade link is not only a commercial link between partners, but also a financial commitment in form of a technological investment. This paper aims to complement the previous research with a special focus on the effects of digitalisation on food safety within the AFSC.

Review Methodology

Research plan

The aim of this work is to provide an insight for agri-food supply chain researchers and professionals from the focal industry into the digitalisation-based support for food safety over the last 11 years (2011-2023). Another aim of this paper is to reveal a summary of the topic along the existing literature through identifying key themes building on previous practices (Apriliyanti and Alon, 2017; Maditati et al., 2018). The aim of author was to find out which are the most researched areas in relation to food safety that have come to the fore in recent years, including the question which new research trends are emerging. The interpretation of the methodology of bibliometrics is that both statistical analysis as a part of quantitative research methodology and in-depth interpretation as a way of qualitative analysis may appear in literature review (Maditati et al., 2018). Bibliometric literature review builds on statistical statements regarding the relationships and performance of scholars. It may lead to a better prepared searching process, while looking for the most impactful publications. Figure 1 illustrates the research methodology adopted in this paper.

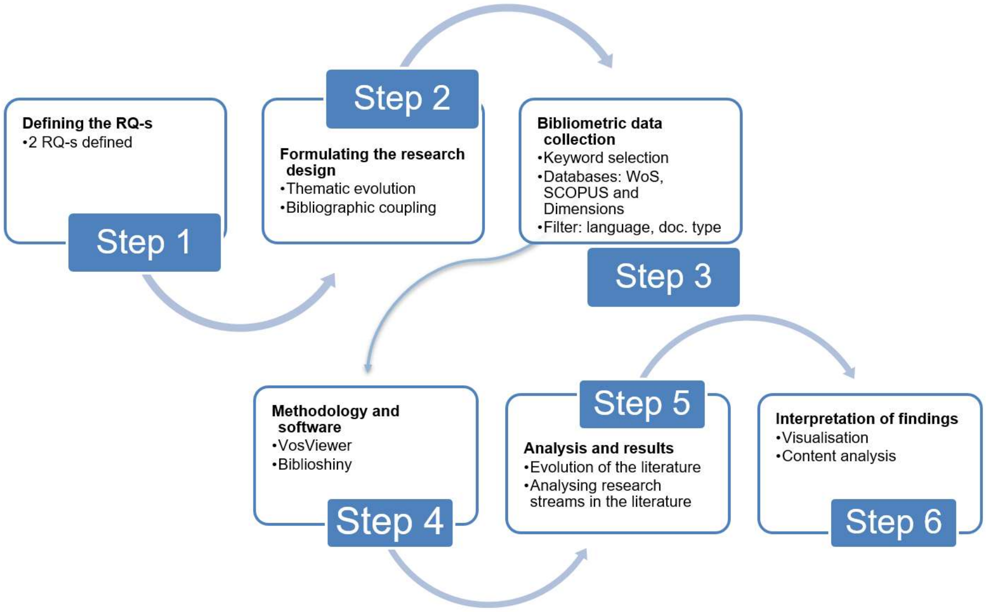

Figure 1: Steps of methodology
Source: Own composition

According to experts (Apriliyanti and Alon, 2017; Aria and Cuccurullo, 2017), thematic evolution can provide an answer for RQ-1 as it shows how the examined research topic changes over a period of time. Bibliographic coupling (BC) is a useful analysis tool to check how scholars are related to each other (Jose and Shanmugam, 2020). Bibliographic coupling "uses the number of references shared by two documents as a measure of the similarity between them" (Aria and Cuccurullo, 2017, p. 434). The author chose BC because of the intense development of technologies which may have an impact on AFSC. BC creates clusters from recent publications which cite previous ones. BC also allows to observe in which direction the field is evolving, as well as the emerging topics (Aria and Cuccurullo, 2017).

Description of keywords

Keyword search	**Number of articles (SCOPUS)**	**Number of articles (WoS)**
Before filtering: ("agr* food supply chain" OR "food supply chain") AND ("food safety" OR trac*) AND "digi*" OR "*4.0" OR "blockchain" OR "big data" OR "internet of things" OR "robot*" OR "machine learning" OR "sensor" OR "cloud" OR "network")	9958	755
After filtering: TITLE-ABS-KEY (("agr* food supply chain" OR "food supply chain") AND ("food safety" OR "trac*") AND ("digi*" OR "*4.0" OR "blockchain" OR "big data" OR "internet of things" OR "robot*" OR "machine learning" OR "sensor" OR "cloud" OR "network")) AND LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English"))	1339	110

Table 1: Keyword search used on SCOPUS and WoS databases
Source: Own composition

As Table 1 shows, SCOPUS listed more papers. All variations of keyword search were run on both websites and the table only contains the end searching combination. While managing the search engines based on the previously read literature topics, it turned out to be important that entering the keyword "blockchain" emerged the number of articles within the search. It may appear that the importance of blockchain will be shown within the scope of this paper. As similarly important keywords "internet of things" and "sensor" can be listed.

The following step was the examination of the titles and keywords of the articles. Researchers need to read all the abstracts to check whether the found results are relevant for the research. Reading the papers led to complementing the existing keyword list with new ones in addition. New keywords/topics appeared in the listed publications. The term “RFID” and “digital twin” appeared as new ones in contrast to the keywords from the original search. Bouzembrak et al. (2019) highlights RFID (radio frequency identification) as a facilitator in food traceability and product authenticity measures helping IoT (Internet of Things) systems enabling communication with other machines or humans and computing resources. The publication of Bhandal et al. (2022, p182.) presents the term of “digital twin” together with the term “cyber physical system” as “the most recent instalment of Industry 4.0 technologies that promises to further exacerbate the ongoing trend”. These terms completed the preconception of the author. Since none of the places showed direct reference to the combination “agri-food supply chain & food safety & digitalisation”, the publication was excluded from the database. Bibliometric research requires that the analysed papers are literature reviews. Other than this, a language limitation to English was applied. These two steps reduced the database (see in Table 1). The observed dataset contained data from two important databases. Web of Science (WoS) and SCOPUS served as searching engines for this bibliometric literature review. The listed papers were manually checked in regard to the question, whether the scope is fulfilling the requirements. The author filtered out the biological papers because nanotechnology is not the focus of the current research. The author aims to provide a management related view and she assumes that nanotechnological developments would have changed the direction of the paper. After having checked the validity of the searched paper, 466 articles remained on the SCOPUS list and 78 articles on the WoS list. To reach an appropriate database without duplications, the merging function of R Studio’s bibliometrics package was used. As a result of the merging process, 499 documents form the dataset of the current literature review. The publications are all literature reviews. Conference proceedings, case studies and other empirical studies are excluded. The timespan is wide enough to examine the second research question (RQ-2). Papers that appear on the list were published between 2005-2023.

Results and Discussion

Results were generated using the bibliometric analysis software Biblioshiny and the network visualisation software VosViewer. Biblioshiny was used to answer both RQ-

1 and RQ-2 and VosViewer to present the interpretation for RQ-2. Before applying the methodology, the author filtered the data through the search criterion "publication year". 438 articles of the original 499 remained, after having set the year range between 2012 and 2023. Citation data from the year 2023 may not influence the result, but the aim was to take into account the recently published papers to interpret the evolution of this literature.

The annual scientific production indicator shows a huge increase from 2017 until the beginning of 2023. Figure 2 shows the average citations per year, so the graph visualises the results until the end of the year 2022 since the paper was conducted in spring 2023. The annual growth rate is 16.195% and a protrusion is seen in 2022 when the number of the published articles more than doubled compared to 2020. This exponential growth is followed from the year 2018.This might mean that the improvement of the technology (Rejeb *et al.*, 2022a) may have served as an inspiration of the authors. Articles in connection with the digital improvements regarding the agri-food supply chain management seem to appear as a consequence of this rapid technical development wave.

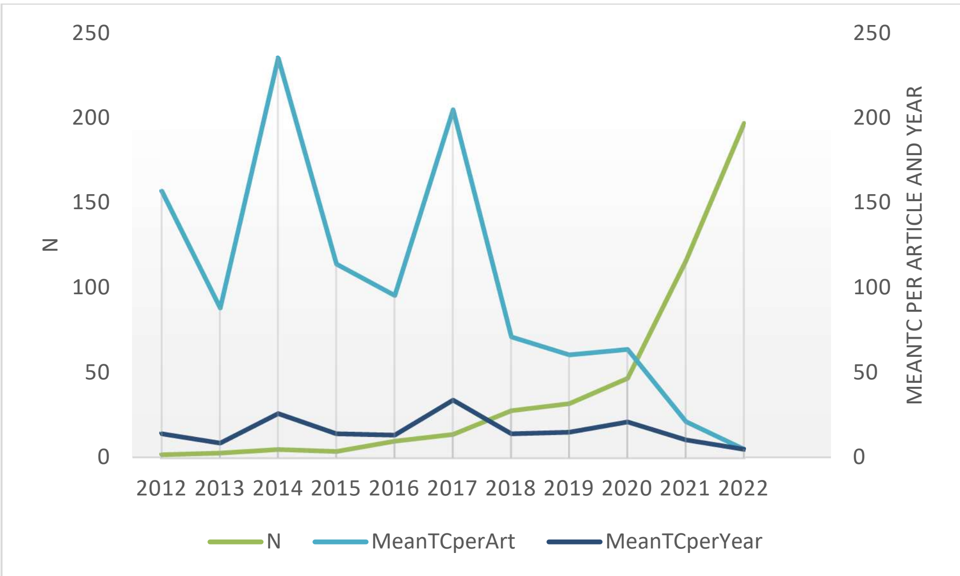

Figure 2: Annual citation per year
Source: own composition based on data generated from Biblioshiny (2023)

Besides this, the average cited data declares a significant decrease from 2020, which shows that due to their recent appearance of papers from the last 2 years, the citations could not be that high yet. The arrival of the Covid-19 pandemic cannot be disregarded. In spring 2020 (~March) European countries started to implement actions like lockdowns, which generated interest in digital technologies (European Comission, 2022). The agri-food industry is not a typical home office-capable industry, so the application of digital support must appear in another forms. It is also a possible that the shortage of human workforce (especially the migration wave in the direction of Western-European countries (e.g., Germany) might have led to the application of non-human resources within the AFSC as well (Mitaritonna and Ragot, 2020, Nagy et al., 2020).On the other hand, this increases the need for an IT-educated workforce (Demeter et al., 2020), something which also pushes academics in the direction of research areas which can contribute meaningfully to future workforce training.

The three-field plot can adequately represent the connection between the most important authors based on the number of papers they have published, their countries, and the research topics, which appear in their published papers. The size of the nodes represents frequency data, the bigger the node is the more dominant role publication has. Figure 3 shows which topic was the most dominant research topic in the respective year in the sample existing origin countries. India seems to be the most influential country due to its publication volume. This country is from where all kinds of topics are researched within the examined research frame. The food supply is a prominent issue in these regions of Asia (such as China and India). The parameters of the population justify a country's ongoing work on security of food supply. These developing countries must manage the problem of the large amount of necessary food supply.

In whole sample, blockchain counts as one of the dominant Industry 4.0 solutions (11.22% of the listed articles deal with blockchain), which support the establishment and maintenance of food safety (Lezoche et al., 2020; Srivastava and Dashora, 2022). According to experts (Creydt and Fischer, 2019), blockchain is a technological solution to accomplish an efficient traceability on the entire way of the product.

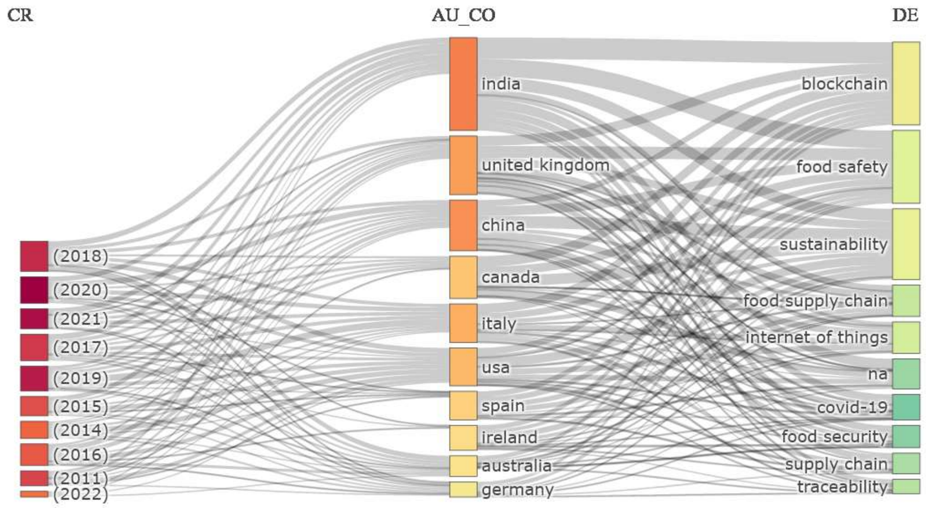

Figure 3: Three field plot
Source: own composition based on data generated from Biblioshiny (2023)

Besides blockchain, Internet of Things appears as a tool for ensuring traceability during the food supply chain. IoT can be interpreted as a package of devices and technologies enabling sharing of data (Ben-Daya et al., 2021). As an umbrella term, food safety is in the centre of this analysis as well. Food safety incorporates all standards and regulations, which regulate and control the transactions within the agri-food supply chain.

