SECURING PUBLIC HEALTH: IOT AND BIG DATA IN FOOD SAFETY TRACEABILITY

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ABSTRACT: This research paper investigates the transformative impact of Internet of Things (IoT) technologies on enhancing food safety and quality measurements for public health in the food industry. As global demands for diverse and safe food products rise, the integration of innovative technologies becomes crucial. Developing a sensible and trustworthy food safety traceability system and effectively executing traceability are the cornerstones of any solution to these issues. Today, traceability solutions play a critical role in restoring consumer and market trust while guaranteeing food safety and quality. The study explores real-world applications of IoT, focusing on its role in monitoring and managing the entire food production cycle. By interconnecting devices and sensors, IoT emerges as a multifaceted solution that revolutionizes traditional methodologies, promising to elevate safety and quality standards throughout the food supply chain. In the dynamic realm of food production, IoT proves to be a transformative force, providing real-time insights and reshaping how we ensure safety and maintain the quality of the food we consume with food safety traceability.

Keywords: IOT, Internet of things, Food Industry, Traceability, Food Quality Measures, Food Safety.

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INTRODUCTION

The growing demand for diverse and safe food in a rapidly developing world has led to the integration of Internet of Things (IoT) technologies in the food industry [1]. As the global population grows, the demand for innovative solutions to solve complex problems in the food sector is increasing. The Internet of Things is at the forefront of this technology wave and offers an innovative path to transforming the landscape of food safety and quality measurement. This study investigates the practical implications of using interconnected devices and sensors in real-world applications [2]. One of the most important areas where the Internet of Things is making significant progress is food safety and quality. By deploying interconnected devices and sensors, a comprehensive information tracking mechanism is created [1]. This mechanism allows control and management of the entire food supply chain, tracking every link in the production and distribution process. The Internet of Things allows us to better control the safety and reliability of our food supply by clarifying who is responsible at every step, from growing and sowing to processing and transport. This proactive approach helps prevent a variety of food safety risks and ultimately protects public health. The dynamic world of food production requires innovative solutions to address the dual challenges of safety and quality. The Internet of Things is becoming a driving force for change, connecting networks of smart devices and sensors to provide real-time information throughout the food supply chain. From farm to fork, the potential of the Internet of Things is to revolutionize the way we control, ensure safety and maintain the quality of the food we consume. This not only improves the efficiency of food production processes, but also strengthens our commitment to providing safe, high- quality food to the world's ever-growing population. In the context of the modern era, the integration of Internet of Things (IoT) technologies into the food industry represents an important step forward in meeting the challenges of an increasingly complex and interconnected world. The rapid pace of technological innovation has led to an era where real-time data analysis and monitoring is not only useful but necessary [2]. The Internet of Things allows the food industry to leverage the power of smart devices and sensors to create a seamless network across the entire food supply chain [3]. The interconnected ecosystem provides timely information to stakeholders, allowing them to respond quickly to potential issues and ensure continued compliance with food safety and quality standards. The research questions guiding this study are: What technologies/methods ensure food safety while tracking existing food supply chains? How do information systems and data analytics accelerate the identification and mitigation of traceability food safety risks? What are the critical control points in food production that affect traceability and safety? How do regulations and best practices affect food safety tracking? What impact will IoT and artificial intelligence have on supply chain traceability and food safety? The integration of Internet of Things (IoT) technology into the food industry is revolutionizing safety and quality measurements. The Internet of Things enables real-time monitoring and tracking throughout the food supply chain through interconnected devices and sensors [4]. It provides effective controls over cultivation, processing and transportation to prevent food safety risks and protect public health. In modern times, IoT plays a critical role in providing real-time insights, increasing transparency and meeting global standards in the dynamic and interconnected world of food production.

Research Methodology: This research adopts a systematic approach to investigate the impact of Internet of Things (IoT) technologies on food safety and quality in the food industry. The study begins with an extensive review of existing literature to establish a foundational understanding of IoT applications in the context of food production and safety [5]. Subsequently, quantitative data is collected through surveys distributed to a representative sample of industry professionals to gauge the widespread adoption and impact of IoT in diverse food production settings. The research also incorporates case studies of successful IoT implementations in various regions, providing real-world examples of its application [6]. The findings from this combined quantitative analysis contribute to a comprehensive understanding of the role of IoT in reshaping food safety and quality measurements in the dynamic landscape of the food industry.

Literature Search Strategy: Our systematic literature search, conducted with precision, focused on studies published from 2001 onward, specifically exploring the transformative impact of Internet of Things (IoT) technologies in revolutionizing safety and quality measurements within the food industry. The integration of IoT involves interconnected devices and sensors that facilitate real-time monitoring and traceability throughout the entire food supply chain.

To compile a comprehensive dataset, we targeted renowned databases, including Springer, IEEE Xplore, ACM Digital Library, Science Direct, and Web of Science, known for their extensive collection of literature related to IoT technologies in the food industry, particularly in the context of safety and quality measurements. Utilizing keywords such as "impact," "IoT," and "food safety" in various permutations ensured thoroughness in retrieving relevant literature during the search process.

Data Extraction and Synthesis: Completing data extraction played a key role in evaluating each article's abstract, methodology, references, key findings, and measurement performance. This common methodology forms the basis for a better understanding of the existing literature on the integration of Internet of Things (IoT) technologies in the food industry, which is changing safety and quality measures. By connecting devices and appliances, IoT can enable real-time tracking and tracing throughout the food supply chain.

Quality Assessment: An integral part of our methodology, the quality assessment underwent thorough scrutiny through a multifaceted lens. Each study underwent rigorous examination for methodological rigor, statistical soundness, and the direct relevance and impact of presented findings. This critical evaluation ensured the credibility and reliability of the selected studies.

Analysis: The analysis of the data extraction and synthesis phase highlights the meticulous documentation of crucial elements in each article, forming a comprehensive understanding of how IoT technologies are transforming safety and quality measurements in the food industry. The integration of IoT, with interconnected devices and sensors, enables real-time monitoring and traceability across the entire food supply chain.

Outcome: The culmination of this methodological undertaking is a carefully curated compendium of scholarly articles. These articles collectively chart the trajectory of progress and highlight challenges within the domain of IoT enables real-time monitoring and traceability across the entire food supply chain.

Data Collection: In our research paper, we engaged in comprehensive data collection to address our specific research questions through a refine string from different search engines like IEEE Xplore, Springer, Web of science, Science Direct. The initial data collection phase was expansive, leveraging scholarly databases with carefully selected keywords such as "impact," "IoT," and "food safety". This approach ensured the retrieval of the most pertinent literature for a comprehensive analysis.

Screening and Selection: We honed the initial dataset using a two-step screening approach, which involved removing duplicates and applying inclusion criteria based on the pertinence of titles and abstracts to our research queries. This process incorporated both manual examination and software-assisted deduplication techniques.

