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Reforming Food Security and Safety: The Impact of Emerging Technologies

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ABSTRACT

Introduction: Our daily life is significantly influenced by the technological advancements and the field of food production and safety has been no exception. The integration of new technologies has brought a paradigm shift in how we approach food security and safety. Bibliometric software can help academics, to analyze published results and insights, facilitate debates on hotspots and development trends in the study field, and promote academic collaboration.

Aim of the Study: This article aims to provide a comprehensive bibliometric analysis of the trends in food security and food safety untill 2023. It seeks to identify emergent trends and assess their impact on the industry.

Methodology: The study accessed data from Google Scholar, Web of Science, Scopus, and Dimensions Analytics. Data visualization tools such as VosViewer and CiteSpace were employed to analyze document counts, keywords, research collaborations, disciplines, citations, and top-cited articles.

Results: The analysis revealed that chitosan, phenolic compounds, edible coatings, and polysaccharides are increasingly used to enhance the shelf life of food. The highest number of articles published in 2023, totaling 2,041, focused on chemical spoilage. The study also found that in 2021, approximately 20,350 research and review articles were published on shelf life in food safety and security. In terms of recent trends, there were about 941,000 articles on automation, 3,600 related to nano-fertilizers, and 18,300 on Internet of things (IoT) in 2023. The United States, Italy, and the United Kingdom were identified as active contributors to research in these areas.

Conclusion: The study concludes that technological advancements, particularly in hydroponics, IoT, vertical farming, edible coatings, and nano-fertilizers, are making a significant impact on enhancing food production and safety. However, there is a deficiency in the literature regarding the long-term effects of these technologies on human health and the environment, which warrants further research. The results underscore the importance of technology in advancing food security and safety, suggesting a promising direction for future innovations.

INTRODUCTION

Food safety includes controlling chemical qualities such as allergens, removing dangerous particles, and preventing contamination by bacteria, viruses, and toxins. It entails handling, preparing, and storing food in a way that minimizes the risk of disease and harm. Food security guarantees that everyone always has access to enough, healthy, and safe food on a physical, social, and economic level. It covers things like food supply stability, availability, and accessibility. Food security and safety are closely related to sustainable agriculture (Bhagwat; Pakdel et al., 2023). In recent years, growing attention has been paid to leveraging technology to enhance food production, reduce post-harvest losses, improve food quality, and mitigate the risks of foodborne illnesses. These technological trends are reshaping the agriculture and food industry, ensuring

a more stable and sustainable food supply for the world's expanding population (Chen et al., 2024; Kyaw et al., 2024).

The production of food is one of the main areas that influenced by emerging technology. The rising need for food cannot be satisfied by traditional agricultural methods alone, as the world's population is expected to exceed 9.7 billion by 2050 (Dissanayake et al., 2024). As a result, innovative approaches such as precision agriculture, vertical farming, and hydroponics are gaining traction. Precision agriculture utilizes technologies like GPS, sensors, and drones to optimize farming practices, enabling farmers to monitor crop health, apply targeted interventions, and maximize yields while minimizing resource inputs (Jeffrey and Bommu, 2024).

Edible coatings have appeared as an auspicious key to enhance food preservation and reduce waste. These coatings, made from natural materials, provide a protective layer that prolongs fruits and vegetables shelf life, ensuring their quality and freshness for a longer duration (Nunes et al., 2023). The monitoring and management of crops by farmers has been completely transformed by the use of IoT sensors in agriculture. These sensors gather real-time data on various parameters, such as temperature, moisture levels, and nutrient content. With this information, farmers are able to minimize risks, use resources optimally, and make data-driven decisions (Alahmad et al., 2023). The use of nano fertilizers has gained considerable attention as they deliver nutrients to plants more efficiently; leading to improved crop yields and reduced environmental impacts. These nanoparticles allow for targeted nutrient delivery, ensuring that plants receive the required nutrition in a more sustainable manner (Yedoti et al., 2024). Vertical farming and hydroponics are innovative approaches that maximize space utilization and save water resources. By growing crops vertically and without soil, these methods overcome traditional farming limitations and create opportunities for year-round cultivation in urban areas (Świąder et al., 2023). The controlled environments enable optimal growth conditions and significantly reduce the need for pesticides, ultimately promoting sustainable agriculture. Automation, another key trend, that transforming agricultural practices by reducing manual labor and enhancing overall efficiency. Crop monitoring, harvesting, and planting are among the jobs that are increasingly being performed by robotic systems. This automation not only improves productivity but also addresses labor shortages and reduces costs in the long run (Al Bashar et al., 2024).