In addition, the importance of sustainability seems to have increased. 19% of the reviewed articles deal with the phenomenon of sustainability regarding food safety characteristics as well. This figure also reveals that the topic of sustainability is strongly connected to countries with a large population (e.g., India, China, Canada, USA). It may happen that organising food sector developments implementing a sustainable aspect is important for those countries that have to provide for a huge population. Furthermore, national, and international efforts of authorities (e.g., EU) can push scientific research in the direction of sustainability by applying funding and tender opportunities (European Commission, 2023).

As to topics of the published papers, Figure 4 demonstrates the evolution of these between 2012 and 2023. The author decided to cut the timeline into four as Figure 4 shows because the rapid growth of the annual citation data highlighted the importance of the period between 2017 and 2023.

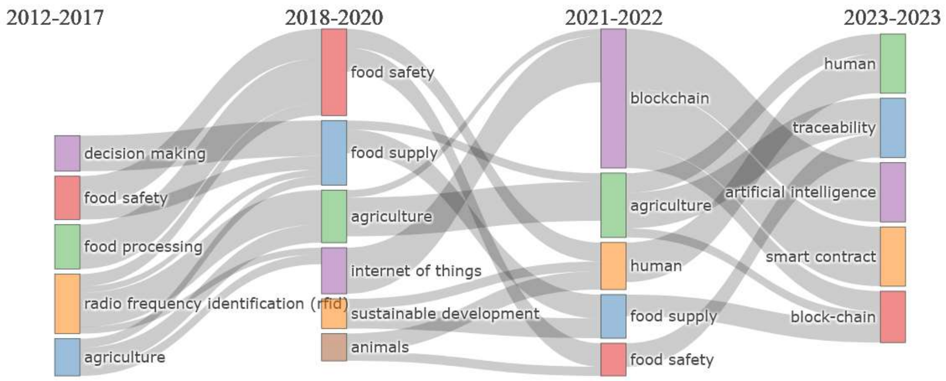

Figure 4: Thematic evolution
Source: own composition based on data generated from Biblioshiny (2023)

This thematic evolution shows a huge wind-up of the topic after 2017: more and more Industry 4.0 solutions appear in the publications. As Figure 4 shows, blockchain is indisputably an emerging topic. Its dominance has not changed in recent years. However, it is interesting to observe that the factor "human" appears, and this is regularly connected with sustainability. The evolution of the topic shows a wide opening in which mostly the core definitions, like food supply chain and food safety and traceability, were in focus. Their existence is important for the future publications because they serve as the basis for recent theories about the technological solutions supporting food safety.

Regarding results made by VosViewer, Figure 5 presents the bibliographic coupling of the articles and the visual indicator of clusters by colour. The closer two articles are related the more references they share (Marchiori and Franco, 2020). This literature analysis states that two documents are bibliographically coupled if they both cite one or more documents in common (Aria and Cuccurullo, 2017). A minimum of five common citations were set. The nodes' size in Figure 5 represents the total number of citations of the 285 articles which met the threshold. It can be seen on Figure 5 that more than the half (285 out of 466) of the examined papers are bibliographically coupled.

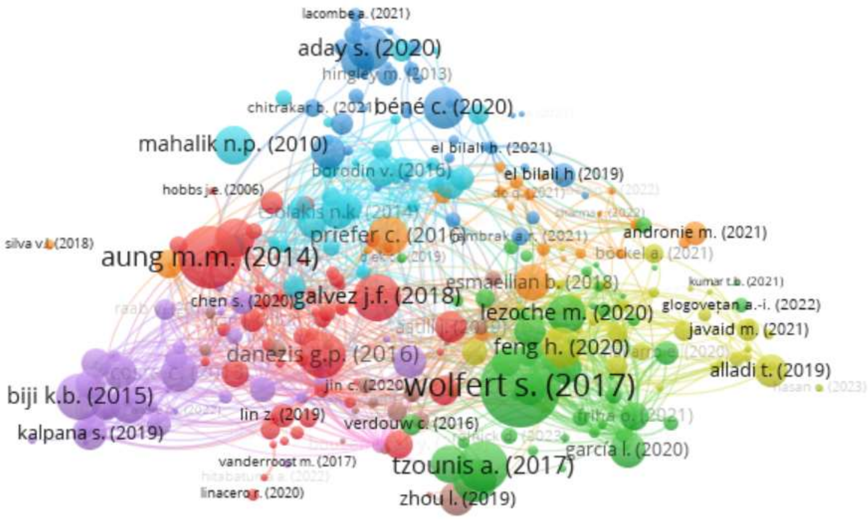

Figure 5: Bibliographic coupling of selected articles from SCOPUS
Source: own composition based on data generated from VosViewer (2023)

Using the papers and meeting the threshold, seven clusters have been implemented by applying bibliographic coupling methodology with the VosViewer software. After reading and interpreting the articles, the author tried to name the clusters, with a view to starting the in-depth analysis. Table 2 contains the labels and the distribution of the seven clusters that were generated by the software.

Cluster ID	**Distribution of the analysed papers**	**Name of cluster given by the author**
Cluster 1	20%	Traceability challenges in AFSC
Cluster 2	18%	Quality management in AFSC
Cluster 3	17%	Agri-food 4.0
Cluster 4	15%	Future trends of AFSC
Cluster 5	12%	Impact of the Blockchain
Cluster 6	10%	Smart packaging
Cluster 7	8%	Circular economy

Table 2: Identification of clusters
Source: own composition based on data generated from VosViewer (2023)

Traceability challenges in AFSC

Generally, agri-food supply chains face comprehensive traceability challenges. The biggest cluster contains literature reviews about possible traceability solutions. According to experts, there are drivers such as legislation, sustainability, consumer satisfaction, international standardisation or even food safety itself, which may contribute to define traceability (Islam and Cullen, 2021). As can be seen in the reviewed literature, technological improvements supported by digitalisation are seen as enablers for the traceability requirements of the 21st century (Magalhães et al., 2019; Violino et al., 2019).

Furthermore, technologically supported traceability within the AFSC ensures a high level of reliability. Technological solutions for traceability provide stakeholders of AFSCs a social, economic and environmental sustainability as well, with its characteristics of reducing food waste and food loss, building trust and creating transparency within the AFSC (Rahman *et al.*, 2021). Reducing food waste and loss can contribute to environmental sustainability by optimising consumption. On the one hand, society should learn how to avoid the production of food waste (traceability data can provide data to calculate it). On the other hand, harvesting and processing less food leads to a sustainable natural environment. A comprehensive view about the AFSC processes serves as a pillar for trust both from a social and financial (economic) perspective. Negative effects, like mislabelling products, can ruin trust processes. However, technology supported traceability (e.g., blockchain solutions) can lead to stability within food safety (Lo et al., 2019).

Quality management in AFSC

While traceability is a highlighted and specific area of food safety, there are also general factors of quality management in AFSC, in which digitalisation may be an important contributor. Quality management can be discussed from an enabler perspective with regard to its consequences. The *enablers* can be technological solutions or standardisation and regulation processes of decision makers. According to the reviewed studies, companies need to have special technological solutions if they wish to manage their agri-food supply chain successfully. There are numerous software-provided methods supporting quality management systems. The main question of ensuring a stable quality management system is the ability to collect, store and analyse data. Data can be collected with the help of sensors (Hitabatuma et al., 2022). To analyse and interpret the gained data, Big Data and IoT are suitable (Ben-Daya et al., 2021; Rejeb et al., 2021). Artificial Intelligence, Deep Learning and the creation of a Digital Twin serve as simulations for decision making, monitoring and maintenance (Mavani et al., 2022; Verboven et al., 2020; Zhou et al., 2019). Cloud and smart storage represent the surfaces where these data can be responsibly stored for future usage (Nychas et al., 2016). Blockchain is a technology which offers a comprehensive solution for producing, storing, and transferring data real time with full transparency and irreversibility (Galvez *et al.*, 2018).

An interesting fact is that the second cluster does not contain regulation specific papers, which the author will consider in the conclusion part of this paper. The consequences may appear in form of food frauds, food waste and food loss and they mean both financial and social quality managerial losses for corporations (Visciano and Schirone, 2021; Wu et al., 2021).

Agri-food 4.0

The agri-food industry has obtained a dominant position in the literature recently. Terms such as Agriculture 4.0 and Agri-food 4.0 have appeared, generally referring to an interpretation of Industry 4.0 in this sector (da Silveira et al., 2021; Lezoche et al., 2020).

Name of technological solution	Areas of usage	AFSC members meeting with it	Effects of technology on AFSC members
Artificial Intelligence (AI)	obtaining useful information, enables computers to interpret data	producers, software&hardware service providers (suppliers), distributors, consumers	Pros: quick "ready-to-go" information available, huge data processing capacity, no need of regular human interruption Risks: surface handling capability needed, misleading information/fraud based on non-human led processes, mistrust in given information
Big Data	food processing, food transportation, and food retail: data processing, obtaining useful information	producers, software&hardware service providers (suppliers), distributors	Pros: huge volume of data collectable, comprehensive, by human unmanageable dataset available Risks: data analytics capability needed, misunderstanding of data analysis, unsure decision-making input
Blockchain	"farm to fork" availability: tracks data, proves the originality (indirectly raises trust in food safety)	producers, software&hardware service providers (suppliers), distributors, consumers	Pros: theoretically proven trust in data, tracking solved if each member participates Risks: huge investment required within the whole AFSC to run it, possibility of being declined by users because of lack of understanding/trust
Cloud Computing	better cooperation between logistics and consumers with shared surfaces	producers, software&hardware service providers (suppliers), distributors	Pros: easy availability of real time data, available for all AFSC members real time

			Risks: stable internet access must be ensured permanently, risk of cyber-attacks
Cyber Physical Systems (CPS)	farming, food processing: real-time integration of physical and computational algorithm and so facilitating to food safety and food waste reduction	producers, software&hardware service providers (suppliers), distributors	Pros: no need of human interruption, mainly maintenance and program setting are required by the human workforce Risks: problems may occur because of instable electricity networks/internet access, risk of cyber-attacks
Digital Twin	farming and food processing: real-time monitoring of physical world (farm) and updating the state of virtual world	producers, software&hardware service providers (suppliers), distributors	Pros: suitable for simulations (interruptions without endangering animals/plants/manufacturing processes are possible) Indirect: huge investment required, lack of real life simulations can lead to doubts of users
Drones	farming: spreading pesticides, logistics: package delivery	farmers, producers, software&hardware service providers (suppliers), distributors (e.g., logistics)	Pros: quick transportation, high-quality observation, precise processing methods Risks: non-applicable at each sector, e.g., pesticides for grape yards (while corn can be sprayed from above, grape must be sprayed from the side between the lines), disturbing noises, doubts in people: feeling of being observed
Flexible Wearables for plants	farming: gaining data from animal behaviour, performance management	farmers, software&hardware service providers (suppliers)	Pros: functioning can be controlled, suitable for moving animals (location change does not mean a problem) Risks: non-applicable for all AFSC members (mainly farmers), plants or even animals can suffer from being analysed on a real time basis
Information and Communication Technologies (ICT)	farming, food processing: monitoring conditions (e.g., temperature) and serving with real-time data to extend shelf life	farmers, producers, software&hardware service providers (suppliers), distributors (e.g., logistics), consumers	Pros: availability of communication and storage for all AFSC members, being connected Risks: problems may occur because of instable electricity networks/internet access, risk of cyber-attacks

Internet of Things (IoT)	whole AFSC: data analytics, operating drone farming, monitoring farm/processing operations	farmers, producers, software&hardware service providers (suppliers), distributors (e.g., logistics)	Pros: comprehensive service during the whole value creation Indirect: investment into devices which are able to communicate with each other is required, problems may occur because of instable electricity networks/internet access, doubts/misleading because of non-human interruptions are possible problems, risk of cyber-attacks
Machine Learning	Food processing, farming: substance of AI, interpretation of raw data	producers, software&hardware service providers (suppliers), distributors (e.g., logistics)	Pros: advantages of cost-efficiency (based on enabling machines create algorithms instead of programmers) Risks: problems may occur because of instable electricity networks/internet access, failures may occur because of small human control
Precision Farming	Farming: farm management, from gaining to interpreting data and making decision-making offers to farmers	farmers, software&hardware service providers (suppliers)	Pros: comprehensive management tools are available for farmers mainly, decision-making support Risks: non-applicable for all AFSC members, IT infrastructure needed to be synchronised with by the authorities required IT software
Robotics and Autonomous Systems (RAS)	Farming, food processing, distribution: material handling, processing	farmers, producers, software&hardware service providers (suppliers), distributors (e.g., logistics)	Pros: fewer human resources are needed, capacity problems can be solved by RAS Risks: non-applicable at all AFSC members (mainly processing), human contribution: mainly programming, maintenance, higher value-adding jobs
Radio Frequency Identification (RFID)	Food processing, logistics: identification, serving data for tracking	producers, software&hardware service providers (suppliers), distributors (e.g., logistics)	Pros: identification and data transfer available in connection with devices, materials, animals or even humans Cons: danger of radio frequency, non-readable situations may decelerate processes
Sensor	Food production: monitoring food	farmers, producers, software&hardware service providers (suppliers),	Pros: investment is not that expensive anymore, suitable

	safety and collecting data	distributors (e.g., logistics)	for data collection within the whole AFSC Risks: positioning might cause difficulties (e.g., at a crop field)