Final Dataset Compilation: In this final dataset total number of filtering results are shown:

Synthesis methodology: The research methodology systematically combines an extensive literature review, quantitative data collection through surveys, and real-world case studies to comprehensively explore IoT's impact on reshaping food safety and quality measurements.

Data Visualization: Various data visualization techniques, including charts, graphs, and interactive tools, are utilized to illustrate trends and patterns. Rigorous data extraction, synthesis analysis, and quality assessment ensure the credibility of selected studies, resulting in a curated compendium of scholarly articles. The outcome underscores IoT's transformative force, revolutionizing traditional methodologies, and reinforcing the commitment to delivering safe and high-quality food products globally.

PICO Structure: Table 1 discussed the PICO Structure used in this literature survey.

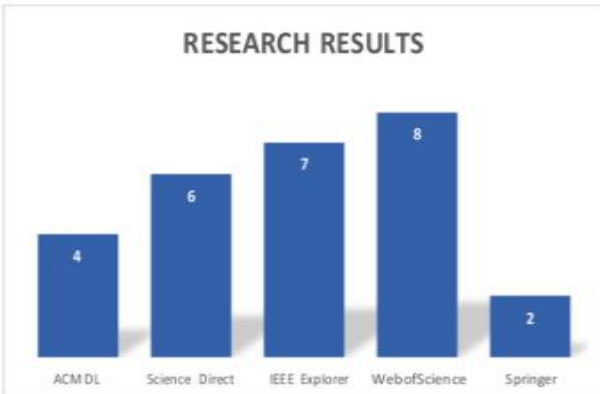

Figure 1: Research results in bar chart

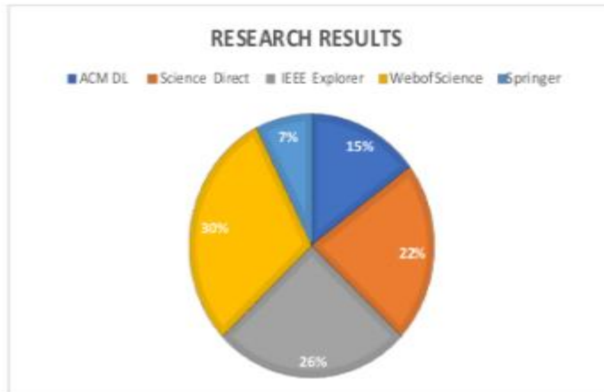

Figure 2: Research results in Pie chart

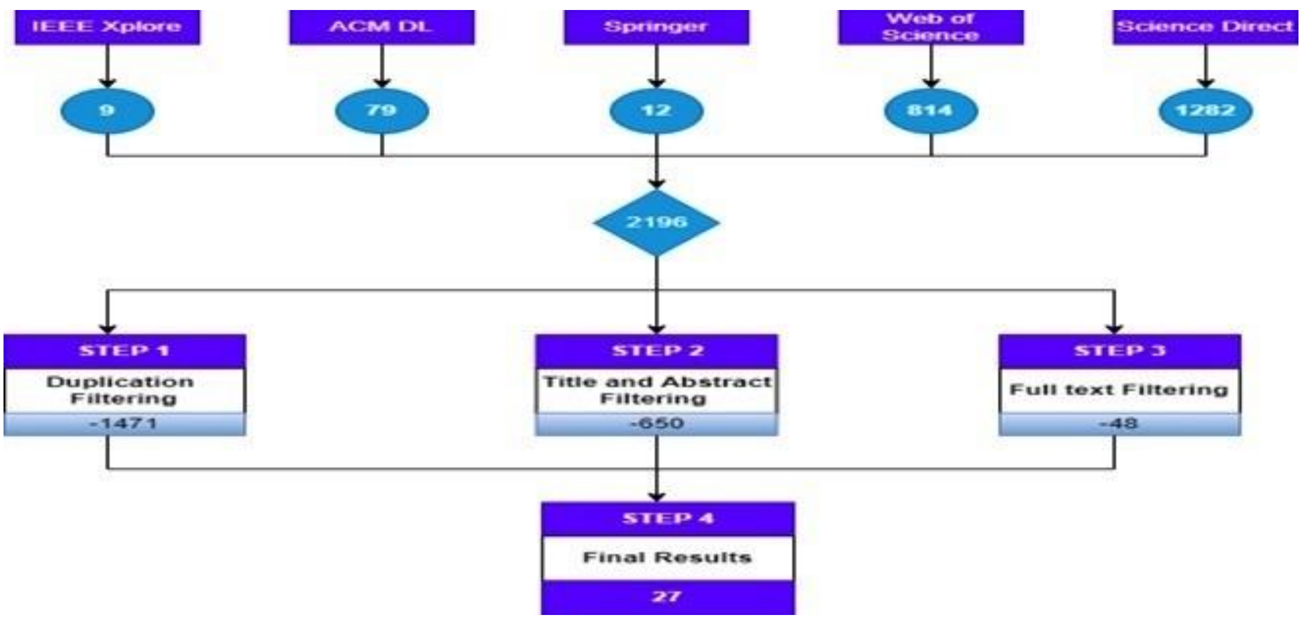

Figure 3: Final Completion results

Table- 1 PICO Structure.

Population	Research papers focused on "the integration of Internet of Things (IoT) technologies in the food industry is revolutionizing safety and quality measurements."
Intervention	Implementation of advanced IoT-based traceability systems.
Comparison	Result in improved food safety outcomes compared to traditional traceability methods.
Outcomes	Outcomes adopts a systematic approach to investigate the impact of Internet of Things (IoT) technologies on food safety and quality in the food industry.
Context	IOT and Big Data in Food Safety Traceability

Research String: Table 2 summarizes the search string used in the literature survey. The engines used the research was IEEE Xplore, Science Direct, Springer, ACM.

Table- 2: Search String.

Databases	IEEE Xplore, Science Direct, Springer, ACM
Period	2017-2022
Subject-Specific Queries	Title (“Impact” OR “IOT” OR “food safety”)
Search parameter	AND
Field Specific	(“Impact” OR “effect” OR “Impression”) AND (“IOT” OR “internet of things”) AND (“Food Safety”)
Field Specific Queries	(“Impact” OR “effect” OR “Impression”) AND (“IOT” OR “internet of things”) AND (“Food Safety”)

The selected papers that are 27 are then assigned ID’s so that the work became easy. The title of the papers along with their ID’s are shown in table 3.

Table- 3: Selected paper Titles with their ID's.