Vertical farming, on the other hand, involves cultivating crops in vertically stacked layers, often in urban environments. Sated method reduces the need for vast expanses of farmland and allows year-round production with controlled conditions, leading to higher productivity and reducing the environmental impact. Hydroponics, a soilless cultivation method, further optimizes resource utilization by providing plants with nutrient-rich water solutions, resulting in faster growth and higher yields (Nirmal and Ahmad, 2024).Another critical aspect of technological trends in the food industry is the reduction of post-harvest losses. The Food and Agriculture Organization (FAO) estimates that every year, almost one-third of the food produced worldwide is lost or wasted (Vesković Moračanin et al., 2023). Technology offers innovative solutions to address this issue. For instance, IoT-enabled sensors and monitoring systems are being used to track and maintain optimal storage conditions for perishable goods. Real-time data on temperature, humidity, and other environmental factors helps prevent spoilage and extends shelf life (Gillespie et al., 2023).

Furthermore, advancements in packaging technologies, like modified atmosphere packaging and smart packaging, help preserve the freshness and quality of food products. These technologies create a protective environment, reducing oxygen levels and controlling moisture, thereby slowing down the deterioration process (Thirupathi Vasuki et al., 2023). Additionally, cold chain management systems ensure that temperature-sensitive products, like vaccines and fresh goods are moved and kept in storage at the proper temperatures to preserve their quality and security (Pajic et al., 2024; Pedro et al., 2023).

Improving food quality is crucial characteristic of technological trends in the food industry. Customers are gradually concerned about the nutritional value, safety, and authenticity of the food they consume. Technology plays a vital role in food security and food safety (Oriekhoe et al., 2024; Skawińska and Zalewski, 2023). We can protect our long-term health by implementing sustainable agriculture techniques. This ensures a consistent and dependable food supply in addition to aiding in the production of safe, high-quality meals.

MATERIALS AND METHODS

Bibliometric analysis was performed on technological trends of food security and food safety from 1970-2023, focusing on the impact of emerging technologies. Key academic databases such as Web of Science, Scopus & PubMed, and Google Scholar, were used for retrieving scholarly articles related to food security, food safety, and emerging technologies. Search were made from January 1970 to December 2023 on 2nd January 2024 from Web of Science, Scopus & PubMed and 5th January 2024 from and Google Scholar.

Key Technological Themes

To find the main technological themes in the chosen articles on food security and food safety technologies, text mining techniques including topic modelling and keyword analysis were used. By examining the articles' content, these methods assisted in identifying trends and topics in the study. By identifying patterns of co-occurring terms that reflect themes in the research, topic modelling identified abstract subjects or themes from the collection of documents. To find often discussed subjects, innovations, or patterns in the study of food security and safety, keyword analysis looked at the keywords used in the publications. Specific terms like "shelf life", "chitosan", and others were selected for an additional bibliometric search due to their relevance to enhancing food security and safety through technological means. These terms refer to particular technologies or elements that are essential to the study of food security and safety, like the use of chitosan in edible coatings or the emphasis on shelf life

extension. The results highlight technological concepts that are especially relevant to current research trends in food security and safety by concentrating on extra phrases. This aids in identifying particular technological themes, such as improving shelf life or employing chitosan for food safety are receiving focus in food security and safety research, as well as which technologies, such as edible coatings, nanotechnology, or IOT are prominent.

Search Queries

A comprehensive set of search queries using keywords related to food security and food safety and emergent technologies terms as food security & edible coating, food security & chitosan, food security & nano-fertilizer, food security & phenolic compounds, fruits and vegetables & physical spoilage, fruits and vegetables & microbial spoilage, fruits and vegetables & chemical spoilage and food security & shelf life, automaton, IoT, vertical farming, and hydroponics were developed and implied. Search included synonyms and alternative terms to ensure comprehensive coverage. Boolean operators (AND, OR) as ("food security" OR "food safety") AND ("edible coating" OR "chitosan" OR "nano-fertilizer") were used to combine different keywords effectively.

Retrieving Articles

Executed the search queries in the selected databases and retrieved the relevant articles within the specified time range (1970-2023). Exported the search results into a reference management software EndNote for easier organization and analysis.

Data Cleaning and Preprocessing

Dataset were cleaned by removing duplicates, irrelevant articles, and non-peer-reviewed sources. Excluded articles that do not focus on technological trends, food security, or food safety. Representability and reliability of datasets was ensured.

Bibliographic Information

It was feasible to discover influential authors and journals that are regularly mentioned, demonstrating their significance in the field, as well as influential papers with high citation counts, indicating significant impact, by looking at the citation patterns. Co-authorship analysis uncovered collaboration networks that highlighted important research teams or organizations at the forefront of food security and safety technology development. The results of this analysis helped chart the field's evolution by offering insights into trends and identifying research leaders, or the prolific writers and organizations advancing food security and food safety technology.