Table 3: Technological solutions characterising Agri-food 4.0
Source: own composition based on the collection of Cluster 2

Table 3 demonstrates the technological trends appearing in literature reviews recently. Agri-food 4.0 can be interpreted as a merged technological solution building on data. As Table 3 shows, there are technological solutions which are responsible for gaining and transferring data or even taking special interventions. The hardware-intensive methods are mainly: Cyber Physical Systems (CPS) (Smetana et al., 2021), drones (Rejeb et al., 2022a), Radio Frequency Identification (RFID) (Gómez et al., 2021), Flexible Wearables for plants (Qu et al., 2021) and sensors (Tsolakis et al., 2019). After having collected data, the surface of data storage, transfer and sharing follows as a next group of Agri-food 4.0 technologies. Big Data is suitable not only for storing data in a structured way, but it can also be used for analysis and decision-making processes (Wolfert et al., 2017). Cloud computing (Mustapha et al., 2021) can be a helpful tool for serving real time data for humans or even machines within processes and enable them to analyse or even intervene in processes observed.

IoT (Raj et al., 2021; Sinha and Dhanalakshmi, 2022), Information and Communication Technologies (ICT), and Robotics and Autonomous Systems (RAS) contribute to managing agri-food operations automatically while reducing human interventions in the process. These are followed by Artificial Intelligence (AI) (Ben Ayed and Hanana, 2021), Machine learning (Raj et al., 2021), Digital Twin (Nasirahmadi and Hensel, 2022), which are solutions for handling processes without human interruption to achieve the highest safety possible. AI can learn, interpret, and process huge amount of data coming from e.g., Big Data on its own (Zhou et al., 2022). This capability can affect the AFSC both in a positive and a negative way. Technologies operating (quickly) without human interruption can avoid instability in the information flow but may also raise doubts in the mind of their users. AI can learn on its own and this also creates an uncontrolled sphere, in which rational interruptions can be hardly implemented. “Facts” that are wrongly interpreted but treated as data may have negative effects for AFSC members (e.g., financial consequences, or misinformed consumers) (Rana et al., 2022). However, these technologies are suitable for simulating processes, testing the possible outcomes of interventions and they can make decisions based on their previous analysis.

Precision farming and Blockchain (Finger et al., 2019; Rejeb et al., 2022b) are comprehensive solutions for the stakeholders to track, record and manage changes within the agri-food processes. While precision farming is rather a collection of suitable technologies listed above for management tasks, blockchain is an enabler surface for both managerial and financial tasks. Table 3 includes also pros and risks connected to the prior effects of technologies introduced within this cluster. As observable, most of the listed solutions can replace human workforce, which is on one hand a great capacity enabler. On the other hand, risks as cyber-attacks appear in the results, because of relying on technologies hundred percent. All examined solutions need electricity and internet connection to function, and their ensuring process is paramount for AFSC members.

Future trends of AFSC

The cluster of future trends incorporate the reaction of the AFSC to signs from the changing world. First, it is important to state that food supply is a critical task of governments to be ensured for the citizens and is a part of food safety tasks too. The Covid-19 pandemic has played a dominant role in changing the food safety and especially food supply processes recently (Aday and Aday, 2020; Alabi and Ngwenyama, 2022). According to experts, the resilience of AFSCs should be strengthened, in order to be able to deal with coming crises (Béné, 2020; Derossi et al., 2021). This empowerment can be connected to both national and international authorities and organisations with a special focus on sustainability within the agri-food sector (EU Green Deal, 2020). The necessity of these adjustments is paramount as a reaction to the challenges of climate change processes. The European Union has worked on strategies to achieve a sustainable condition from an economic, environmental, and also social aspect. Policy aims regarding AFSCs within the European Union can be described by CAP (Common Agricultural Policy) aims to achieve fair, healthy, and environmentally friendly food systems (Farm to Fork Strategy) while ensuring and maintaining biodiversity (EU Biodiversity) with a view to mitigating climate change effects (EU Green Deal, 2020).

There are various ways to establish resilience, which is a difficult task, especially within wide AFSCs. Resilience and sustainability goals can lead to one direction if using improved food safety methodologies (Agnusdei and Coluccia, 2022). On one hand, combined usage of Agri-food 4.0 solutions can lead to the maintenance and stabilisation of agri-food processes (Hassoun et al., 2022). They contribute to establish digitalisation supported processes both within production and consumption (Musa and Basir, 2021). This cluster revealed an important method as an enabler of food supply challenges. According to experts, 3D food printing may contribute to deal with the effects of crises, like the Covid-19 pandemics (Derossi et al., 2021). Derossi et al. (2021) state that 3D food printing is characterised by ensuring food safety (programmable production solutions without human interruption), producing only the required quantities (reducing food waste) and offering personalised food. 3D printing can also imply a food safety risk from the perspective of cleaning opportunities. Printers should have CIP (clean in place) systems to ensure the regular hygienic cleaning process during the production. On the other hand, applying 3D food printing could entail a limitation of the shelf-life of products because of the artificial changes of the structure of food. Thus, post-processing steps may be required because of customisation (Demei et al., 2022).

Impact of the Blockchain

Coming from this cluster, blockchain can be interpreted as a platform, which stores blocks strung on a chain. Due to its characteristics blockchain is "a distributed ledger feature, every record in this ledger is secured by rules of cryptography which makes it more secure and tamper-free" (Gad et al., 2022, p. 2). There are blocks, filled with data about transactions during the whole process (Ronaghi, 2021; Xu et al., 2022).

From the perspective of members of the AFSC who have stable IT knowledge and infrastructure, blockchain technology can build trust because it provides a faster and more reliable traceability. Challenges of the food supply chain, like food safety, food fraud, fair trade, foodborne illness outbreaks, or even the environmental impact of food production can be supported by blockchain technology (Astill et al., 2019). The stakeholder group of consumers or even smaller farmers and suppliers might have doubts related to the blockchain because of a lack of understanding of the technology. They might not even have a financial background that is stable enough to invest into this solution. The mechanism of blockchain is very complex. Theoretically, it relies on a mathematical basis which allows the technology to be handled in a tamper-proof manner (Gad et al., 2022).

Experts claim that blockchain is a disruptive technology which can lead to changes of business and supply chain models (Ronaghi, 2021). Frizzo-Barker et al. (2020) add that this disruptive characteristic may appear not only with a financial focus (e.g., lower transaction costs), but that it has also several risk opportunities, such as unreliability of data provided first and being saved or that the lack of universal standardisation might lead to difficulties in its disruptive growth on the market (Frizzo-Barker et al., 2020).

According to Zhang et al. (2022) both upstream and downstream supply chain members participate in information sharing and storage regarding traceability. They point to the characteristics of blockchain-enabled traceability models. They can ensure efficiency, trust, quality, and resilience within the food supply chain (Zhang et al., 2022). The impact of blockchain shows itself as an effective tool of traceability. Both the end consumer and the processor can require data about the food, so this is a two-way process. According to the literature blockchain is sufficiently accurate to serve these needs.

Smart packaging

The sixth cluster represent papers about a prominent operation within AFSC: smart packaging. Smart packaging is also a tool of food quality monitoring (Azeredo and Correa, 2021). Smart packaging can contribute to establish food safety, meet the customer requirements, and reduce food waste at the same time (Soltani Firouz et al., 2021). Emerging packaging technologies have an impact on the protection of products, extending their shelf-life and informing all AFSC members, and even the consumers about the entire background of the products from farm to fork (Drago et al., 2020; Nemes et al., 2020). According to experts, smart packaging covers the areas of food safety and quality, traceability, managing food loss and waste and due to these characteristics, it contributes to the sustainability of food processing as well (Chen et al., 2020; Yousefi et al., 2019).

Circular economy

The sustainable development of AFSCs has already appeared within the results coming from Biblioshiny (see Figure 3 and 4). Experts point to the fact that there are links between circular economy, sustainability and digitalisation supported developments (Ada et al., 2021; Rejeb et al., 2022c). Circular economy represents a perspective that can establish sustainable production and consumption with keeping resources in usage as long as possible (Ada et al., 2021). On both of the sides (production and consumption) waste management represents a dominant part of the circular economy concept which may be supported by digitalisation providing prevention by the technological solutions introduced above in the clusters (Esmaeilian et al., 2018; Oguntegbe et al., 2022).

Discussion

This bibliometric analysis focuses on determining the research trends in terms of thematic evolution and bibliometric coupling. Based on the read and analysed references, a two-sided structure emerges. The literature lists both hardware (e.g., sensors, robots, etc.) and software (Big Data, cloud, etc.) solutions (Derossi et al., 2021; Duong et al., 2020; Lezoche et al., 2020).

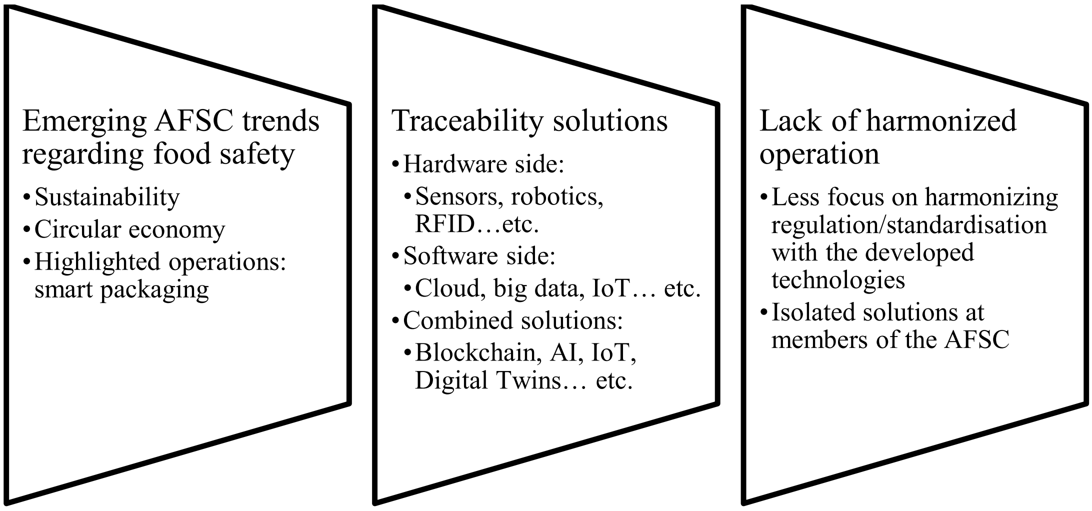

Figure 6: Interpretation of the results
Source: own composition

Figure 6 demonstrates the relevant pillars of traceability. Beside the two-sided approach (hardware and software), there are other technological solutions which require both sides to function efficiently (e.g., blockchain, IoT, etc.). The intersection of the triad of (1) agri-food industry, (2) digitalisation and (3) food safety depends primarily on the level of the data quality available, and the analyses derived from it. The results show that, in terms of the collection of adequate real-time data, the introduction of digital technologies such as Industry 4.0 solutions can be helpful. Considering the entire food supply chain, the key to implementing digitalisation technologies is the use of tools such as Big Data, IoT, or cloud-based communications (Astill et al., 2019; Niknejad et al., 2021). The implementation requires hardware that can collect data, and on the other hand, software that makes the system capable of handling data. For ensuring traceability cooperation of these two factors is indispensable. Reading the literature, it turned out that some authors deal with the coherence of technological solutions such as blockchain and IoT (Ben-Daya et al., 2021; Kaur et al., 2022), but only a few focus on the total harmonisation of advanced technologies. The requirement for implementing a well-functioning food traceability system consists of at least three fundamental areas. First, a network-capable device (sensor, RFID, etc.) is needed to transmit real-time data

(Nasirahmadi and Hensel, 2022). Second, due to data collection big data is generated. Big Data analysis can contribute to decision making, tracking or even prevention processes (Astill et al., 2019; da Silveira et al., 2021). Third, the storage and sharing of a large amount of data is possible with the help of cloud-based repositories or IoT solutions (Kaur et al., 2022). Nevertheless, the results also present that not only technological solutions are needed for ensuring traceability. After the clarification of the possible positive and risky effects of each digitalisation solution, AFSC members must ensure that both the workforce and management have an appropriate understanding of the possible developments.