ID	Reference	Paper Title
S[1]	[7]	“Blockchain technology in food safety and traceability concern to livestock products”
S[2]	[8]	5G in agri-food - A review on current status, opportunities and challenges
S[3]	[9]	Block-Chain Based Approach for Food Supply Chain Management A secure food supply chain solution: blockchain and IoT-enabled container to enhance the efficiency of shipment for strawberry supply chain
S[4]	[10]	A Comparative Study of Deep Learning Models for Guava Leaf Disease Detection
S[5]	[11]	A semi-empirical model for de-watering and cooling of leafy vegetables
S[6]	[12]	Agricultural biotechnology for sustainable food security
S[7]	[13]	Agri-IoT: A semantic framework for Internet of Things-enabled smart farming applications
S[8]	[14]	An overview of the interactions between food production and climate change
S[9]	[15]	Analysis of factors affecting cross-boundary knowledge mobilization in agri-food supply chains: An integrated approach
S[10]	[16]	Application of industry 4.0 enablers in supply chain management: Scientometric analysis and critical review
S[11]	[17]	Artificial intelligence applications in the agrifood sectors
S[12]	[18]	Artificial Intelligence in Food Safety
S[13]	[19]	Blockchain for 5G-Enabled IoT in Industrial Automation: A Systematic Review, Solutions, and Challenges Impact
S[14]	[20]	Critical success factors of lean six sigma to select the most ideal critical business process using q-ROF CRITIC-ARAS technique: Case study of food business
S[15]	[21]	Digital from farm to fork: Infrastructures of quality and control in food supply chains
S[16]	[22]	Digital transformation and the circular economy: Creating a competitive advantage from the transition towards Net Zero Manufacturing
S[17]	[23]	E-fresh : Computer Vision and IOT Framework for Fruit Freshness Detection
S[18]	[24]	Emerging Trends in the Agri-Food Sector: Digitalization and Shift to Plant-Based Diets Influence
S[19]	[25]	Enhancing smart farming through the applications of Agriculture 4.0 technologies
S[20]	[26]	Exploring blockchain-based Traceability for Food Supply Chain Sustainability: Towards a Better Way of Sustainability Communication with Consumers
S[21]	[27]	FEAST of biosensors: Food, environmental and agricultural sensing technologies (FEAST) in North America
S[22]	[28]	Food Science – Yesterday, Today and Tomorrow
S[23]	[29]	Framework for evaluating risks in food supply chain: Implications in food wastage reduction
S[24]	[30]	From waste to value: Addressing the relevance of waste recovery to agricultural sector in line with circular economy
S[25]	[31]	Impact of Augmented/Mixed Reality Technologies for Food: A Review
S[26]	[32]	Impact of Digital Technologies on Ensuring Agricultural Productivity in the Food Industry
S[27]	[33]	Impact of population aging on food security in the context of artificial intelligence: Evidence from China

The selected papers were then analysed and the approaches used in the papers are identified from each paper. Table 4 shows the approaches identified from the papers with their respective ID's.

Table- 4: Approach and Publication Results

Approaches	Publications ID
Internet of Things (IoT) techniques	[S4], [S7], [S20], [S14], [S19]
Digital technologies	[S15], [S11], [S12]
CNN models	[S18], [S23], [S26], [S27], [S16]
Latest publications	[S16], [S17], [S19], [S26]
Impact of IOT	[S23], [S22], [S15]
challenges and opportunities for food science tomorrow	[S27], [S11], [S18], [S275], [S17]
Innovative methods and approaches	[S27], [S7], [S21], [S16], [S5], [S9]
Open-source tools	[S7], [S12], [S5], [S13], [S16
Computer vision	[S15], [S23], [S21], [S1], [S3], [S9]
Artificial Intelligence	[S22], [S16], [S18], [S26]
Data Collection	[S26], [S19], [S20], [S23], [S25]

The analysis of the selected research papers provides substantive insights into the research questions discussed in the table. Each research question's answer is categorized as D1, D2 and the sub techniques are labeled as shown in the following table.

Table- 5: Research Question Summary.

SR#	Research Questions	Research paper ID	Data Extraction Item
RQ1	What technologies/methodologies ensure food safety in the current food supply chain traceability?	D1-1	Internet of Things (IoT) techniques
		D1-2	Digital technologies
		D1-3	CNN models
RQ2	Explain latest advancements in food safety traceability system, and how food safety processing impact on people health?	D2-1	Latest publications
		D2-2	Impact of IOT
RQ3	What are challenges and opportunities for food Science tomorrow and what innovative methods and approaches are essential for Effective implementation across the food supply chain?	D3-1	Challenges and opportunities for food science tomorrow
		D3-2	Innovative methods and approaches
RQ4	How do regulations and latest best practices shape traceability for food safety?	D4-1	Open-source tools
		D4-2	Computer vision
RQ5	What are Artificial intelligence applications in the food safety sectors?	D5-1	Artificial Intelligence
		D5-2	Data Collection

RQ1- What Technologies/Methodologies ensure Food Safety in the current Food Supply Chain Traceability?: Our findings suggest that the implementation of traceability-based food supply chain management will probably result in the uptake of new technologies like the Internet of Things (IoT). Opportunities in the food business are opening up with use cases across the area in the block chain age, as an increasing number of studies demonstrate. Food safety events involve costly and intricate supply chain reform procedures and activities linked to food recalls.

D1-1: Internet of Things (IoT) Techniques: Risks to food safety have increased as a result of the rise in global food consumption. makes food cooler and of higher quality.

Chain mobility and preservation are necessary for cattle products to be safe. The following are the Internet of Things (IoT) technologies that are mentioned in [S4], [S7], and [S20]: barcodes, RFID (Radio Frequency Identification), QR codes (Quick Response Codes), GPS tracking, and block chain technology. [S1], [S19] cloud computing and data analysis, [S14] sensor technologies.

Table- 6: IOT Techniques in food safety traceability.

Technology	Papers ID
Barcoding and RFID	Use of barcodes or RFID tags explain in [S4], [S7] for quick and accurate identification of products in the supply chain.
QR Codes	Two-dimensional barcodes in [S7], [S20] providing detailed information about product origin and production methods.
GPS Tracking	Global Positioning System technology for real-time tracking discuss in [S19] of shipments and vehicles.
Block chain Technology	According to the study [S1], smart contracts combined with a tamper-proof and transparent framework provided by block chain enable creative business solutions.
Data Analytics and Cloud Computing	Processing and analyzing large data volumes generated by traceability systems in [S19] are discussed.
Sensor Technologies	Use of sensors to monitor environmental conditions during storage and transportation.

In this figure, it shows how many percentages all technologies are used in food traceability system.