Publication Trends

The growth rate, hotspots, and new study areas in the field of food security and food safety technologies from 1970 to 2023 were determined by looking at publication trends throughout time. Understanding the evolution of research output in this field was the goal of this analysis. It is feasible to determine whether interest in particular areas within food security and safety technology is growing or declining by examining the growth rate of publications. Research hotspots are regions that have attracted a lot of interest and activity. New research directions show the direction of technical advancements in the sector. To have a better understanding of the development of these technical trends in food security and safety, the data was visualised using VosViewer and graphs or charts were created.

RESULTS

In searching for articles, the key words used in general were related to “food safety, food security and emergent technologies”. After making a thorough study and analysis of articles from 1970 to 2023, following terms were selected for more bibliometric search; “shelf life”, “chitosan”, “phenolic compounds”, “biological spoilage”, “chemical spoilage”, “physical spoilage”, “edible coatings”, hydroponics, “Internet of things (IoT)”, “automation”, “vertical farming”, and “nano-fertilizers”.

Food Safety and Food Security

The search using the keywords shelf life, chitosan, phenolic compounds, biological spoilage, chemical spoilage, physical spoilage and edible coatings resulted in Google scholar were 20350 research and review articles in 2021. Articles analysis also shows that highest number of articles in 2023 is reported on chemical spoilage. Figure 1 represents overall articles count and research trend related to food safety and food security from 1970 to 2023. The number of articles published on these topics has generally increased over the years, with noticeable spikes in certain periods. The graph differentiates between various key terms such as “food safety & shelf life,” “food Security & edible coatings,” and “food safety and spoilage,” among others. The colored bars and lines indicate trends and comparisons over time, showing how interest in different aspects of food safety and security has evolved.

Keyword Co-Occurrence

Food safety and food security co-occurrence of words observed is illustrated in Figure 2, Network visualization map created by VOSviewer, highlights the co-occurrence of keywords in articles related to food safety and food security. The study reveals two main clusters: "food security" and "food safety." The terms "contamination," "heavy metals," "mycotoxins," and "salmonella" are frequently used in relation to food safety, suggesting a high emphasis on problems pertaining to both public health and food contamination. Key words for food security, such "nutrition policy," "agriculture," "climate change," and "COVID-19," imply a general concern in the environmental and socioeconomic elements influencing food access and availability. Strong linkages or common topics of research within this discipline are shown by the density of connections between specific phrases. Notably, the cluster centered on public health concerns such as "COVID-19" draws attention to current research patterns and the pandemic's effects on food security.

Documents by Country Collaboration- Co Authorship Relation

The network visualization shows the documents weights and countries fractionalization map. The network’s complexity, with many interconnections, highlights the global nature of research in food safety and food security. Bibliometric network visualization uses colored dots to

represent different countries, with the size of each dot indicating the volume of publications or the degree of collaboration. Lines connecting the dots show the collaborative relationships between countries. Countries collaborate worldwide to address food security and safety challenges, as shown by the visualisation of country cooperation in food security and safety research. With a total link strength of 1970, there is a noticeable degree of cooperation. Eight groups based on network visualisation and document weighting are formed by co-authorship relationships among 71 countries. For example, Cluster 01 contains 18 goods from nations including Denmark, France, and Malaysia. Among the 14 entries in Cluster 02 are Brazil, Mexico, and Spain. With 11 articles, Cluster 03 features partnerships with nations like Germany, Poland, and the United Kingdom. This graphic aids in recognising important participants and comprehending the state of global partnerships in tackling concerns related to food security and safety.

Cluster 04 has six items of international collaborations, including those with Singapore, Australia, and New Zealand. While clusters 07 and 08 each comprise partnerships among five countries, clusters 05 and 06 each have six elements. Notably, the larger dots in this network of collaboration represent the centrality of China and the United States. This implies that they collaborate widely in this sector and produce a large number of publications. Though not as much as China and the United States, other nations including Brazil, Spain, Italy, and India also exhibit a noteworthy degree of engagement and cooperation (Figure 3a).

Searching “food security shelf-life edible coating chitosan phenolic compound biological spoilage" "chemical spoilage" physical spoilage" from google scholar a total 26 research items came into search, whereas search results extended to 37 for including search item “include citations”. Among these 7 search results were review articles and other were research articles. Top 10 articles details are provided in Table 1.

Figure 3b denotes the bibliometric analysis of publication output on food safety and food security. Leading institutes such as the Agricultural Research Service, Chinese Academy of Sciences, and the United States Department of Agriculture are prominent contributors in this field, indicating their significant research efforts. The analysis underscores a strong focus on food safety and food security, highlighting these topics as critical areas of research. The document count on the x-axis provides an idea of the relative contribution of each institute. Additionally, the presence of multiple institutes from different countries suggests collaborative international effort to address issues related to food safety and food security.