Bibliographic coupling showed us 7 clusters based on the calculations of VosViewer. The analysed clusters represent an interesting situation about the emerging trends of AFSC's digitalisation regarding food safety. Cluster 1, 2, 3, and 4 describe comprehensive research areas in connection with the agri-food supply chain specifical, technological and quality managerial issues. Meanwhile, it can be observed that even though cluster 5, 6, and 7 would fit the first 4 clusters, they appear in the results highlighted separately – and this is an important new finding. Their importance and dominant role either within the technology or in the AFSC processes might be the reasons for this separated appearance. Incorporated in the clusters 6 and 7 (smart packaging and circular economy), social-environmental economic impacts also appeared in the findings. Their less-than-dominant position within the findings of the literature search signifies that these effects of digitalisation have not been subjected to detailed academic research so far. The dominant pattern in the results instead relates to technological solutions.

Conclusions

The current paper aims to provide a bibliometric analysis of the publications on food safety supporting technologies applied in the agri-food supply chain. However, a considerable amount of literature is available in the observed research field, in which it can be observed that bibliometric analysis has not yet been commonly applied to the field. The usage of a workflow of bibliometric literature reviews generated a complex methodology relying on a statistical background. The trend of scientific review publications was investigated, and the author aimed to uncover recent research streams and define potential future directions within the field.

Two main research questions appeared in the paper. RQ-1 focused on the area: "Which are the emerging topics of AFSCM regarding food safety?" and RQ-2 dealt with the question: “How has the topic of food safety in AFSCM evolved during the last 10 years?”. For accurately answering RQ-1 a bibliometric analysis in form of bibliographic coupling by using VosViewer was conducted and for answering RQ-2, a bibliometric analysis was carried out by using bibliometrix R-package (Biblioshiny platform). The analysis highlights that there are some “popular” digital solutions such as blockchain or IoT which influence the literature (Astill et al., 2019; Niknejad et al., 2021). This dominance of the technological solutions leads the author to think about their role within the agri-food supply chain. It takes a long time to make the products flow from farm to fork and many members of the agri-food supply chain are involved in digitalisation-based development projects (Dadi et al., 2021). The accurate cooperation of the members may serve a full line traceability which requires a huge financial and professional investment from each member. Due to this it is rarely seen that one or two technological solutions can appear during the whole supply chain. One of the main findings of this paper which is a new result is that not only the 4 previously expected topics (traceability challenges in AFSC, quality management in AFSC, Agri-food 4.0 solutions), but also the last 3 topics of the clusters (the impact of the Blockchain, smart packaging, and circular economy) are emerging and are gaining significance, which is also reflected in the bibliographic analysis results. Table 3 shows the characteristics of the examined technologies. It is seen that there are positive and sometimes risky effects, which have as well social (considering stakeholders), environmental (emissions, production, and functioning data), and economic (financial effects, as investments, maintenance, but also cost efficiency) effects.

Furthermore, there are unexplored topics which are suitable for further research. It has been showed that standardisation and regulation are the basics of food safety. Nevertheless, researchers have not really focused on combining the requirements of regulations with the emerged technological solutions. Cyber security appears as a second future research direction. It should be more researched and published from a managerial point of view. If professionals (e.g., managers or engineers or operators of a farm) do not start to deal with technology-based solutions that were introduced in this paper, it may lead to cyber-attacks or other negative consequences (Bayramova et al., 2021). Limitations of the research are on one hand the broad scope of the research questions, and the lack of the appearance of the term cyber security during the searching steps. However, it is recommended to mix the software for the analysis, and VosViewer software cannot work with the merged database, something which also counts as a limitation of this research. A more detailed analysis can be conducted in the future examining co-citation or co-word relations with a view to obtaining a stronger overview of the pillars of the field. In addition, emphasising the social-economic-environmental effects during the search for the existing effects can widen the list of findings within the literature.

In general, traceability within a whole agri-food supply chain is difficult to implement due to the large number of AFSC members. This paper shows that recent technological solutions can support food safety. Research dealing with the consistency of technologies and regulation platforms can potentially pave the way for a yet more holistic understanding of the AFSC.

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9. BRIEF INTRODUCTION OF PAPER NR. 3

9.1 Bibliometrics

Nagy, J., Jámbor, Zs., & Freund, A. (2020). Digitalisation in the food industry–case studies on the effects of IT and technological development on companies. *AGRIS on-line Papers in Economics and Informatics*, 12(4), 77-92. Doi: 10.22004/ag.econ.320239

Ranking of journal in year of publishing: SJR Q2.

9.2 Targeted research question

The third original PhD research question focuses on the application and implementation of the available technological solutions. PhD-RQ3: *How do food industry companies perceive the realisation of digitalisation and ICT based improvements in their operations and organisation?* and this question was the RQ of Paper nr. 3. as well. I made the choice because it frames the thesis in a way I planned.

9.3 Research gap

Although statistical organisations such as KSH or STATISTA can provide annual reports on the state of Industry 4.0 applications, these analyses cannot detect the decision-making methods applied by AFSC members. To develop an analytical framework which might serve as measurement system of digitalisation offered solutions whether to apply or not at different organisational levels. The research identifies a gap in the literature on isolated operation of Industry 4.0 solutions, which can be observed in the analysis of available case studies. The aim of the study is to explore and illustrate the steps of digitalisation adoption at strategic levels of the organisation.

9.4 Key findings

The results of the third paper show that the success of food companies' digitalisation strategies and the adoption of ICT-based developments depends to a large extent on the corporate background (e.g., international relations, ownership structure), the commitment of top management, and the technology adoption and innovation ideas of blue-collar workers. The research showed that although the existence of Industry 4.0

strategies and conscious digitalisation actions are rare, companies are taking advantage of the opportunities offered by technology, often driven by labour shortages, the need to remain competitive and food safety regulations. The analysis also highlighted barriers to technological improvements such as high investment costs, data security issues and processing capacity constraints.

An important finding is that the impact of digitalisation goes far beyond production processes and significantly affects different levels of organisational functioning. The four company case studies presented here provide useful reference points for AFSC stakeholders, while highlighting the opportunities and challenges of digitalisation, helping to set future strategic directions. The study aims to fill a gap in the literature on the isolated operation of Industry 4.0 applications and has contributed to a better understanding of the organisational integration of digitalisation.

9.5 Author contribution

Zs.J., J. N. and A. F. designed the study together, data collection and analysis were also a joint task. Zs.J. and J.N. built the methodological model for the analysis, A.F. conducted the literature review. All authors contributed to the writing of each chapter in the paper equally.

10. THE ORIGINAL TEXT OF PAPER NR. 3

Digitalisation in the food industry – case studies on the effects of IT and technological development on companies

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Abstract

In recent decades as a result of the development of information and communication technologies (ICT) and the Internet, we have witnessed major changes in companies. The ICT support of the processes is becoming more and more extensive and comprehensive, which enables the realization of digitalisation. The interconnection of processes, machines, people in a single network makes another level of optimization available. The changes turned up by digitalisation are not only technological, they also have an impact on the company's organization and strategy. The aim of our study is to create an analytical framework and map the opportunities that digitalisation promises in the food industry and the organizational changes that ICT and technological development brings, with special emphasis on the impact on strategy, employees, and corporate culture. Our results show that companies are not consciously engaged in the digitalisation yet, but they exploit its opportunities, and make improvements in this sense. Adaptation of digital solutions is often forced by labour shortage, the pressure to achieve higher efficiency and thus to remain competitive and to service the growth strategy.

Key words

Digitalisation, ICT development, food industry, strategy, interviews

1. Introduction

The development of information and communication technologies (ICT), database systems and increasing digitalisation is a hot topic not only in the corporate but also in the academic sphere. Robots and automation have long existed, but the Internet (or any internal company network like this) is revolutionizing process management by connecting them into a network. Thanks to the increasing digitalisation, the company's devices, and machines, and in some cases the products themselves, are able to connect and cooperate, realizing Industry 4.0 (I4.0). Devices such as sensors, RFID chips, 3D scanners, cameras and robots generate data which literature calls big data. It is a huge challenge to store, process and interpret, and is essential for the implementation of I4.0 (Hermann et al., 2015; Ilie-Zudor et al., 2011). Digitalisation is not only an ICT development, its extensive use in the company processes also affects the organization (Horváth and Szabó, 2019), employees (Frey and Osborne, 2017) and business partnerships (Pagani and Pardo, 2017).

Most of the published studies deal with digitalisation from a technological point of view (Dworschak and Zasier, 2014; Hermann et al., 2016) or from a theoretical point of view (Fettig et al., 2018; Dalenogare et al., 2018) however, the number of studies presenting specific company cases is limited. The impact of digitalisation and I4.0 is most significant in the electronics and machine industry, most of the research reports illustrate their solutions (Demeter et al. 2020; Nagy, 2018; Horváth and Szabó, 2019; Gauger et al., 2017). In our study, we focus on another manufacturing sector, the food industry, which is not a typical subject of digitalisation studies. Robotics and automation have long been present in many subsectors of the food industry. Real-time data streaming, big data, and information sharing, first and foremost within the company and then at the supply chain level, are of paramount importance for food safety and tracking purposes, and industrial digitalisation solutions offer many opportunities to improve these areas.

1.1 World trends in the food industry

Due to global trends, it is very important to focus on the agriculture and food industry: on the one hand, in order to supply a growing world population, more efficient production and processing are needed, and on the other hand, guaranteeing food safety is already a global requirement. The world population has tripled since the 1950s, reaching over 7.8 billion in February 2020. This figure, although slowing, continues to grow and is estimated to exceed well over nine billion by 2050 (Chaime, 2020). The World Economic Forum estimates that food demand will increase by nearly 70% so far (World Economic Forum, 2018). Another important aspect is that with the development of the countries, due to the increase of the living standard of the population, the amount of food to be consumed changes significantly, the energy demand of the population is much higher and the daily intake of animal protein is increasing (Sen et al., 2017). Meeting growing and changing demand and reducing and relieving environmental impacts mean major challenges for farms as well as actors in both agriculture and the food industry (Demartini et al., 2018).

One of the industries most exposed to the variability of consumer demand is the food industry. Even if the quantity needed does not change dramatically, the type of products demanded - e.g. increasing trend of healthy food– causes significant changes (Carpenter and Wyman, 2017). The production of healthy foods requires new, high quality ingredients and production methods, which can reduce sugar and / or fat content, use alternative substitutes, and retain higher levels of vitamins and minerals. The food industry should take into account for example Europe's aging societies and changing nutrition needs, and childhood obesity, as a growing problem in the developed world when developing (new) products (Santeramo et al., 2018).

In addition to consumer trends, the food industry also has to cope with pressure from retailers, which means lower prices, higher quality, a constantly renewed range of products and, of course, unquestionable food security (Kittipanya-ngam and Tan, 2020). In order to address these challenges from both sides, development of ICT, digitalisation and I4.0 tools can provide solutions.

Regarding the structure of the paper, after we give a brief description of the world food industry trends and the possibilities of ICT based digitalisation and I4.0, in the methodological section we present the theoretical framework we used for the analysis and the method and process of the case studies. The fourth section summarizes the experiences of the company interviews, after which we draw conclusions. Finally, research limitations and future research directions will be presented.

1.2 Industry 4.0 and digitalisation in the food industry

IT based automation and robotization have long been present in many subsectors of agriculture and the food industry (e.g. pasta, dairy), while in others are only partially applicable, because of the high demand for human workforce since processes are poorly standardized or too sophisticated (meat industry, bakery products). As Kittipanya-ngam and Tan (2020) states, there is not a single ICT solution for digitalising the food industry and agriculture processes. According to Simutech (2016), machine downtime in food processing can cost up to $ 30,000 per hour, so the use of in-process predictive maintenance sensors to prevent machine failure can quickly pay off. Processes made transparent with sensors can help increasing energy efficiency, reducing rejected deliveries and waste. Agility, rapid machine change-over, and the ability to produce smaller series are important considerations when selecting new technology (Carpenter and Wyman, 2017).

Meeting the changing customer demand also transforms and accelerates the product development process. With 3D printing, the prototype of either the product itself or the advanced packaging is shortened, so consumer testing can be accomplished in a much shorter time.

According to experts (Bibi et al., 2017; Carpenter and Wyman, 2017; Bottani and Rizzi, 2008), food safety and traceability are definitely the areas where information and database systems as the representatives of I4.0 can greatly support the management of agriculture and food industry. For example, identification systems based on the EPC Global system can trace raw materials incorporated into food and/or packaging from the place of origin to the place of use. Thus, in case of any problem or product recall, the affected product series can be clearly identified and quickly withdrawn from the market (Bibi et al., 2017; Carpenter and Wyman, 2017).