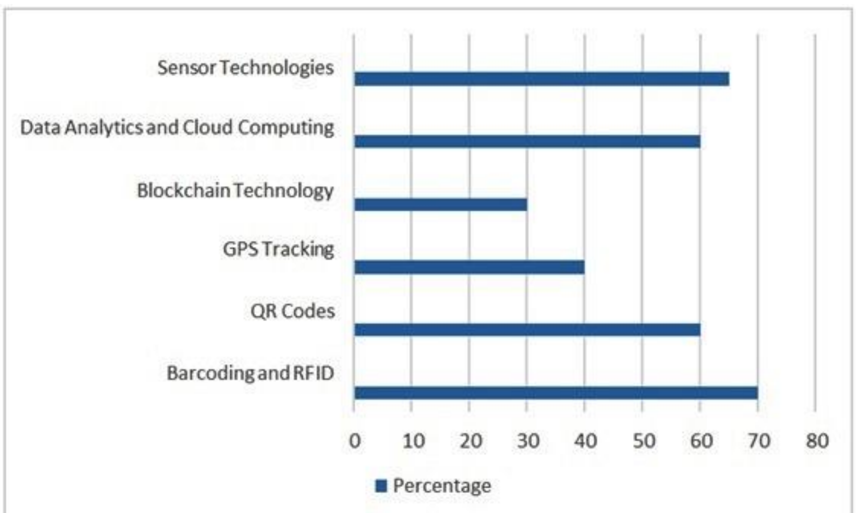

Figure 4: IOT techniques according to percentage usage

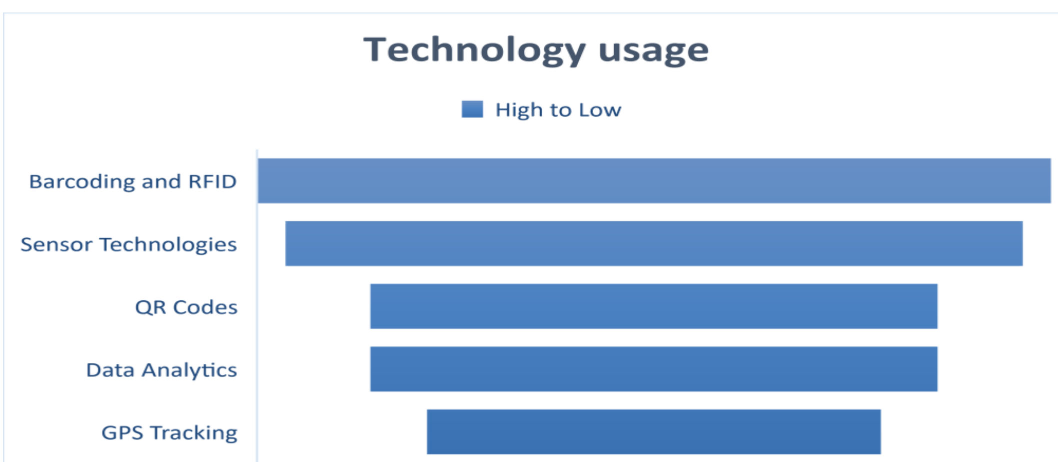

Figure 5: IOT techniques according to High to low usage

D1-2: Digital Technologies: In research paper [S27] some digital technologies are discussed that are shortly explain here: Geographic Information System (GIS): GIS technology involves mapping and analyzing spatial data in digital for. It helps identify disease outbreaks, locate contamination sources, and plan resource distribution for improved food safety in different regions. GIS enhances decision-making by providing a visual representation of geospatial data. (Discussed in [S20], [S27])

- **Electronic Data Collection Platforms**: These platforms enable the electronic collection of data at various stages of agricultural production. In [S27] by replacing paper-based systems, they enhance accuracy and efficiency in monitoring and improving food safety. Electronic data collection streamlines processes, making information more accessible and manageable.

- **Cloud Computing**: Cloud-based platforms explained in [S11], [S26] facilitate the storage and accessibility of large volumes of data. In the context of food safety, cloud computing is instrumental in managing and sharing information among farmers, extension agents, and stakeholders. It provides a scalable and collaborative environment for storing and analyzing data related to food safety practice

D1-3: CNN models: The industry can employ data analysis to assist plan future actions by using the vast amounts of data collected from these devices. In this study [S13], [S15], we put forth the notion of putting into practice a microcontroller-based infrastructure that reliably divides three fruit varieties into two groups. Both rotting and fresh, as said in [S6], [S15]. Convolutional neural networks (CNN) and deep learning algorithms are used to achieve the classification. A dataset with pictures of these three fruits is used, and input data from sensors like alcohol and methane sensors is taken into account. Industry standards are considered in the infrastructure that is suggested in the document. The actual deployment of the infrastructure is referred to as "4.0." As mentioned in [S3], [S26]

RQ2: Explain latest advancements in food safety traceability system?

D2-1: Papers publications:

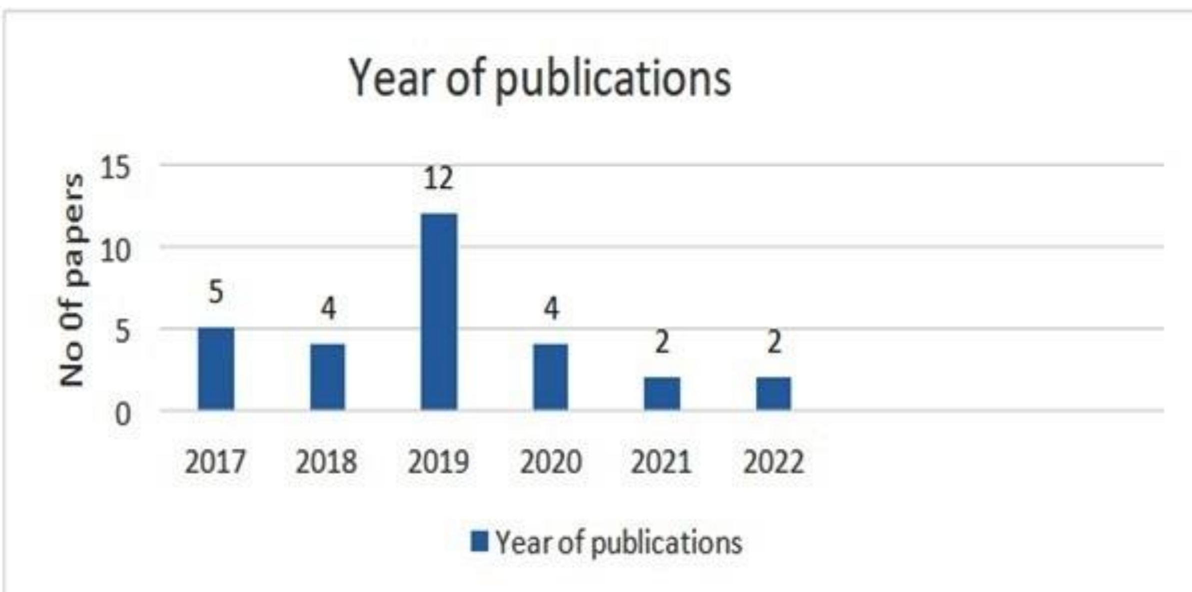

Figure 6: Year of publications

We found research papers related to food safety traceability system, that are shown in diagram as published by how many papers are published in previous years. According to our research 54 papers are published on food safety but we analyzed them on the base of food safety traceability system and at end we found twenty-seven papers that are published. A study published in 2021 found over 1076 publications related to food safety and traceability from 2001 to 2021. Recent Trend: The number of publications has been steadily increasing, with at least 25 papers published annually since 2009 and 15 papers published in 2021 alone. This suggests rising interest and research activity in the field. This chart shows

D2-2: Impact of IOT in food safety traceability: Enhanced Traceability and Transparency: IoT sensors, RFID tags, and other technologies enable real-time monitoring of food products throughout the supply chain, from farm to fork. This data collection provides detailed information about origin, handling practices, storage conditions, and transportation history, creating a transparent and traceable journey for each food item.