Food Security and Nano-Fertilizers

Highest number of documents on nano-fertilizer for food security were published in 2021, with the highest number of books in the field of agriculture, biology, agronomy, engineering, biotechnology and other fields. Chinese academy of sciences published more articles on food security and nano-fertilizers with highest number published by Elsevier as shown in Figure 4a. The bar chart (a) shows the documents count per year for publications on nano-fertilizers from 2000 to 2024, there is a noticeable increase in the number of publications over the years, especially after 2010. This indicates a growing interest and research activity in the field of nano-fertilizers. The number of publications has been particularly high in the last few years, peaking around 2020-2022. This could be due to increased funding, technological advancements, or heightened awareness of the benefits of nano-fertilizers. It was concluded that the expanding research landscape in nano-fertilizers, with a diverse range of document types of conference proceedings, journal articles, books and book chapters and preprints and reports contributing to the field.

Data retrieved from dimensions on 2nd January 2025 provided an overview of the interdisciplinary nature of research on nano-fertilizers. Agriculture leads with the highest number of publications (591), indicating a strong focus on improving agricultural productivity and sustainability through nano-fertilizers. Materials Science, with 84 publications, explores the development and characterization of nanomaterials used in fertilizers, emphasizing the importance of material properties in enhancing efficiency. Environmental Science, with 76 publications, reflects interest in understanding the environmental impacts and benefits of nano-fertilizers, such as reduced pollution and improved soil health. Chemistry, with 59 publications, focuses on the chemical properties and reactions of nano-fertilizers, including their synthesis and interaction with plants and soil. Biology, also with 84 publications, examines the biological effects of nano-fertilizers on plant growth and development, as well as potential toxicity. Other disciplines like Ecology, Engineering, and Biotechnology contribute unique perspectives, highlighting the collaborative effort across various scientific fields to advance the understanding and application of nano-fertilizers for more sustainable and efficient agricultural practices.

The bibliometric analysis of publications on nano-fertilizers by various research institutes represented in Figure 4b reveals several key insights. The leading contributors in this field, with institutes are Chinese Academy of Sciences, University of Massachusetts Amherst, and Imperial College London showing significant publication outputs. It indicates a strong research focus on nano-fertilizers across these institutes, suggesting that this is a critical area of study. The document count on the x-axis provides an idea of the volume of research publications, although specific numbers are not visible. This helps in understanding the relative contribution of each institute. Additionally, the presence of multiple institutes from different regions or countries suggests a collaborative international effort in advancing research on nano-fertilizers.

Analysis of articles by journals revealed that Elsevier is the leading publisher with the highest number of publications, approximately 45 documents. Other publishers have significantly fewer publications, with the second highest publisher having around 20 documents. Elsevier is the most prolific publisher in the field of nano-fertilizers, making it a key source for research in this area. The

dominance of Elsevier suggests that researchers looking for comprehensive information on nano-fertilizers might find the most relevant and numerous studies published by this publisher.

Food Security and Phenolic Compounds

Phenolic compounds have garnered significant attention in recent years due to their potential to enhance food security by improving crop resilience and productivity. Analytics for phenolic compounds trend in these years shown that scholarly works is consisting of 1365 articles, patents citations 97 and scholarly citations 29384 Figure 5 includes the number of documents from each journal, it identifies top journals such as Environmental Science and Technology, Food Chemistry, Journal of Agricultural and Food Chemistry and 'Comprehensive Reviews in Food Science and Food Safety' having the highest document counts.

Food Security and Shelf life

Figure 6a displays a bar chart illustrating the publication output performance of dimensions' analytics, in the shelf-life research category across various scientific disciplines. The vertical axis lists categories such as Chemical Sciences, Economics, Earth Sciences, Health Sciences, Engineering, Biological Sciences, and Agricultural, Veterinary Sciences. The horizontal axis measures the number of publications, ranging from 0 to 20,000. A rapid increase in research interest towards shelf-life in food safety has been observed.

From the chart, it is evident that certain categories, such as Agricultural, Veterinary Sciences, Biomedical and Health Sciences and Biological Sciences, have higher publication outputs compared to others. This suggests a significant research focus and activity in these areas related to shelf life. Interpreting this bibliometric data involves recognizing the trends and distribution of research efforts across different disciplines. The higher publication counts in specific categories may indicate greater interest, funding, or advancements in those fields. Figure 6b presents a line graph depicting the publication output performance related to shelf life over the years.