Researchers see blockchain technology as an appropriate tool for food monitoring (Tian, 2017; Tse et al., 2017). As discussed in the previous paragraph, ICT based solutions, such as RFID, barcode, and wireless sensors are well-suited to the food supply chain for transparency and traceability reasons, and especially for data collection and transmission. However, we need a medium that makes this information visible (Carlozo, 2017). Blockchain raises the level of trust by making the flow of data, goods, or money transparent and traceable.

Thus, both the agriculture and the food industry can take advantage of the ICT based I4.0 applications and the solutions offered by digitalisation, in many ways. However, some technologies and information and database connected methodologies are either expensive, immature, or have little practical experience, so there is no benchmark for learning.

Our research question is how do food industry companies perceive the realization of digitalisation and ICT based improvements in their operations and organization? The novelty of our paper is twofold. On one hand, we create a research framework which helps to systematically analyse a company's digital situation. Besides the applied ICT solutions, we invoke additional research aspects and propose to analyse the digitalisation's effects on strategy, organization, employees, and company culture. On the other hand, until now only a few academic papers have analysed the presence and effects of I4.0 and digitalisation in the food industry. Our results widen the knowledge on digitalisation in the food industry, points out its effects not only on technology but on the entire organization and could be benchmarks for practitioners, too.

2. Materials and methods

In order to systematically examine the impact of I4.0 and digitalisation on the food industry companies, we looked for relevant analytical aspects in the literature. The purpose of this analysis is to get to know how I4.0 and digitalisation transforms the entire company as well as to call the attention of business professionals that I4.0 not only affects the technology in a company, but also the organization itself.

The paper presents case studies which are based on four interviews and was conducted in the three largest subsectors of the Hungarian food industry. According to Yin (2011), case study is an appropriate methodology when researchers want to understand *how* digitalisation affects companies and aim to gain a better understanding on *what* and *why* firms decide and do to move towards I4.0. The case studies are not intended to produce generalizable or representative results (Denzin and Lincoln, 2011), however they might help to identify good practices in the sector and further directions for improvement.

2.1 Analytical framework

To get a broad picture about how I4.0 affects the organization we tried to identify relevant analytical dimensions. We found that I4.0 maturity models involve a great variety of aspects, which seemed to be useful of our analysis, too. Many authors and consulting companies have developed maturity models that evaluate companies in several aspects before determining their degree of maturity and many of these aspects are common. We do not aim to examine the maturity of the analysed companies, because the sample size is not large enough, but some maturity dimensions can serve as a basis for our own analysis, because they examine the individual organizations (Table 1). In the following, three highly cited maturity models are presented and compared to determine our own analytical framework.

The most cited maturity model comes from Schumacher et al. (2016), who examine companies' digital status from nine perspectives. The analytical dimensions include strategy, leadership, customers, products, operations, technology, culture, people and governance. The study does not detail the nine assessment factors but reveals that they are built of another 62 dimensions. As we can see, Schumacher et al. analyse the effects of I4.0 on the organization from various points of view, which suggests us not to narrow our investigation only on technology. From amongst the aspects, organizational adaptation is clearly lacking.

Geissbauer et al. (2016) have formulated a maturity model which involves cross-company digital connectivity with customers, suppliers, and other stakeholders, who are all integrated horizontally and vertically into a digital ecosystem. The scope of the analysis is very broad, besides the digital business model (change of strategy), agile IT infrastructure and data analysis, many new aspects are emerging, including organization, taxation and data analysis. In their approach, I4.0 also has a comprehensive effect on organizations, besides the technological improvement.

Schuh et al. (2017) developed a complex index to measure the maturity of companies in I4.0. They examine the structural characteristics of firms such as resources, organizational structure, information systems, and culture. Corporate processes are also reviewed along functional areas, and performance is evaluated also along the functional areas. Specialty of this approach is that the maturity of the functional areas underpins the maturity of the entire company. On the other hand, this approach is not fortunate, because the primary area of I4.0 development is usually manufacturing (Hofmann and Rüsch, 2017; Brettel et al., 2014), and other functional areas are usually followers, if developed at all. Overall, this model can give us a complete picture of the development of a company in I4.0 since a company should not be judged solely on the level of development of its manufacturing process.

The Schuh-model combines analytical aspects that are already present in earlier maturity models in many ways. The resource category includes all movable resources - machines, products, tools, materials - including people and their abilities. Information systems category include all formal communication solutions, including ICT (information and communication technology). The organizational structure examines the existence of agile organization and inter-company relationships that allow developing technology and continuous adaptation. Culture captures the soft side of all this, such as knowledge management, decision-making, corporate values, and the support of innovation. Thus, the company and the functional units are analysed according to these aspects, in the form of a questionnaire.

We do not include it in the analysis, but there are other (less-cited) maturity models that try to extend the above ones or similar to them. In their model, Lichtblau et al. (2015) propose six criteria for determining the maturity of companies. These six aspects are broken down into a further 18 in detail, very similar to Geissbauer's.

According to Gracel and Łebkowski (2018), the Manufacturing Technology Maturity Model (MTMM) wants to categorize companies along the digital support of manufacturing, but in fact, they did an extensive analysis based on eight dimensions, already mentioned in the previous models, and primarily focused on manufacturing. The maturity model presented by Gill and Van Boskirk (2016) is short and concise, analysing companies from four perspectives: culture, technology, organization, and insights. The latter involves data analysis, the ability of the company to analyse and use data from customers or processes to support the strategy.

Table 1: Maturity models examined. Source: own edition

Authors	*Aspects of maturity analysis*	*No. of citations (Google Scholar)*
Schumacher et al., 2016	Strategy, Leadership, Customers, Products, Operations, Technology, Culture, People, Governance	596
Geissbauer et al., 2016	Digital business models and customer access, Digitization of product and service offerings, Digitization and integration of vertical and horizontal value chains, Data & Analytics as core capability, Agile IT architecture, Compliance, security, legal and tax, Organization, employees and digital culture.	266
Schuh et al., 2017	Structure: Resources, Organizational structure, Information system, Culture Processes: Functional areas (Development, Production, Logistics, Services, Marketing & Sales)	115

From the maturity models presented and the underlying analytical considerations, we will use the dimensions that evenly appear in the models. Technological improvements to gain a better data collection and analysis are the basis of the developments within a company, and since the maturity models emphasize the issue we included it into our analysis, too. The extensive technological advances – not only in data-issues but in manufacturing and other areas, too - are another characteristic projection of I4.0, which we obviously need to analyse. After these two fundamental changes that typically occur in every company, we wanted to examine the effects of I4.0 on the organization from multiple aspects. First, we choose employees, since they are the ones who use the new technology and provide or analyse data, make decisions. Because of the probable changes in decision making process, we also keep it important to get to know how strategy and organizational structure as well as the company culture changed. These aspects can also be derived from the cited maturity models.

The purpose of this paper is not to determine the degree of maturity, but to provide a structured presentation of the technological and organizational development that is taking place in the studied companies as a result of digitalisation. We will apply analytical dimensions of strategy and organization, data analysis, technology, employees and corporate culture to highlight how the Hungarian food industry companies move towards I4.0. The relationship between these and the most important competitive factors for the food industry is illustrated in Figure 1.

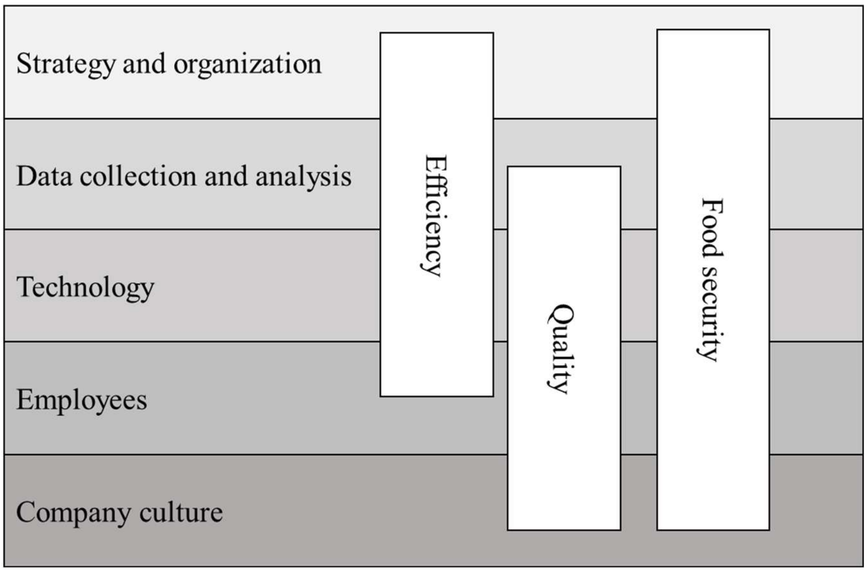

Figure 1: Relationship between research aspects Source: own construction

Figure 1 summarizes the five analytical dimensions along which the interviewed companies will be analysed. The three most important competitive factors – efficiency, quality and food security – was derived from the literature review and are the largest challenges of today food industry. We are intended to analyse how these competitive factors are affected by the changes indicated by the digitalisation. The most important factors in increasing efficiency – which, according to Kürthy et al. (2016), is a serious lag in the Hungarian food industry – are the strategy which incorporates the understanding of the firm's actual situation and the adaptation, the technology, which is changed as a result of educate employees, and use the resulting data for further optimization. Technology also has a great impact on quality, and by analysing the data, it can be further developed, faster prototype production and testing can be achieved. Commitment to quality must also be part of the corporate culture, which is reflected in the work of the employees. Digital developments in all areas serve a high level of food safety and traceability. Overall, the analytical aspects of the interviews will therefore help better understanding the three competitive factors.

2.2 Case studies

In accordance with the above identified analytical aspects, we edited interview questions to get insight into the companies' I4.0 practice, motives, and achievements. Data were collected from four food companies in Hungary, whose names will not be disclosed upon request. The most important data on the investigated companies are presented in Table 2.

Table 2: Interview data Source: own construction

Company Characteristics	„A"	„B"	„C"	„D"
Sub-sector	pasta manufacturing	dairy production	dairy processing	meat processing
Location	Western-Hungary	Western-Hungary	Western-Hungary	Eastern-Hungary
Interviewee	plant manager	farm manager	plant manager	CEO
Interview date	23.08.2018	21.02.2019	04.04.2019	21.08.2018

The interview questions started with strategy. We asked the companies about their market, the changes they experience and the possible answers they are giving to these changes. The data collection, analysis and other technological improvements were asked as what kind of improvement project have been carried out or planned at the companies. We also asked them about how and what extent the employees are involved into the development process, and how the changes affected them. We were curious about the organisational changes caused by I4.0, for example new positions or the probable downsizing. The company culture was captured by questions like how employees adapted to changes, what steps the companies do to make the staff accept the new technologies. Full question list and their connection to analytical aspects can be seen in Appendix 1.

We made 1.5-2 hours long structured interviews with company executives, and we talked about the company's I4.0 approach, the digitalisation solutions used, the projects and the directions of development. As all interviewees were top executives of a given company, they were aware of both production and strategic issues and were considered relevant sources of information. The reliability of our research is enhanced by the fact that although the number of interviews is low, they were conducted with the three largest subsectors of the Hungarian food industry, the meat industry, the dairy industry and the bakery and pasta industry. Three of the four firms are market leaders in their sub-sector, but because of confidentiality reasons, we cannot reveal them.

Based on these, our experience with the digitization of the food industry in Hungary is diverse. The wide range of technologies and solutions used in the automotive industry (Nagy, 2018; Demeter et al., 2020) is far from that of in the food sector. At the same time, it is very important that many processes have long been robotized and / or automated in the food industry, otherwise the efficiency and food safety that customers and the authority expect of companies would not be achieved. However, the further development of these, I4.0, digitalisation and the exploitation of big data are in the focus of corporate thinking.

3. Results and discussion

In this section, we will examine companies' I4.0 practices according to the analytical framework created in Chapter 2.1.

3.1 Strategy and organization

In the strategy and organization analytical dimension, we examined phenomena such as the existence of I4.0 strategy or the effect of I4.0 on strategy. We examined whether the organizational structure has changed as a result of digitalisation. It was also interesting where the initiation of improvements began.

For two of the four companies examined, the move towards I4.0 was induced by the growth strategy. With the capacities available before the developments, they were no longer able to further increase production, so a decision had to be made as to whether they were satisfied with the current size of their business or wanted to grow. The latter was chosen by both of them and the new technologies purchased include digital solutions.

With the investments made, the pasta factory has multiplied its output capacity, since its aim was to increase its domestic market share and conquering the export markets. We cannot talk about specific I4.0 strategy, but when building the new factory and selecting the technology, they clearly wanted to take advantage of the opportunities offered by digitalization: *"The factory is 21st century standard, so far we have focused on it. Now, the coming years will be more about how we can support the back-office activities, which is also important."* In the case of the company, organizational changes have not yet taken place, but they already see the need, because the number of employees in the IT and maintenance departments has started to grow significantly. High-volume developments - such as choosing the technology for the new factory - was a top management decision, but operators were also involved in the design, fine-tuning and minor improvements.