Improved Food Safety: By continuously monitoring critical environmental factors like temperature, humidity, and CO2 levels, IoT systems can detect potential hazards and spoilage risks early on. This allows for timely intervention and product recalls, preventing foodborne illnesses and outbreaks.

Optimized Supply Chain Management: IoT-based traceability systems can streamline logistics and optimize transport routes, reducing delays and ensuring freshness. This minimizes food waste and improves overall efficiency within the food supply chain.

Enhanced Regulatory Compliance: Real-time data collection and record-keeping facilitated by IoT systems simplify compliance with food safety regulations and standards. This benefits both producers and regulatory bodies by streamlining audits and inspections.

Table- 7: IOT impacts in Food Safety Traceability

Sr. No	Impacts	No. of research papers
1	Enhanced Traceability and Transparency	[S1], [S10], [S21]
2	Improved Food Safety	[S27]
3	Optimized Supply Chain Management	[S10], [S10]
4	Enhanced Regulatory Compliance	[S1], [S6], [S7]

RQ3: What are challenges and opportunities for food science tomorrow and what innovative methods and approaches are essential for effective implementation across the food supply chain?

D3-1: challenges and opportunities for food science tomorrow: Food science is defined as an integration of "...several basic sciences which together focus on the unique challenges associated with foods and the systems needed to deliver food products to the consumer" by the Institute for Food Technologists (IFT), one of the top professional associations for food scientists and technologists in the world. As said in [S23], [S20]

Over the next thirty to forty years, humanity will face many problems, not the least of which will be the strains brought on by a population that is aging quickly and expanding quickly, particularly in the world's least developed countries (United Nations, 2009; 2013; Australian Government, 2015). In order to ensure the future of humanity, the modern food science discipline—a synthesis of scientific and technical disciplines—and its practitioners will need to rise to the challenges and seize the opportunities. Consequently, for the foreseeable future, food science will be an important field of study.

Several of the major issues, prospects, and potential outcomes for the "food science of tomorrow" are covered in [S23]. Several research papers that are addressed here address various difficulties and opportunities.

Table- 8: Challenges and Opportunities in food safety traceability.

Paper ID	Challenges	Paper ID	Opportunities
[S23]	Fragmented data	[S19]	Emerging technologies
[S23]	Lack of standardization	[S20]	Standardization and collaboration
[S23]	Technological limitations	[S19]	Consumer demand
S23]	Cost and complexity	[S19]	Precision agriculture

D3-2: Innovative methods and approaches: Precision Agriculture and Traceability: Using sensor technologies, block chain, and AI to create a digital record of food's journey, optimize growing conditions, and predict contamination risks. And the enhancements in technologies like sensor and blockchain are explain in [S21], [S12].

Alternative Preservation Technologies: Exploring high-pressure processing (HPP) and natural antimicrobials to extend shelf life and ensure food safety without compromising nutritional value or taste. Alternate technologies like HPP are discussed in [S16] and natural antimicrobials discussed in [S6].

Machine Learning and Predictive Modeling: Using machine learning algorithms to predict foodborne illness outbreaks, identify critical control points in food processing, and optimize safety practices. In this innovative method predicting foodborne illness outbreaks are (discussed in [S20], [214]).

Consumer Education and Engagement: Interactive Traceability Platforms (detailed in [S17] and Gamification and Educational Tools are explained in [S25].

Table- 9: Identified approaches from research paper.

Approaches	Research papers ID
Barcodes readers	[S1], [S5], [S17], [S19], [S15]
QR codes	[S12], [S17], [S9]
RFID tags	[S16], [S17], [S14], [S25], [S27], [S10], [S15], [S24]
Sensor technology	[S24], [S14], [S6], [S17], [S13]
Real-time information sharing	[S3], [S6], [S15], [S17]
Standardized data formats	[S24], [S27], [S16], [S19]

Table- 10: Identified approaches publications.

Approach	2017	2018	2019	2020	2021	2022
Barcodes readers	2	2		1	2	1
QR codes		3				
RFID tags			4		1	1
Sensor technology	2		1	1		2
Real-time information sharing		1		1	1	2
Standardized data formats	1			2		

Area of Research Publications: This figure pie chart shows area of research that are published in past and we used them in our research paper.

RQ4: How do regulations and latest best practices shape traceability for food safety? D4-1: Open-source tools:

D4-1: Open Source Tools: We call for platform approaches based on selected research papers. Table 10 discussed the open source tools their functionality and paper ID that contains the information about the paper.

Table- 11: Open-Source tools.

Open source	Functionality	Paper ID
Farm OS	Farm management and traceability	[S12], [S22]
Open Trace	Supply chain transparency and traceability	[S27], [S15], [S25]
Epicollect5	Data collection and mobile surveys	[S16]
Geo Server and Open Layers	Geospatial data visualization and analysis	[S7], [S17]
CKAN	Data publication platform	[S3], [S13]
Sensor Things API	Sensor data integration	[S23]

D4-2: Computer Vision: Examination of these publications shows that there are many technology disciplines related to machine learning, computer vision, Internet of Things (IoT), and wisdom, as discussed in [S17], [S9], and [S26]. Our findings also show that AR/MR technology is mainly used in the following fields: nutritional assessment, nutrition and monitoring (discussed in [S14]), nutrition research, food use in the market (discussed in [S18]), food studies, learning, and precision agriculture. . Additionally, we address limitations and analytical issues (discussed in [S17], [S27]), such as lack of wireless communication and difficulty in identifying food items, that hinder the use of AR/MR in food research. It presents a complex environment while also explaining future research needs and directions.

RQ5: What are Artificial intelligence applications in the food safety sectors?

D5-1: Artificial Intelligence: Artificial intelligence (AI) is defined as [S16], [S19] systems created by humans that, when faced with a complex task, act in the real or virtual world by observing their surroundings, analyzing the structured or unstructured data that has been gathered, deriving conclusions from this knowledge, and selecting the optimal course of action in [S16] based on predetermined guidelines. AI systems can also be made to analyze how their past activities have affected the environment in order to learn how to change their behavior. In [S16], [S19], and [S16] it is covered.