The results indicate a growing trend in research activity in the field of shelf life. There was a relatively flat trend in publications until around the year 2000, after which there was a significant increase. This trend peaks near or slightly after 2023 with just under 9000 publications. The sharp rise in recent years suggests a growing research interest and activity in the field of shelf life. It indicates advancements in technology, increased funding, or heightened awareness of the importance of shelf life in food security and safety.

Publication Trends

After making a detailed review of articles on food safety and food security the identified emergent trends are hydroponics, internet of things (IoT), vertical farming, edible coatings and nano-fertilizers. Among these, automation is at top as represented in Figure 7. Top cited articles of dimensions clarivate on "food safety, food security, IoT, automation, nano-fertilizer, vertical farming, and hydroponics are presented in Table 2.

Internet of Things (IoT)

IoT technology like Radio Frequency Identification (RFID) tags, sensors and linked devices offer real-time visibility that provides precise and contemporary information of location, state, humidity, temperature, gas concentrations, and state of the food inventory items. As per google scholar record about 18,300 articles on IoT sensors from 1970 to 2023 are present, among these 18,200 articles are from 2000-2023, whereas about 83, 60 articles are by year 2023.

The number of publications on the IoT across various journals over a specific period were retrieved from Dimensions. Journal IEEE stands out with a significantly higher number of publications compared to others, indicating it is a leading source for IoT research. This suggests that "IEEE Access" is a primary platform for disseminating IoT-related studies, reflecting its prominence and influence in the field. Other journals like "Sensors" and "Sustainability" also show notable publication outputs but are considerably lower than the IEEE journal. This distribution highlights the primary journals contributing to IoT research, providing insights into where most academic work on IoT is being published. Figure 8 illustrates an increasing interest and research activity in the field of IoT from 2014 to 2018, suggesting a steady increase in publications during these years. The publications were highest in the period from 2020 afterwards, indicating a significant surge in IoT research publications. This could be due to advancements in technology, increased funding, and growing applications of IoT in various industries. The size of the bubbles in the years 2020 and beyond suggests that these years have the highest number of publications. This peak could be attributed to the maturation of IoT technologies and their widespread adoption

Figure 9 illustrating the network of authors helps identify key contributors and collaborations, providing insights into the structure and dynamics of the scientific community in food safety and food security from 2000 to 2023. Each author's name is surrounded by a colored halo, indicating their involvement and collaboration within this research area. The different colors likely represent clusters or groups of authors who have worked together or on related topics. The size of the text for each author's name may correspond to their level of contribution or number of publications in this field. It highlights the interconnectedness of researchers and can be useful for identifying potential collaborators, understanding research trends, and recognizing influential authors in this domain.

Hydroponics

Although initial setup costs can be higher compared to traditional farming methods, hydroponics can provide a consistent income stream due to higher crop yields and premium prices for fresh, locally produced vegetables. Additionally, the capacity to grow food closer to metropolitan areas lowers the transportation expenses and carbon emissions that come with distributing food across great distances. A total 17,500 articles on hydroponics from 1970 to 2023 are present, among these 16,500 articles are from 2000-2023, whereas about 2,780 articles are by year 2023. Publications years and research

category data for hydroponics and food security retrieved from Dimensions is represented in Figure10a line graph illustrating the publication output performance in hydroponics, the x-axis represents the years, while the y-axis shows the number of publications. The graph starts with zero publications in 1975 and remains relatively flat until around 2009, where a slight increase is observed.

A significant spike occurs after 2011, peaking at nearly 90 publications around 2021, followed by a sharp decline closer to the present day. This data indicates a growing research interest in hydroponics within the context of food safety and security, particularly in the last decade.

The peak around 2021 suggests a heightened focus on this area, possibly due to advancements in technology. The subsequent decline might reflect a shift in research priorities or the saturation of certain research topics within this field.

Figure 10b presents the publication output performance in hydroponics across various fields of research. The field of Agricultural, Veterinary, and Food Sciences has the highest number of publications, with over 190 publications. This implies that research on food security and safety technologies is heavily focused on this sector. The high volume of papers in this area suggests that there is a lot of research being done on using technology from the food, veterinary, and agricultural sciences to improve food safety and security. This is followed by Psychology with 52 publications, Physical Sciences with 51, and Mathematical Sciences with 49. Other notable fields include Law and Legal Studies (48), Philosophy and Religious Studies (47), and Language, Communication, and Culture (50). Fields such as Education (39), Health Sciences (42), and Commerce, Management, Tourism, and Services (35) also show significant publication activity. Built Environment and Design (33), Biological Sciences (31), and Earth Sciences (37) have moderate publication outputs. Engineering (46), Information and Computing Sciences (40), and Environmental Sciences (41) also contribute substantially to hydroponics research. This data highlights the interdisciplinary nature of hydroponics research, the diverse research output indicates a broad interest and application of hydroponics in addressing food safety and food security challenges.