In the case of the dairy production company, in addition to growth, survival and regulatory compliance also contributed to the technology innovation decision. The plant was obsolete by the end of the 2000s, and it was not possible to grow or increase efficiency with the existing number of workforce and technology: *"The company's decision was to develop this plant"*. Regulatory standards also tightened, so they definitely had to improve. To this end, *"a large-scale project was launched and one of the best and most efficient sites nationwide was established"* - as our interviewee told us. As a result of the development, it was also possible to collect data that could be used to further increase animal welfare. In this case, we cannot talk about a developed I4.0 strategy, nor have any organizational changes been reported.

The dairy processing company is a member of an international group with a well-defined I4.0 strategy, and the Hungarian subsidiary also has responsibilities to fulfil it. According to the interviews, we distinguish between group-level developments that focus primarily on big data and analysis, improving forecasting and planning accuracy; and smaller, local-level developments that utilize I4.0 and digitalisation solutions to address a specific enterprise problem. *"We realize our own ideas and a lot of things that have already been implemented in other factories in the group, we take over here."* The most common force that triggers local development is the lack of manpower, which they try to solve with partial automation and robotization. The company, through the projects implemented, is explicitly seeking to increase food safety and to meet or exceed standards. The C-level director of digital development is present at the international level only, in the Hungarian factory there is no dedicated leader. Local development can come from any level of the organization, and operators are motivated to submit their proposals.

For a meat processing company, there is no explicit I4.0 strategy as well: *"It will affect the industry within 5 to 10 years (I4.0). Now it's only in the minds of those executives who are open."* In their case, the developments began as a result of a risk analysis that revealed the jobs where the risk of a labour migration would seriously jeopardize the operation of the plant. Subsequently, steps were taken to automate and robotize these operations. The other direction of development when building a new plant was sensory data collection, monitoring of the meat processing process, and thus increasing process efficiency. The sources of development proposals are mainly senior management, but employees at the bottom of the organizational hierarchy also have the opportunity to submit ideas. Organizational changes have not yet occurred due to digitalisation.

We have found that the companies are changing, but in all cases the digital transformation is underway, the starting point is mainly a top management decision to move the company towards growth and efficiency. The specialty of the food industry is that a better compliance with regulations also motivates the developments, as it was suggested by Kittipanya-ngam and Tan (2020) and Carpenter and Wyman (2017). We also found that, although improvements had begun, this did not change the strategy, there was no formal I4.0 strategy and the transformation of the organization to the new business model had not yet begun. Amongst the reasons for development changing customer needs and retailer pressure were not identified in the case companies, contrary to literature.

3.2 Data collection and analysis

The purpose of this section is to explore what data the companies collect, and how it is collected, processed, and used in decision making.

The *pasta company* has intended to take advantage of the technology when designing the new production facility and gathers as much data as possible about the production process. The raw material entering the automatic production line passes through sensors of weight and humidity. The consistency of the dough being made is also controlled and so is the temperature of the dryer. The finished pasta passes through several control points both before and after packaging, where any piece of metal found in the production process is screened with a metal detector and the weight and bar code of the package are also checked. The machines are equipped with preventive maintenance sensors (operating hours meter), any deviation from the norm can be detected immediately and the necessary intervention can be decided. The manufacturer also provides remote diagnostic services and uploads maintenance tasks to be performed when a particular operating hour is reached. The goal is to reduce downtime or, if there is a downtime, to find the causes and avoid them next time. Based on these, the maintenance task can be scheduled, employees receive the task on a tablet, which informs them what task to perform, what materials to use, what error to correct (or not if it failed). There is also a monthly report on the machine's performance and operating characteristics. Analysing data is a big task for a company. By their own admission, they did not expect the analysis of the extracted data to be so important when building the new plant, so the development of the supportive IT background is lagging behind. Their goal is to have the most important data instantly online and make real-time decisions: *"So if the production manager wants to look at the production, then he doesn't have to look at the machine and see what happens, he just take out his notebook and can watch the process."*

The technology of the *dairy production company* enables the collection of a large amount of data. At starting the dairy production process, animals are individually identified using an RFID chip hanging in their ears. This chip stores the animal's identity, breed, ancestry, physical characteristics (e.g., lactation phase), and all interventions in which the animal was involved (vaccinations, calving, etc.). Milk yields from individual cows are also known, so when the animal arrives at the milking machine, it calculates an expected milk yield: *"If the cows at the start of lactation, then obviously the expected amount of milk is up, if she is the end of lactation the milk production will keep going down then the system obviously will change the expectations day by day. We get a lot of data from this device."* If the expected milk yield is not met, it will be checked first if the milking machine has been set up correctly, and if the yield is less than expected for an extended period of time, the animal will be examined by a veterinarian. The milking machine also checks the quality and composition of the milk that is being milked. It can calculate from the milk flow rate whether the milking worker has properly triggered the milking reflex (that is, the animal has given as much milk as possible), which is also reflected in the performance pay. The milking machine allows to access a variety of reports. The milking process can be queried in different compositions and focus. Latter are determined and evaluated by the animal breeding engineer. The availability of preventive maintenance and remote diagnostics was an important consideration when choosing the technology. The manufacturer constantly monitors the condition of the machines and makes recommendations for necessary maintenance. The feed consumed by the animals is also recorded in the computerized system. Cows are grouped according to their age, milk yield, lactation status and receive feed of appropriate quality and quantity. The composition of the fodder needed for a group of animals is determined by the feeding manager who uploads it into a flash drive and from that onto the feed mixing machine, which indicates which type of feed to load (by weight) and then mixes them.

Digital development, encouraged by the parent company of the *dairy processing firm*, is data collection and analysis. They are already trying to extract and analyse data from the PLC (Programmable Logic Controller). This can be a great help in preventive maintenance or even avoiding quality problems e.g. the scales built into the production process are able to monitor which component is being dosed and, if out of range, suggest which component should be added more, which is less. Tracing allergenic substances is also a requirement for food safety: *"In our industry, traceability of batches is very important, especially if the product contains allergenic substances."* The aim is to see production data that allows immediate intervention.

Developments that ensure food safety and compliance with official regulations are of paramount importance to the company, as the internal rules of the international group are stricter than Hungarian or even EU rules. For example, when a component is added to a product, it is recorded which raw material is blended from which supplier's production batch, thus ensuring traceability. This tracking is even more thorough with allergenic materials, when it is also recorded who cleaned the machine after production.

The *meat processing company* deliberately chose digital technology to monitor processes and closely control the production line at its new plant, thereby helping to increase the accuracy of data control and process efficiency, and to support performance pay: *"we built in everything that can provide data for ERP, controlling and process control"*. Another area of data collection is the monitoring of machine condition for preventive maintenance. Machine shutdown is a major cost factor in this sector as well, and an important reason for the development of data collection in this area.

Collecting and analysing data was a very important factor at every company when choosing technology. Companies also report that they have a wealth of data and are struggling to process it and turn it into relevant information that they can use in real-time decision-making. At the same time, it seems that the production and storage of data is just one problem, the other is the development and purchase of software and systems that can analyse and display them. Food safety - as a reason behind developments - came up several times during interviews, as the literature claims (Kittipanya-ngam and Tan, 2020). However, the literature does not address the cost and challenge of building and operating such IT systems at companies that are able to store and share data of a quality and composition compliant with food safety regulations. Although blockchain would be suitable technology for solving this problem, we have not identified any traces of the application in the Hungarian company practice, yet. An appropriate system for data collection and analysis is challenging in all respects and companies are investing significant sums in this regard.

3.3 Technological solutions

In this section, we present all the technological solutions - be it automation, robotics or IT development - that have resulted in great progress in the company in terms of both efficiency and data processing. We also cover the issues of data security and cyber security that concern companies.

The *pasta company* is implementing a high degree of automation and robotization in its new factory. The production of the dough goes through an automatic process from the breaking of the eggs to the unloading of the finished and packed pasta in the form of a unit load. In the dough-making machine, sensors monitor the dough's texture, moisture, humidity and temperature. A heat recovery is built in the drying process, which allows significant energy savings. The packaging is carried out by an automatic packaging line after production. After several weighing and metal detector screening, the pasta packages are placed in a cardboard box and then conveyed by the conveyor to the warehouse preparation area. Here, unit-loading robots receive the boxes and form stacks of products of the same type identified by barcode scanning. The stacks are captured by the wrapping machine and then, through it, an automatic signal is sent to the AGV (automatic guided vehicle) forklifts, which, after identification, transfer the unit load to the high bay racks warehouse designated for end products and hand it over to the high bay racking machine. When the unloading request is received, the former process is reversed, the racking machine finds the desired unit load, hands it over to the automatic forklift, and it forwards it to the delivery area.

Sensors built into the above process (balance, barcode scanner, metal detector etc.) continuously produce data that is stored on company servers. The plant manager highlighted cyber security, which they try to secure through operating their own server and differentiating permissions.

When purchasing the technology, the possibility of connecting the machines and equipment to each other and to the production centre was especially important. Remote diagnostics allow the company to detect the fault much faster, spare parts can be ordered sooner and, in the case of foreign-made machines, does not incur the cost of transporting the service staff to the site: *"Each machine has a remote diagnostic service and the device monitors continuously the operation, forces, temperatures, etc. In case the system signals or detects a malfunction or abrasion, we will be notified and then obviously we can request proper service for the machine"*.

In the case of a *dairy producing company*, it is worth examining two directions of technology, on the one hand, milking technology, and on the other hand, animal welfare equipment. They identified cattle by RFID chips hanging in their ears, which store a plenty of data about them (see Chapter 3.2 Data analysis). The milking machine is set up manually, but the milking machine milks the cattle in 4-5 minutes and automatically stores quantitative and qualitative information: *"The computer automatically calculates the expected milk from the previous days' milk production and lactation stage"*. Animal welfare fundamentally affects milk yield, so a number of "convenience" solutions can be observed at the farm. For cattle, temperatures above 25 degrees Celsius cause heat stress, so above this temperature limit, the water spray is switched on in the paddock, which automatically releases water more and more frequently as the temperature rises. Similarly, when the temperature limit is reached, the fans also turn on. The basically open side-walled paddocks allow good airflow, but in case of bad weather (rain, wind), a tarpaulin automatically lowers to protect the animals from discomfort.

The computer-determined feed composition is mixed in the feed mixer, which indicates how much nutrient should be added to each group of goods according to the uploaded plan. The fodder is poured along the paddocks and can be consumed by the cows leaning out of the paddock. While eating, they inevitably break through the paddock, so a feed-sweeping robot walks through the paddocks several times during the day to dig it back to where the animals can reach it. The content of the feed is checked several times a week and the composition is revised if necessary.

At the *dairy producing company* the technology is not as integrated as in the pasta factory. The investments made focused on key processes to comply with food safety regulations which would not be possible otherwise. The system stores a lot of information about animals, skimmed milk, a significant part of which is prescriptive, while analysing the other part of the data allows creating an appropriate environment, nutrients and caring for the animals. The data collected is used to increase animal welfare, formulate optimal feed, and determine workers 'performance pay. Although there is a significant amount of data generated that is stored on corporate servers, the issue of cybersecurity has not been addressed.

The *dairy processing company* makes developments in two directions. On the one hand, there are expectations from the parent company to improve productivity and carry out other digitalisation projects, and on the other hand, employees within the company are very creative and make suggestions for improvement. This company operates a very labour-intensive production process, which resource, however, is scarce. To replace the workforce, cobots (cooperative robots) have been implemented that can be operated safely among humans and take on monotonous, demanding, or repetitive tasks: *"Cobots are relatively smaller and therefore cheaper than large industrial robots and can be implemented amongst humans. Work safety is very important"*. A similar palletizing robot works as at the pasta manufacturer, which is not an own, customized development, a ready-made system has been purchased and adapted. Like the dairy producer, a lot of data is collected (Chapter 3.2) and processed, some of which is used to fit regulations and others for process development and efficiency. The data is stored partly locally and partly at group level at central data storage, while analyses are carried out at all levels. The goal is to be able to intervene immediately as soon as an emergency warning is generated.

The new plant at the *meat processing company* has been specifically built with the intention to give management a complete overview of the process through built-in sensors. Here, the process of raw material arrival, receiving and first processing is monitored, which are essential for the resale of the raw material or processing by further plants. Based on the sensor data, the net expected amount of gross incoming raw material can be better planned, the system not only calculates the loss (gross-net deviation), but also monitors the raw material weight, moisture and protein content: *"We use sensors in the raw material processing. This is repeated at several stages during the process."* Once again, the goal is the possibility of immediate intervention. Although they cannot yet measure efficiency per worker, only at the production line level, they can already use the data for performance pay. Another element of development was the equipment of machine with preventive maintenance function to reduce downtime. The company used lean solutions before, and the current developments were also coordinated by this team.