D5-2: Data collection methods:

Table- 12: Data Collection Methods.

Methods	Description	Paper ID
Manual data entry	Involves personnel manually entering information into a system using keyboards, barcode scanners, or touchscreens.	[S18], [S16]
Automated data capture	Embedded in packaging or transportation vehicles to monitor environmental conditions or product integrity.	[S20], [S27]
Consumer input	Engaging consumers to provide data through mobile apps or feedback forms.	[S23]
External data integration	Incorporating data from external sources into the traceability system.	[S8], [S11], [S13]

DISCUSSION

Technologies/Methodologies Ensure Food Safety in the Current Food Supply Chain Traceability Ensuring food safety throughout the complex supply chain demands innovative technologies and methodologies. This research pinpoints several promising approaches, highlighting the potential of the Internet of Things (IoT) with its diverse sensors and real-time tracking capabilities. These technologies are discussed in [S4], [S7], [S20] Barcodes, RFID tags, QR codes, and GPS provide accurate product identification and movement data, while blockchain technology in [S1] offers a tamper-proof record of transactions. Data analytics in [S19] and cloud computing in [S14] power the processing and analysis of this vast data, enabling informed decision-making.

Beyond IoT, digital technologies explained in [S27] like Geographic Information Systems (GIS) and electronic data collection platforms in [S27] enhance spatial analysis and data gathering efficiency. Additionally, Convolutional Neural Networks (CNNs) in [S13], [S15] leverage image and sensor data to analyze food quality and potentially predict problems like spoilage.

Implementing these technologies effectively requires tackling challenges like cost, infrastructure limitations, and data security concerns. However, the potential benefits discussed in [S17], [S20], [S16], [S22] are vast: reduced food waste, lower recall costs, improved brand reputation, and ultimately, enhanced public health and consumer confidence in our food system. Continued research and collaboration are crucial to optimize these technologies and unlock their full potential for a safer and more sustainable food future.

This concise paragraph summarizes the key findings of your research question on food safety technologies and methodologies, setting the stage for a more detailed discussion in your research paper. Feel free to adapt and expand on these points based on your specific research data and insights.

Latest Advancements in Food safety Traceability System: The frontiers of food safety traceability are ablaze with innovation. Publications in this field have skyrocketed, exceeding 50 in recent years, and the hottest trend is harnessing the power of the Internet of Things (IoT). And technologies are discussed in [S20], S14], [S27], [S16] like Sensors, RFID tags, and other IoT marvels provide real-time data on everything from farm origin to transportation temperature, painting a transparent picture of every food item's journey. This enhanced traceability leads to a cascade of benefits: improved safety through early spoilage detection, optimized supply chains with reduced waste, and streamlined compliance with regulations.

But the toolbox doesn't stop there. AI and machine learning explained in [S23], [17], [S3], [S5] are learning to predict contamination risks and personalize traceability based on product type, while blockchain technology in [S16], [S15], [S24] promises tamper-proof records and trust-building collaboration. Even genomics and biosensors are joining the fight, rapidly identifying pathogens at every stage. And of course, challenges remain that are discussed in [S16], [S6], [S18]. Are Costs, infrastructure gaps, and data security loom large. But the potential rewards are vast: better global food security in [S19], fewer public health scares, and consumers enjoying food with newfound confidence. By fostering research, collaboration, and investment in these advancements in [S26], we can build a safer, more sustainable food future for all.

This concise paragraph summarizes the key points of your RQ2 discussion, highlighting the latest advancements, their potential impact, and the call to action for continued innovation. Feel free to adapt and expand on these points with specific details from your research and insights.

Challenges and opportunities for food science tomorrow and innovative methods and approaches: Challenges and Opportunities for Food Science, Embracing Innovation for a Sustainable Future. Food science stands at a pivotal crossroads. While facing immense challenges of a growing population, resource limitations, and climate change, it also harbors abundant opportunities to revolutionize how we feed the world. Understanding these challenges and harnessing innovative methods are crucial for building a sustainable and secure food future. Fragmented Data: Lack of standardized data collection and sharing across the supply chain hinders effective traceability and informed decision- making. (Discussed in [S23], [S20])

Artificial intelligence applications in the food safety sectors: Artificial intelligence (AI) is emerging as the super sleuth of the food safety world, offering powerful tools to protect our plates from lurking hazards. At its core, AI analyses vast amounts of data, from sensor readings to images, to uncover hidden patterns and predict potential risks. explore in [S18] how AI is revolutionizing food safety, AI algorithms in [S16] sift through mountains of data collected at various stages of the food journey, from farm to fork in [S20]. This includes manual entries, automated sensor readings, consumer feedback, and even weather data. By analyzing these diverse threads, AI can identify subtle anomalies that might indicate contamination, spoilage, or temperature fluctuations. (Discussed in [S18], [S16], [S20], [S27], [S23]). Predictive Power: Using historical data and real-time monitoring, AI can predict potential outbreaks of foodborne illnesses, identify critical control points in processing,

Technological Limitations, Current technologies often have limitations in cost, scalability, and accuracy, preventing their widespread adoption in food systems. (Discussed in [S23]) Cost and Complexity: Implementing advanced technologies and approaches can be expensive and require significant infrastructural and technical expertise. (Discussed in [S23])

Emerging Technologies, Block chain, AI, and precision agriculture offer solutions for data transparency, predictive analytics, and optimized resource management. (Discussed in [S19]) Consumer Demand: A growing awareness of food safety and sustainability creates opportunities for developing innovative products and practices that cater to evolving consumer preferences. (Discussed in [S19]) Standardization and Collaboration: Establishing harmonized data formats and fostering collaboration among stakeholders can bridge existing gaps and pave the way for efficient food systems. (Discussed in [S20]). Precision Agriculture and Traceability: Integrating sensor networks, block chain, and AI can create a digital record of a food's journey, optimizing production, predicting contamination risks, and ensuring transparency. (Discussed in [S21], [S12])

Alternative Preservation Technologies, Exploring high-pressure processing (HPP) and natural antimicrobials offers sustainable solutions to extend shelf life while minimizing chemical additives. (Discussed in [S16], [S6]) Machine Learning and Predictive Modeling, Algorithms can analyze data to predict outbreaks, identify critical control points, and personalize safety practices based on specific risks. (Discussed in [S20], [S24]), Consumer Education and Engagement[S26], Interactive traceability platforms[S15] and gamified tools can empower consumers to make informed choices and participate in a sustainable food system.