Vertical Farming

Vertical farming involves cultivating crops in vertically stacked layers, often in urban environments. This approach reduces the need for vast expanses of farmland and allows year-round production with controlled conditions, leading to higher productivity and reducing the environmental impact. Among 21,900 about 17,800 articles on vertical farming from 1970 to 2023 are present, among these 17,800 articles are from 2000-2023, whereas about 17,500 articles are by year 2023. Publication output performance in vertical farming by journal category and by year from dimensions is presented in Figure11. Vertical farming reveals that the majority of publications or citations are concentrated in the field of agriculture. Horticulture also shows significant activity, reflecting the importance of plant cultivation techniques. Environmental science has a notable presence, highlighting the focus on sustainability and environmental impacts.

During the early years (1990-2000), research activity was relatively low in vertical farming. However, there was a noticeable increase around 2008, indicating growing interest in vertical farming. A surge in research, possibly due to increased awareness of sustainable farming.

Table 1

Top 10 Google Scholar Articles on "Food Security Shelf-Life Edible Coating Chitosan Phenolic Compound Biological Spoilage" "Chemical Spoilage" Physical Spoilage"

Sr. No.	Title	Year	Publisher/Journal	Authors
1	Chitosan-Based Materials as Edible Coating of Cheese: A Review	2021	Wiley Online Library/ Starch	Muhammad Waheed Iqbal, Tahreem Riaz, Iqra Yasmin, Ali Ahmad Leghari, Sabahat Amin, Muhammad Bilal, Xianghui Qi (Iqbal et al., 2021)
2	Novel Prosopis juliflora leaf ethanolic extract coating for extending postharvest shelf-life of strawberries	2022	Elsevier/Food Control	Iman Saleh, Mohammed Abu-Dieyeh (Saleh and Abu-Dieyeh, 2022)
3	The challenge of exploiting polyphenols from olive leaves: addition to foods to improve their shelf-life and nutritional value	2021	Wiley Online Library/Journal of Science food and Agriculture	Graziana Difonzo, Giacomo Squeo, Antonella Pasqualone, Carmine Summo, Vito M Paradiso, Francesco Caponio (Difonzo et al., 2021)
4	A Review on Edible Film and Coating Applications for Fresh and Dried Fruits and Vegetables	2021	BSEU Journal of Science	Taze ve Kuru Meyve ve Sebzelerde Yenilebilir Film ve Kaplama Uygulamaları (Tufan et al., 2021)
5	Recent innovations in bio nanocomposites-based food packaging films – A comprehensive review	2022	Elsevier/Food Packaging and Shelf Life	Aswathy Jayakumar a, Sabarish Radoor a, Jun Tae Kim b, JongWhan Rhim b, Debabrata Nandi a, Jyoti shkumar Parameswaranpillai c, Suchart Siengchin a (Jayakumar et al., 2022)
6	A Comprehensive Review on Bio-Preservation of Bread: An Approach to Adopt Wholesome Strategies	2022	MDPI/Foods	Rahman, M.; Islam, R.; Hasan, S.; Zzaman, W.; Rana, M.R.; Ahmed, S.; Roy, M.; Sayem, A.; Matin, A.; Raposo, A.; Zandonadi, R.P.; Botelho, R.B.A.; Sunny, A.R. (Rahman et al., 2022)
7	Biodegradable packaging and edible coating for fresh-cut fruits and vegetables	2015	Italian journal of food Science	Fernanda Galgano (Galgano, 2015)
8	Silk for post-harvest horticultural produce safety and quality control	2023	Journal of Food engineering	Tracey, Chantal T., Anastasia V. Kryuchkova, Takshma K. Bhatt, Pavel V. Krivoshapkin, and Elena F. Krivoshapkina (Tracey et al., 2023)

9	Evaluation of the effect of corn starch film composed of Ag-TiO_2 nanocomposites and Satureja khuzestanica essential oil on the shelf-life of chicken fillet	2022	Food and Health Journal	Sallak, Neda, Abbasali Motallebi Moghanjoughi, Maryam Ataee, Seyed Amir Ali Anvar, and Leila Golestan (Sallak et al., 2022)
10	Evaluation of microbial and physicochemical properties of mayonnaise containing zinc oxide nanoparticles	2022	LWT	Hakimian, Faezeh, Aryou Emamifar, and Mostafa Karami (Hakimian et al., 2022)

Table 2

Top Cited Articles of Dimensions Clarivate on "Food Safety, Food Security, IOT, Automation, Nano-Fertilizer, Vertical Farming, and Hydroponics"