Overall, in connection with the development of technology, most companies find proper digital solutions, the connection of machines to the network is realized, data collection works, it is partly analysed and used in some part of decision-making. An I4.0 solution can be observed in the pasta factory, in which machines are not only connected to each other, but the production forms a unified whole with the automated warehouse and logistics processes, and automated, robotic processes can also be observed. Besides digitalisation, robotics and automation are already appearing at the milk processing company, but the solutions do not form a system, isolated developments can be observed.

There are many European Union and Hungarian state funds available for technological developments. The majority of companies examined have won tenders and have also been able to achieve a favourable return on their deductible. However, participation in further tenders is now so expensive because of the price of the technology and the construction, and so difficult to find a contractor for the project, that these jeopardize the project to fit in the budget and the time frame at all.

3.4 Employees

The purpose of analysing this dimension is to examine how the company involves its employees in digital developments. We also examined what jobs were created and transformed as a result of new technologies and process developments.

Contrary to what is described in the literature (Deloitte, 2015; Carpenter and Wyman, 2016), the examined companies not only do not decrease staff due to technological developments, but rather struggle with labour shortages, or only improvements can help avoiding shortage.

The *pasta company* has always used a lot of automation in production, so blue-collar staff was low in the past, too. Currently, the pasta factory employs approximately 100 people, producing more than 50,000 tons of pasta per year, in three shifts a day. As a result of the current developments, they realize that they will increasingly need workers who can operate, maintain, or program machines. In this respect, they have no problems yet, but the increase in staff has begun. The number of maintenance staff has doubled in the last 5 years and the organization of the technical directorate has also expanded. In total, 14 people are already working to ensure the technical maintenance of production. Because automation was already present in production processes in the past, accepting the new technology with workers was not a problem, although generational differences appear (young people are basically easier to get used to working with a robot, they also learn programming faster than their older peers). *"By automating a lot of things, we've triggered a lot of manual work. On the other hand, there is a great need for a staff that can not only operate these machines, but also understands them and intervene if necessary"* the interviewee said. Workers on the production line are also involved in generating development ideas, and company management is open to development proposals from any level.

The *dairy production company* is faced with the situation that the improvements made it possible that they have enough manpower: *"There is a growing shortage of manpower here, and unfortunately I have to say that it is not a question of money. Because if I were to pay twice as much, there would certainly not be more milkers who want to do it."* The roles of veterinarian, animal husbandry engineer and feed manager have been expanded through digitization, they keep electronic records, upload animal data to the central register, compile reports that summarize and analyse milking results, and electronically plan the fodder, which is assembled and loaded into a feed mixer. Their task is to query and compile new types of reports from the available data, which can be further developed. At the company, development ideas come more from white-collar employees, and investment planning is a top management decision. The company also faced the dilemma of knowing that more advanced technology would be available and they would buy it, but there are very few professionals in the country who could be able to operate it. This is seen as a serious constraint of further development.

The *dairy processing company* is struggling with labour shortages. The unemployment rate in the region is very low (1-2%), so they often have to hire workers they consider just right to do the job, and the fluctuation is high. Its developments have also been driven partly by the creation or assistance of jobs in areas with the greatest labour shortages and fluctuation. The workers accept the technology, are happy to work with the cobots, and experience it as a modern technological environment. On the one hand, the company receives the development directions from the parent company, on the other hand, generates them from the inside. The source of the latter is typically engineering, quality assurance, or plant management. However, in the case of a problem, they first look at the group level, whether a similar one has arisen somewhere amongst the affiliates, and how it has been solved there: *"Colleagues here are very creative, there are also Western European factories asking for advice from us"*. For the time being, the company does not feel that the structure of the workforce is changing due to digitalisation and robotization, but they see that in 5 years they will need many more technicians, PLC programmers and maintainers.

For the *meat processing company*, labour shortage is also a typical problem. There are jobs in which learning manual work is very time-consuming, and with the knowledge gained, many are more likely to be move to Western Europe. That is why one of the drivers of the developments is the replacement of jobs where there is a high risk of emigration. However, there are complex manual tasks that cannot be taught to a robot: *"I see only partial opportunities (for the introduction of I4.0 devices) in production, and more in logistics especially in warehousing. It is also important in operations and maintenance."* Sources of development ideas can be both blue-collar and white-collar workers, and the company is open to initiatives, and proposals are rewarded if they are successful.

Based on the above, it can be seen that companies perceive that digitalisation is changing expectations of the workforce, making jobs more complex, and requiring much more technological knowledge. However, labour shortage affects food companies seriously, the suction power of other sectors is very strong.

3.5 Company culture

In examining corporate culture, we looked at how open companies are to innovation, how well their employees have the opportunity to make suggestions, and how knowledge sharing takes place in the company.

Despite the fact that the implementation of I4.0-related development was partly forced for most of the companies, the firms made very important and significant investments. In order to maintain growth, the *pasta company* has embarked on the development of a new, modern production unit, which has made it a significant player not only in Hungary but also in Central-Eastern Europe. The commitment of senior management and the involvement of employees should be highlighted as a factor of success. When choosing the technology, it was a clear consideration to choose one, which can serve competitiveness, not to seek the cheapest solution. An explicit knowledge management system does not work at the company, but since it is a small organization, the communication takes place directly: *"Training has always been an important aspect here in the pasta factory."*

The *dairy producing company* opted for a large-scale and fundamental technological change in order to survive. The decision was made by the top management, but like the pasta company, the management mobilized great energies so that the decision makers of the investment could learn about the technological possibilities. They went on study trips abroad to get to know and learn about the technology, so they sacrificed a lot to make an informed decision and to prepare for the operation: *"We constantly - with the support of the top management - go on study trips and employ consultants who are currently introduce new things, novelties"*. In terms of corporate culture, employees are expected to be constantly learning and open to change.

The dairy processing company has taken a number of solutions from the parent company. Innovation is very important centrally, and central digital developments must be carried out. At the group level, a knowledge-sharing portal is now being set up, in which subsidiaries upload the solution to a specific problem, their best practices. They make common knowledge for the group, which can be used by any other subsidiary.

Bottom-up initiatives have a culture in local development: *“Engineering brings together (the ideas), designs a solution for it, calculates how much it would cost, what will improve, how long it can be realized, what savings can be expected”*.

The *meat company* has also taken great strides towards modernization, economic stability, and technological development. According to the expert interviewed, it is very important to have a management in a company that has a vision and can assess where the industry is heading over the next 10 years and dares to make the right decisions and takes risks. As the interviewee says it: *“Here you have to decide not only on the basis of return, but there will be other aspects as well, e.g., where the industry will be in 10 years, what consumer needs will be and what technology will be able to meet it”*. In recent years, a culture of acceptance of bottom-up initiatives has also developed in this organization, but we cannot talk about a knowledge-sharing system.

In the previous chapters, we got to know four organizations committed to innovation and embarking on change. Corporate culture also supports development initiatives in all places, whether they come from below or from above, but the operation of a knowledge management system - with the exception of a company with an international background - is not typical.

4. Conclusion

In our study, we examined the steps taken by the food industry towards digitalisation and I4.0. We sought to increase the validity of the research by interviewing actors from the three most important sub-sectors of the Hungarian food economy.

The main finding of the study is that there are food industry developments in Hungary that take advantage of the opportunities offered by digitalisation and I4.0. Table 3. is following the same structure and logic we created within our analytical framework. Related to strategy and organization dimension, 2 main questions were asked. On the one hand, whether I4.0 strategy exists or not, and on the other hand if the need for organizational changes is obvious for the management and already started. As the table shows, only the dairy processing company has I4.0 strategy (on international level due to its membership of an international group), and only the pasta manufacturer recognized the need for organizational changes due to the new positions (IT, maintenance). Data collection and data analysis questions are raised in the second dimension, where we could observe the developing status of the companies. Within technology dimension we distinguished the field of solutions applied. It came as a question, whether the whole process integrates I4.0 technologies or only it can be found partially, in isolated solutions or supportive processes. In connection with employees' dimension, we concluded that usage of I4.0 technologies in none of the cases ended up with less need for human work but on the contrary. It helped to decrease the risk due to human workforce shortage. Also, the need for new positions (maintenance, IT) appeared in our cases. Related to the involvement of the employees we observed an in-progress status of the companies, as the developments, ideas come mainly from the top management. Our last dimension is the company culture with 2 areas: the openness for innovation and knowledge sharing. We found that all our cases belong to an in-progress openness for innovation as food industry is typically follower compared to very innovative industries. The knowledge sharing aspect of the companies differed significantly in our research. In two cases, formal or informal levels of knowledge sharing practices can be observed on group levels. However, in the other two cases, the knowledge sharing is reaching only a basic level as it is informal and occasional. The main results are summarized in Table 3.

Table 3. Main findings of the study. Source: own editing

Results		*Pasta manufacturer (A)*	*Dairy producer (B)*	*Dairy processor (C)*	*Meat processor (D)*
Strategy and organization	I4.0 strategy	No	No	Yes, on international level	No
	Organizational changes	Embryonic	No	No	No
Data collection and analysis	Data collection	Extensive	Extensive	Developing	Limited
	Data analysis	Developing	Developing	Developing	Developing
Technology	Automation, robotization	Integrated process	Isolated solutions	Isolated solutions	In supportive processes
Employees	Number of personnel	Increasing in maintenance	Shortage	Shortage	Shortage
	Involvement	In progress	No	In progress	In progress
Company culture	Openness for innovation	In progress	In progress	In progress	In progress

	Knowledge sharing	Group level, informal	Basic	Formalized, on international level	Basic

According to Kürthy et al. (2016), the Hungarian food industry is lagging behind its Western competitors in terms of efficiency and technology, although export activity significantly boosts the sales revenue of enterprises. This is also evident in the pasta factory which has reached its capacity limit and has clearly committed itself to a growth strategy that it plans to build on exports by setting up a new plant. In order to achieve higher efficiency, companies can best help to implement further optimization and increase their competitiveness by purchasing state-of-the-art technology and analysing the data it produces. Consistent with the Simutech (2016) survey, interviewees reported significant investments (pasta, milk producer and meat processor) in which decision was based not on the price of the technology rather on its knowledge and capabilities. One of the most important functions are the predictive maintenance, data processing, in which they are still working on the exploitation of opportunities. The low prevalence of I4.0 is indicated by the fact that organizational changes were not typical at the companies, but rather the increase in the number of technical and maintenance departments.

Continuous quality control and improvement is also a central element of corporate development (Santeramo et al., 2018). Productivity has improved, enabling customers to access a wider range of products at affordable prices (pasta), improving and controlling product content (milk production, meat processing), and paying attention to allergens at a higher level (dairy processor).

The results of our study are completely consistent with the research of Bibi et al. (2017), Carpenter and Wyman (2017) and Bottani and Rizzi (2008), according to which the development of technology is an important tool for comply with always tightening regulations. Barcodes play a primary role in tracking, but RFID chips are used to identify and track cows at the dairy farm RFID (or barcode) -based traceability covering the entire supply chain as Tian (2017) suggest is not yet available, and supply chain actors are still looking for a solution to the problem individually. The same way, we could not find evidences of applying (or at least planning to apply) blockchain technology in the analysed firms.

Our research revealed the effects of digitalisation on the food industry companies. We highlighted that besides the technological development firms has to adapt with their organization, as well, and role of human factor in the success is essential. Success does not depend only on the technology acceptance of blue-collar workers, but also on their development ideas as well as the top-management engagement. Our important finding is that although food security regulations force companies to technology – especially IT – development, and besides its high cost it is also challenging in terms of data security, storage and processing capacity and methodology.

In our exploratory study four corporate practices were introduced which also can serve as excellent as benchmarks. We highlighted that although I4.0 and digitization appear various ways in the different companies and sub-sectors, their impact is far from limited to production, affecting several levels of organizational operation.

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Appendix 1: Interview questions

Analysed element	**Belonging interview questions**
Strategy and organization	Describe the company: what characterized the market in the last 10 years, what does today, what to expect? How would you articulate what Industry 4.0 is? What does it mean to you? How do you interpret? How is it interpreted in the company? How does I4.0 appear in your company? What will your industry look like in 5-10 years? Is there a formal expectation from the company owner, centre regarding digitalisation? Does any movement take place locally? Where did the inspiration come from for the company to reach for the digital tools? What areas of the company are affected by the introduction of I4.0 devices? Tell us specifically about one or two previous projects? Who and on what basis decides on the project, what is the purpose of the project? Why these projects were highlighted?