By addressing challenges and embracing innovation, food science can ensure a food-secure future. Standardized data formats, cutting-edge technologies, and collaborative efforts are vital for scaling up efficient and sustainable food production practices. The path forward lies in investing in research, fostering partnerships, and empowering consumers to become active participants in shaping a healthier and more resilient food system. Remember to further tailor this text based on your specific research findings and chosen research papers. Emphasize concrete examples and data from your research to support your arguments and provide a compelling narrative about the future of food science.

Regulations & Latest Best Practices Shape Traceability for Food Safety: Government policies and regulations are setting the foundation for mandatory traceability in key sectors like meat, seafood, and produce. The increasing adoption of global standards like GS1 barcodes and harmonized data formats helps streamline information exchange across borders. (Discussed in [S12], [S22]).Regulatory pressure encourages the adoption of technologies like blockchain and AI-powered traceability platforms, creating a digital audit trail and ensuring compliance with food safety regulations. (Discussed in [S27], [S15], [S25])

And the best practices like ,Open-source platforms like FarmOS[S12] and OpenTrace offer[S22] cost- effective[S27] and customizable solutions[S15] for farms and small businesses to implement basic traceability in ;S25]. (Discussed in [S12], [S22], [S27], [S15], [S25]). Standardized data formats and protocols facilitate seamless data exchange across the supply chain, improving collaboration and information accuracy. (Discussed in [S3], [S13]). Consumer engagement through interactive platforms and educational campaigns promotes transparency and empowers consumers to make informed choices about food safety. (Discussed in [S17], [S25]) and prevents problems before they occur. (Discussed in [S20], [S24] Image Recognition AI algorithms can analyse images of food products to detect contamination explain in [S26], spoilage [S9], and even foreign objects. This can be applied during harvest, processing, and even at retail stores, ensuring only the highest quality products reach consumers. (Discussed in [S17], [S9], [S26]). Personalized Food Safety AI explained in [S23] can learn individual preferences and consumption patterns, providing personalized recommendations for safe food handling and storage. Imagine smart refrigerators suggesting optimal storage conditions based on the food you just bought! (Discussed in [S23]).

Computer vision and AI are revolutionizing food safety by analysing images and sensor data to detect contamination [S17], predict spoilage[S9], and optimize quality control measures [26]. (Discussed in [S17], [S9], [S26]). Augmented reality (AR) and mixed reality (MR) are offering innovative ways to visualize food provenance and provide consumers with real-time information about the food they purchase. (Discussed in [S14], [S18]) and optimize sanitation practices. This proactive approach allows for targeted interventions

Conclusion: As we stand at the crossroads of a growing population, climate change, and evolving food safety challenges, the future of food demands innovation, collaboration, and a unwavering commitment to safety. This paper has e to fork to AI deciphering the hidden language of food hazards, we are witnessing a revolution in traceability and risk management. Yet, challenges like fragmented regulations, data security concerns, and technological accessibility linger. To overcome these hurdles, fostering global collaboration, investing in capacity building, and prioritizing ethical Development are crucial. Remember, ensuring a safe and sustainable food future is not a solo act, but a collaborative orchestra. By harmonizing the rhythms of innovation, policy, and best practices, we can ensure that every bite tells a story of safety, responsibility, and a nourishing future for generations to come. This one-paragraph conclusion summarizes the key themes of your research paper, highlighting the promise of technology, regulations, and best practices while acknowledging the remaining challenges. Adapt it further with specific details and impactful language from your research to leave a lasting impression on your readers.

REFERENCES

[1] Temilade Abass, Michael Alurame Eruaga, Esther Oleiye Itua, and James Tabat Bature, “ADVANCING FOOD SAFETY THROUGH IOT: REAL-TIME MONITORING AND CONTROL SYSTEMS,” *imsrj*, vol. 4, no. 3, pp. 276–283, Mar. 2024, doi: 10.51594/imsrj.v4i3.919.

[2] M. Dhanaraju, P. Chenniappan, K. Ramalingam, S. Pazhanivelan, and R. Kaliaperumal, “Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture,” *Agriculture*, vol. 12, no. 10, p. 1745, Oct. 2022, doi: 10.3390/agriculture12101745.

[3] M. Ben-Daya, E. Hassini, Z. Bahroun, and B. Banimfreg, “The role of internet of things in food supply chain quality management: A review,” *Quality Management Journal*, vol. 28, pp. 17–40, Jan. 2021, doi: 10.1080/10686967.2020.1838978.

[4] S. Taj, A. S. Imran, Z. Kastrati, S. M. Daudpota, R. A. Memon, and J. Ahmed, “IoT-based supply chain management: A systematic literature review,” *Internet of Things*, vol. 24, p. 100982, Dec. 2023, doi: 10.1016/j.iot.2023.100982.

[5] B. Bigliardi, E. Bottani, and S. Filippelli, “A study on IoT application in the Food Industry using Keywords Analysis,” *Procedia Computer Science*, vol. 200, pp. 1826–1835, Mar. 2022, doi: 10.1016/j.procs.2022.01.383.

[6] M. Raj *et al.*, “A survey on the role of Internet of Things for adopting and promoting Agriculture 4.0,” *Journal of Network and Computer Applications*, vol. 187, p. 103107, Aug. 2021, doi: 10.1016/j.jnca.2021.103107.

[7] A. S. Patel, M. N. Brahmbhatt, A. R. Bariya, J. B. Nayak, and V. K. Singh, “‘Blockchain technology in food safety and traceability concern to livestock products’.,” *Heliyon*, vol. 9, no. 6, p. e16526, Jun. 2023, doi: 10.1016/j.heliyon.2023.e16526.

[8] M. Van Hilten and S. Wolfert, “5G in agri-food - A review on current status, opportunities and challenges,” *Computers and Electronics in Agriculture*, vol. 201, p. 107291, Oct. 2022, doi: 10.1016/j.compag.2022.107291.

[9] M. U. A. Gondal, M. A. Khan, A. Haseeb, H. M. Albarakati, and M. Shabaz, “A secure food supply chain solution: blockchain and IoT-enabled container to enhance the efficiency of shipment for strawberry supply chain,” *Front. Sustain. Food Syst.*, vol. 7, p. 1294829, Nov. 2023, doi: 10.3389/fsufs.2023.1294829.

[10] R. Thangaraj, M. M, M. M, L. A, L. T, and K. P, “A Comparative Study of Deep Learning Models for Guava Leaf Disease Detection,” in *2023 Third International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT)*, 2023, pp. 1–5. doi: 10.1109/ICAECT57570.2023.10117860.

[11] M. G. Kamble, A. Singh, N. Kumar, R. V. Dhenge, M. Rinaldi, and A. V. Chinchkar, “Semi-Empirical Mathematical Modeling, Energy and Exergy Analysis, and Textural Characteristics of Convectively Dried Plantain Banana Slices,” *Foods*, vol. 11, no. 18, Art. no. 18, Jan. 2022, doi: 10.3390/foods11182825.