Sr. No.	Title	Year	Citations	DOI
1	Microgreens for Home, Commercial, and Space Farming: A Comprehensive Update of the Most Recent Developments	2023	16	10.1146/annurev-food-060721-024636 (Teng et al., 2023)
2	Novel Materials for Urban Farming	2022	27	10.1002/adma.202105009 (Xi et al., 2022)
3	Application of digital technologies for ensuring agricultural productivity	2023	0	10.1016/j.heliyon.2023.e22601 (Abiri et al., 2023)
4	Resource recovery from hydroponic wastewaters using microalgae-based biorefineries: A circular bioeconomy perspective	2022	10	10.1016/j.jbiotec.2022.10.011 (Ajeng et al., 2022)
5	Hydroponic Solutions for Soilless Production Systems: Issues and Opportunities in a Smart Agriculture Perspective	2019	123	10.3389/fpls.2019.00923 (Sambo et al., 2019)
6	Developing a Modern Greenhouse Scientific Research Facility—A Case Study	2021	8	10.3390/s21082575 (Cafuta et al., 2021)
7	IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation in Precision Agriculture	2020	219	10.3390/s20041042 (García et al., 2020)
8	Species-independent analytical tools for next-generation agriculture	2020	50	10.1038/s41477-020-00808-7 (Lew et al., 2020)
9	IUNS 22nd International Congress of Nutrition – Abstracts	2023	0	10.1159/000530786 (Kato et al., 2023)
10	The Skyscraper Crop Factory: A Potential Crop-Production System to Meet Rising Urban Food Demand	2023	0	10.1016/j.eng.2023.08.014 (Zhang et al., 2023)