Data collection and analysis	What projects have been implemented in connection with the I4.0? What kind of investments were made? What are the steps of a I4.0 project? What results has been achieved? Are the results sustainable? (in economic meaning) What are the general experiences, success criteria, project failure factors? as there an initiative to apply a I4.0 or digital application in the company's external relations? (with suppliers, customers, partners)
Technology	What areas of the company are affected by the introduction of I4.0 devices? What projects have been implemented in connection with the I4.0? What solutions (tools) do you already have experience with? What tools do they think about in the short and medium term?
Employees	Who and on what basis decides on the project, what is the purpose of the project? Who is involved in the project (players)? How did employees welcome the implemented changes? What results has been achieved? Are the results sustainable? (in social meaning)
Company culture	Was there an initiative to apply a I4.0 or digital application in the company's external relations? (with suppliers, customers, partners) Is there a relationship within the company group between the individual units in terms of I4.0 best practices exchange? Is there a formal expectation from the company owner, centre regarding digitalisation? Does any movement take place locally? Where did the inspiration come from for the company to reach for the digital tools? Is there a company you are benchmarking with? Is there a forum between companies in which you would like to participate?

Table 4. Interview questions matching the analytical framework. Source: own editing

11. SUMMARY AND CONCLUSIONS

11. 1. Reflection on the research questions

So far, the key findings from the articles show that both the AFSC members and the industry providing them with technological solutions find themselves in a challenging situation. It can be stated that the generally applicable technological solutions such as robotics, drones, AI, RFID... etc., cannot be implemented by AFSC members in all cases. Those upstream actors who deal with farming or primary processing cannot entirely replace their previous (often human collaborated) technologies with solutions provided by I 4.0 or digitalisation. The reasons for that can be divided into two groups.

The first finding that is derived from both the literature analysis and the case study methodology is that these AFSC members have to cope with the financial burden of these investments. This burden stems not only from financial investments but also from the costs of implementation and maintenance. After having bought the technological solution, a company also needs workforce who can operate them. This challenge concerns not only AFSC member applying the technology, but also the economic policy and the decision makers. Hungary is heavily influenced by the directives coming from the EU regarding the status of the agri-food sector. Developments towards ensuring food safety (and with a special focus, traceability) will be encouraged both at a national and international level. This direction affects all AFSC members, including consumers.

The second comprehensive finding derived from the three papers introduced in the dissertation is the lack of innovative atmosphere. The analysed AFSC members seem to adopt digitalisation mainly because of regulatory compliance, and due to the regional and global challenges they can't really focus on consciously implementing them to be able to compete on the market. There is also a gap between the field of emerging technological solutions (as the introduces papers show, the trend is supported by technology providers) and the AFSC members capabilities to adopt them in a short run. Here comes the importance of the policy-makers into the picture. Policy-makers at a national, and regional level have a key role in supporting the implementation of digital developments to enhance the competitiveness and sustainability of AFSCs in their region. They must get to know the gap between the opportunities (emerged technologies) and the current status of AFSCs to be able to help them with legislative tools, while coordinating the digital changeover.

The collective findings of the three studies suggest that technological innovation and digitalisation in the agri-food value chain (AFSC) is inevitable and, although not always consciously, companies are increasingly exploiting its potential. Improvements are driven by both external pressures (e.g., food safety regulations, labour shortages, competitiveness pressures) and support policies (e.g., tenders, public strategies). However, the adoption of solutions is also hampered by a number of challenges such as investment costs, regulatory uncertainties and lack of appropriate digital competences. Traceability is a central goal of the digitalisation of the agri-food industry, enabled by technologies such as IoT, RFID and blockchain, which allow products to be tracked from production to consumer in real time, accurately and transparently. This not only enhances food safety and consumer confidence, but also supports regulatory compliance and internal process efficiency.

11. 2. Contribution to the existing literature

The contributions of the three studies to the existing literature are first described individually, and then the collective contribution is discussed at the end of this chapter.

Paper Nr. 1. complements the previous isolated discussion of the topic by linking the three pillars of “decision-maker”, “funder” and “technology provider”. It highlights the importance of harmonisation. The first study of my dissertation is a comprehensive hybrid literature analysis of food digitalisation strategies of SMEs in the light of the Covid-19 epidemic. It builds on a quantitative mapping of the literature and content analysis of white papers and so highlights the barriers and opportunities for the adoption of digitalisation solutions. It also contributes to the literature from a practical perspective and the attention of practitioners from the AFSC might be awaken due to the structural introduction of available goal settings of „decision-makers” in form of the Digital Agricultural Strategy (DAS, 2019) and Digital Food Strategy (DFS, 2022), the “funding” opportunities in form of a comprehensive, analytical review and a collection with the supported “technological directions”. Unlike existing research that often focuses on theoretical frameworks or the potential benefits of digitalisation, this study emphasizes the practical interaction between policy instruments and corporate decision-making. By analysing funded projects and their alignment with strategic goals, it bridges a gap between public policy analysis and organisational behaviour, revealing how financial instruments and public incentives shape digital transformation in the highly regulated agri-food sector.

An important finding of Paper Nr. 2. is that the literature so far has not focused on the link between regulatory requirements and emerging technological solutions and, as a consequence, the paper comprehensively examines the impact of digitalisation on AFSC members and, indirectly, on society. The second study of my dissertation examines the impact of digitalisation on food safety using a systematic literature review approach. This research focuses on traceability and regulatory aspects and provides detailed insights into the role of I 4.0 solutions in the safe food supply. This methodological contribution is significant, as it uncovers hidden patterns and underexplored areas such as the lack of regulatory integration and the emerging importance of cybersecurity. By revealing both technological and thematic trends, the paper provides a solid foundation for future research to build on, particularly in understanding the multidimensional impacts—social, environmental, and economic—of digitalisation.

Paper Nr. 3. contributes to the literature by applying a systematic, three-dimensional (strategy-organisation-technology) analytical framework to AFSC actors. The third paper presents case studies on the application of digitalisation in the food industry at enterprise level. Its main finding is, that it supports the theoretical frameworks identified in the two previous overview studies with practical examples and highlights the real challenges of implementing technological innovation. This study contributes to the existing literature by contextualising digitalisation in a real organisational context. Its analytical framework captures dimensions such as strategy, organisational change, employee engagement and corporate culture, providing a holistic view of digital maturity of AFSC members under review.

The three studies are important contributions to the literature on digitalisation in the agri-food industry, as they provide a practical perspective on how technological innovation is implemented in companies from different backgrounds. They provide a shaded picture of the social, economic, and environmental impacts of digital technologies such as IoT, AI, blockchain, highlighting not only their benefits but also the risks associated with their implementation. The dissertation referring to the results both of the preliminary literature review (2. Theoretical background) and the three papers included confirms the strong link between traceability and food safety, underlining that digitalisation is key not only for competitiveness but also for regulatory and trust aspects. A growing role of public and EU support policies as drivers behind technological developments is seen due to the studies. This means an interdisciplinary approach and complements the literature by exploring the technological, organisational, and regulatory context of digitalisation simultaneously.

11. 3. Recommendations for corporate decision-makers, policy-makers

Paper Nr. 1 can define the lines of communication between policy makers and practitioners, thus supporting the further organisation of developments. Furthermore, it serves as a comprehensive overview document for AFSC members before they invest in technological solutions. For AFSC members—especially SMEs—it is recommended to closely align their investment and innovation strategies with national and regional targeted goals like the ones incorporated in the Digital Agricultural Strategy (DAS, 2019) or the European Farm2Fork Strategy (EU Green deal, 2020) to be able to mitigate risk while developing their operations. On the other hand, policy-makers should fine-tune funding offers to reflect to market realities much better, and they should incorporate into their decision-making processes the risk of cost fluctuations and the unique constraints faced by SMEs especially nowadays. Support programs are recommended to be tailored for SMEs providing them capacity-building initiatives which could enhance the financial stability while operating applying digital solutions. In conclusion, it is desirable to have a reflective strategy defined jointly by AFSC members, technology providers and regional/national decision-makers, which is important to be comprehensive and to ensure consistent conditions for all parties involved.

Paper Nr 2. aims to raise the awareness of AFSC members to strive for systemic thinking rather than isolated application of digialisation solutions. Paper Nr. 2. also has the potential to raise awareness among decision-makers of the need to place greater emphasis on broad integration of applied solutions in rule-making, to think systemically when inviting applications and listen to industry's prior views. Therefore, the AFSC decision-makers are encouraged to adopt a selective and integrated approach to digital technologies, recognizing that full-supply-chain traceability and food safety cannot be achieved with fragmented solutions. Policy-makers should focus on helping firms mitigate digital risks while encouraging innovation through supportive and adaptable policies. A standardised, but also flexible way of reporting might contribute to the operations of AFSCs while ensuring traceability and providing trust among the members. Incorporating emerging technologies like blockchain, and IoT based solutions (Alladi et al., 2020, Creyd and Fischer, 2019, Lin et al., 2019) might contribute to a much safer and sustainable operation within the AFSC.

Paper Nr 3. can serve as a benchmark for business decision makers and can also make technology providers aware that I4.0 and digitalisation are manifested in different ways in different sub-sectors, their impact is far from being limited to production, and that they affect multiple levels of organisational functioning. Therefore, company decision-makers should not only invest in modern technologies but also reorganise internal structures to support new roles and responsibilities, such as IT and maintenance positions. This study emphasizes that sustaining these innovations long-term, the management must deal with employee involvement and knowledge-sharing practices to make the newly applied technologies internalized. Policy-makers are encouraged to collaborate with practitioners to be able to motivate them investing in digitalisation while ensuring the stabile and consequent background from the governmental side.

11.4 Limitations and further research directions

According to the limitations of research, Paper Nr. 1. approaches the issue along strongly national and international legal/regulatory lines. Its most important limitation is about its reliance on policy document analysis and publicly available project descriptions, which provides only an indirect view of how digitalisation initiatives are being realised by the agri-food sector actors. Thus, the accessibility of valuable reports is limited, excluding a widespread data collection. However, the paper offers insights into the alignment between national strategies and technological adoption, it lacks empirical input which could strengthen its contribution to the literature. This is partially overcome in Paper Nr. 2., where a systematic literature analysis is added to broaden the scope of research. The scope and methodology of Paper Nr. 2 is its biggest limitation and strengths parallelly. Although this bibliometric analysis successfully identifies major research trends and emerging topics such as blockchain, IoT, and circular economy, the scope of the research questions remains broad. In addition, there is an incompatibility of merged databases with VosViewer and Biblioshiny and it hindered a more comprehensive analysis due to the lack of full accessibility of data to be used. In Paper Nr. 3, the research focuses on the upstream side of the AFSC, especially on a small sample of Hungarian agri-food industry firms, which is considered also as a representativeness barrier. Its limitation is that the research methodology is formed to be exploratory, so no representative outputs are there to be presented, however the deep insights coming from the findings of the three papers of the dissertation lead to a better understanding. Future research should expand the sample size and include diverse actors from different regions and segments of the AFSC.

My future research directions can be connected to two main paths. Overall, I am driven by two main directions: goals from the Food Supply Chain Research Group and personal research objectives, which complement each other. I am a member of the Food Supply Chain Research Group since 2020 (its official establishment), and we are moving in the direction of food as a critical infrastructure from the perspective of transportation as a complementing critical infrastructure. We research resilience of critical infrastructures regarding food and its relations to digitalisation. The Food Supply Chain Research Group is moving towards this direction within an international cooperation, of which I am a member as well. My personal interest is how digitalisation contributes to the agri-food industry. For more comprehensive results, I consider it an appropriate direction to either go deeper within a sub-sector e.g., dairy, or to approach AFSC actors across as many sub-sectors as possible. Therefore, I have participated in an EU funded action research (SchoolFood4Change project - EU Horizont. (2020). Grant number: 101036763.) since 2022 (until present) dealing with sustainable school food catering, which is an area of research focusing on short supply chains (SSC). Here, I could extend the individual research directions of mine while combining sustainability with digitalisation regarding AFSCs from an SSC perspective.

Potential future research directions include research on the AFSC as a whole, where in addition to sectoral diversity, the focus is also on completing the range of supply chain actors. To improve this widespread view while analysing the AFSC members and their relationships with I 4.0 solutions, the scope of our research (Food Supply Chain Research group) has been shifted to the direction of resilience and there are studies under peer review so far dealing with the AFSC resilience supported by digitalisation. Based on Paper Nr. 1, it is worthwhile to include the Digital Food Strategy (DFS) alongside the Digital Agri Strategy (DAS) in the analysis in order to examine the policy objective in the overall AFSC approach.

Furthermore, the findings of Paper Nr. 2. (Freund, 2023) have been utilized and two empirical research papers were written to build on the results of the second paper of my dissertation (Freund et al., 2024, Freund et al., 2025) which examine the practical implementation of the digital technologies from the perspective of AFSC members, building on the clusters of the bibliometric literature review being inserted in my dissertation. The importance of follow-up is also highlighted in the dissertation, but it can be seen that the AFSC is being vulnerable, e.g., Kinder scandal (Focus.de website, 2023), and digitalisation can play a prominent role in ensuring food safety while providing traceability. By focusing on the digitalisation-related capabilities that support resilience, I would extend our existing research on capabilities to examine the relationship between digitalisation and traceability in this light.

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