[12] A. Tyczewska, T. Twardowski, and E. Woźniak-Gientka, “Agricultural biotechnology for sustainable food security,” *Trends Biotechnol*, vol. 41, no. 3, pp. 331–341, Mar. 2023, doi: 10.1016/j.tibtech.2022.12.013.

[13] A. Kamilaris, F. Gao, F. X. Prenafeta-Boldu, and M. I. Ali, “Agri-IoT: A semantic framework for Internet of Things-enabled smart farming applications,” in *2016 IEEE 3rd World Forum*

on Internet of Things (WF-IoT), Dec. 2016, pp. 442–447. doi: 10.1109/WF-IoT.2016.7845467.

[14] W. L. Filho *et al.*, “An overview of the interactions between food production and climate change.,” *Sci Total Environ*, vol. 838, no. Pt 3, p. 156438, Sep. 2022, doi: 10.1016/j.scitotenv.2022.156438.

[15] G. Zhao, H. Chen, S. Liu, D. Dennehy, P. Jones, and C. Lopez, “Analysis of factors affecting cross-boundary knowledge mobilization in agri-food supply chains: An integrated approach,” *Journal of Business Research*, vol. 164, no. C, 2023, Accessed: May 02, 2024. [Online]. Available: https://ideas.repec.org//a/eee/jbrese/v164y2023ics0148296323003648.html

[16] H. Younis and I. Y. Wuni, “Application of industry 4.0 enablers in supply chain management: Scientometric analysis and critical review.,” *Heliyon*, vol. 9, no. 11, p. e21292, Nov. 2023, doi: 10.1016/j.heliyon.2023.e21292.

[17] European Parliament. Directorate General for Parliamentary Research Services., *Artificial intelligence in the agri-food sector: applications, risks and impacts.* LU: Publications Office, 2023. Accessed: May 02, 2024. [Online]. Available: https://data.europa.eu/doi/10.2861/516636

[18] Z. Liu, S. Wang, Y. Zhang, Y. Feng, J. Liu, and H. Zhu, “Artificial Intelligence in Food Safety: A Decade Review and Bibliometric Analysis,” *Foods*, vol. 12, no. 6, p. 1242, Mar. 2023, doi: 10.3390/foods12061242.

[19] I. Mistry, S. Tanwar, S. Tyagi, and N. Kumar, “Blockchain for 5G-Enabled IoT for Industrial Automation: A Systematic Review, Solutions, and Challenges,” *Mechanical Systems and Signal Processing*, vol. 135, Sep. 2019, doi: 10.1016/j.ymssp.2019.106382.

[20] A. Aytekin *et al.*, “Critical Success Factors of Lean Six Sigma to Select the Most Ideal Critical Business Process using q-ROF CRITIC-ARAS Technique: Case study of Food Business,” *Expert Systems with Applications*, vol. 224, p. 120057, Apr. 2023, doi: 10.1016/j.eswa.2023.120057.

[21] A. Donaldson, “Digital from farm to fork: Infrastructures of quality and control in food supply chains,” *Journal of Rural Studies*, vol. 91, Oct. 2021, doi: 10.1016/j.jrurstud.2021.10.004.

[22] O. Okorie, J. Russell, R. Cherrington, O. Fisher, and F. Charnley, “Digital transformation and the circular economy: Creating a competitive advantage from the transition towards Net Zero Manufacturing,” *Resources, Conservation and Recycling*, vol. 189, p. 106756, Feb. 2023, doi: 10.1016/j.resconrec.2022.106756.

[23] A. Gawas, K. Tolia, S. Gaikwad, K. Deshpande, K. Upadhyaya, and S. Jain, “E-fresh : Computer Vision and IOT Framework for Fruit Freshness Detection,” in *2021 International Conference on Advances in Computing, Communication, and Control (ICAC3)*, 2021, pp. 1–6. doi: 10.1109/ICAC353642.2021.9697306.

[24] “(PDF) Emerging trends in the agri-food sector: Digitalisation and shift to plant-based diets,” ResearchGate. Accessed: May 02, 2024. [Online]. Available: https://www.researchgate.net/publication/365425124_Emerging_trends_in_the_agri-food_sector_Digitalisation_and_shift_to_plant-based_diets

[25] M. Javaid, A. Haleem, R. P. Singh, and R. Suman, “Enhancing smart farming through the applications of Agriculture 4.0 technologies,” *International Journal of Intelligent Networks*, vol. 3, pp. 150–164, 2022, doi: 10.1016/j.ijin.2022.09.004.

[26] “(PDF) Exploring blockchain-based Traceability for Food Supply Chain Sustainability: Towards a Better Way of Sustainability Communication with Consumers,” ResearchGate. Accessed: May 02, 2024. [Online]. Available: https://www.researchgate.net/publication/367091948_Exploring_blockchain-based_Traceability_for_Food_Supply_Chain_Sustainability_Towards_a_Better_Way_of_Sustainability_Communication_with_Consumers

[27] E. S. McLamore *et al.*, “FEAST of biosensors: Food, environmental and agricultural sensing technologies (FEAST) in North America.,” *Biosens Bioelectron*, vol. 178, p. 113011, Apr. 2021, doi: 10.1016/j.bios.2021.113011.

[28] G. W. Smithers, “Food Science – Yesterday, Today and Tomorrow,” in *Reference Module in Food Science*, Elsevier, 2018. doi: 10.1016/B978-0-08-100596-5.03337-0.

[29] S. M. Ali, G. Kabir, M. Moktadir, and M. J. U. Rumi, “Framework for Evaluating Risks in Food Supply Chain: Implications in Food Wastage Reduction,” *Journal of Cleaner Production*, vol. 228, Apr. 2019, doi: 10.1016/j.jclepro.2019.04.322.

[30] F. Haque, C. Fan, and Y.-Y. Lee, “From waste to value: Addressing the relevance of waste recovery to agricultural sector in line with circular economy,” *Journal of Cleaner Production*, vol. 415, p. 137873, Aug. 2023, doi: 10.1016/j.jclepro.2023.137873.

[31] J. J. K. Chai, C. O’Sullivan, A. A. Gowen, B. Rooney, and J.-L. Xu, “Augmented/mixed

reality technologies for food: A review," *Trends in Food Science & Technology*, vol. 124, pp. 182–194, Jun. 2022, doi: 10.1016/j.tifs.2022.04.021.

[32] N. K. Singh *et al.*, "Impact of Digital Technologies in Agricultural Extension," *AJAEES*, vol. 41, no. 9, pp. 963–970, Aug. 2023, doi: 10.9734/ajaees/2023/v41i92127.

[33] X. Liu *et al.*, "The impact of urbanization and aging on food security in developing countries: The view from Northwest China," *Journal of Cleaner Production*, vol. 292, p. 126067, Apr. 2021, doi: 10.1016/j.jclepro.2021.126067.