Figure 1

Bibliometrics of Food Safety and Food Security Key Terms from 1970 to 2023

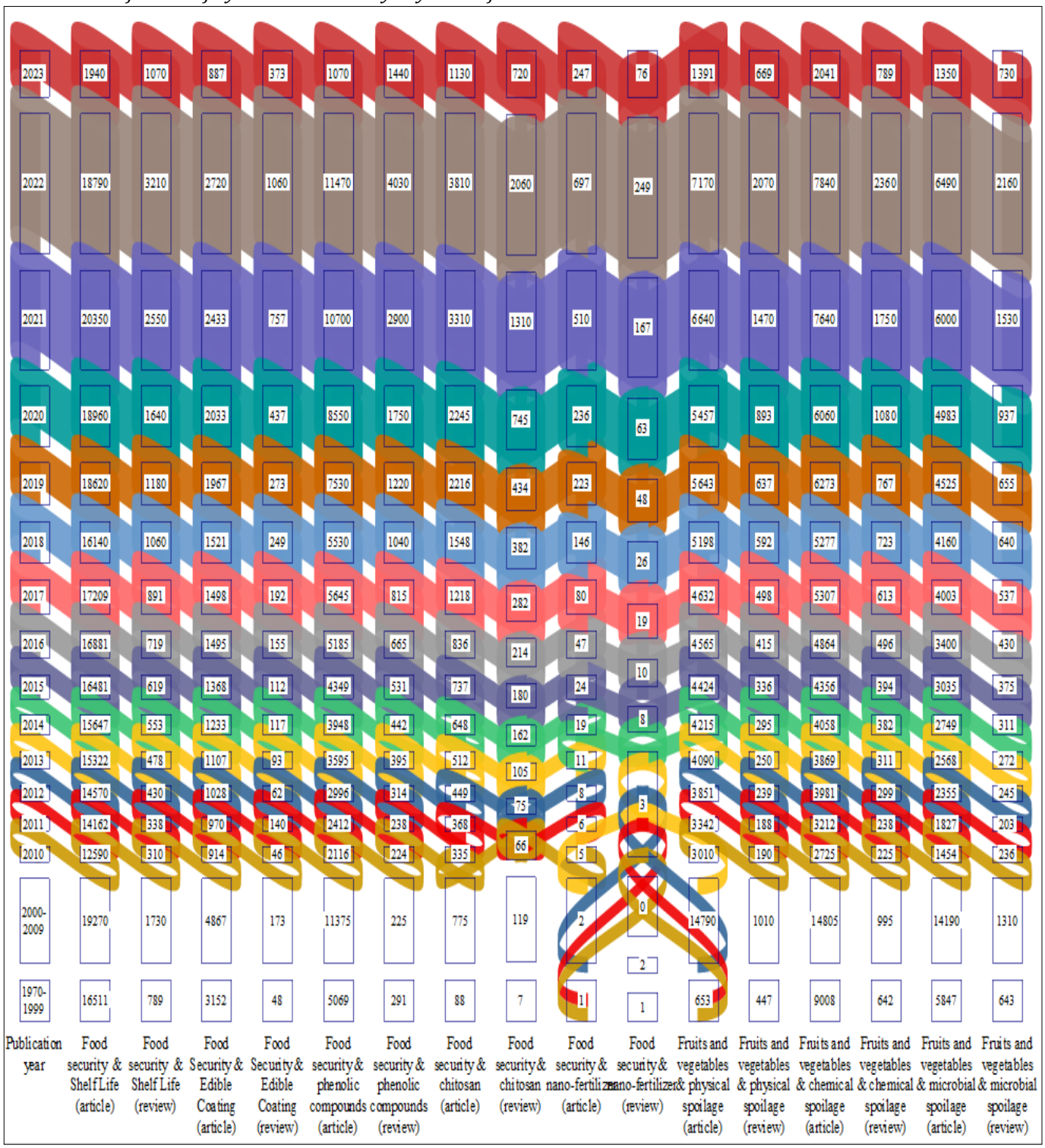


Figure 2
Key words co- occurrence analysis of food safety and food security articles via VOSviewer

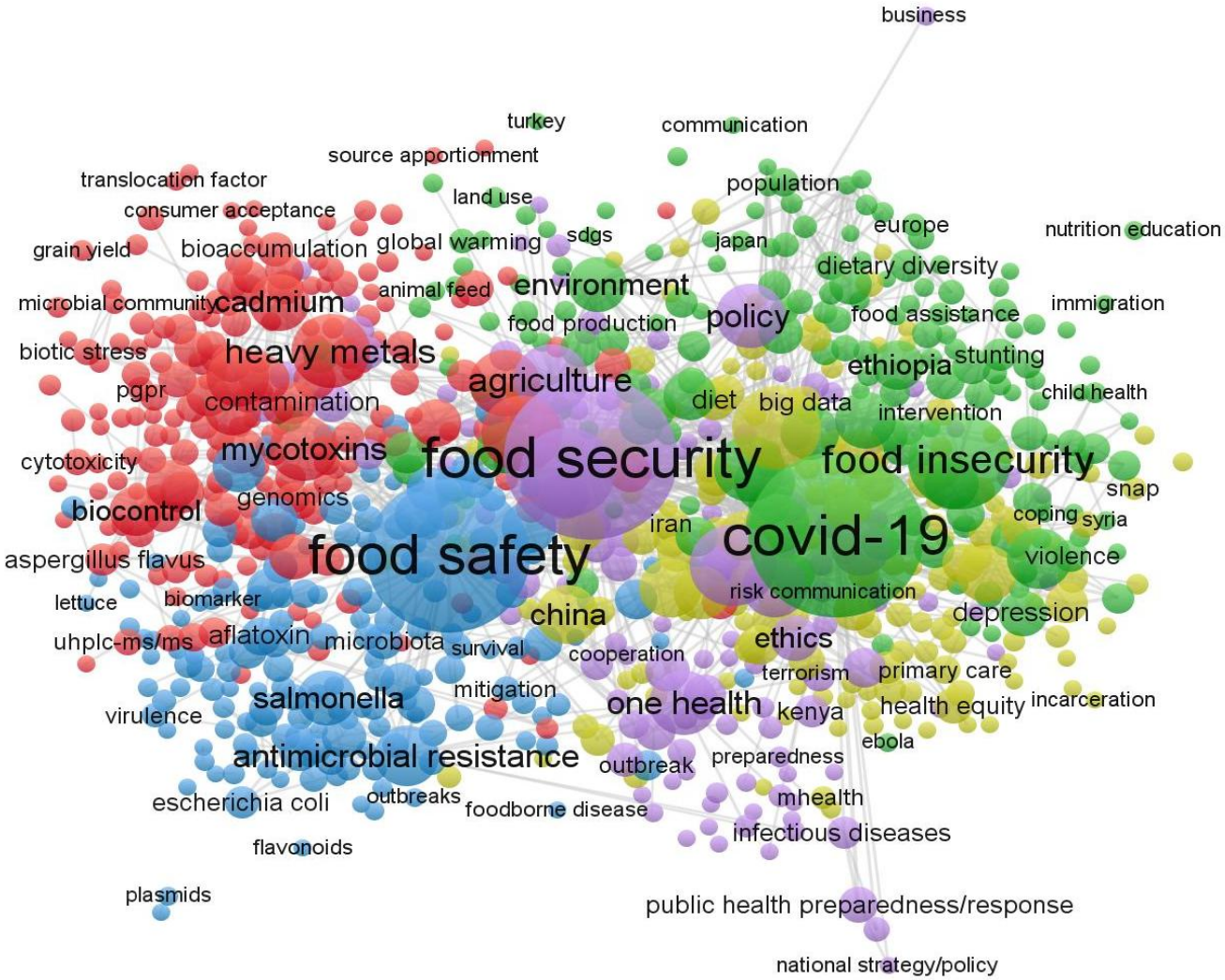
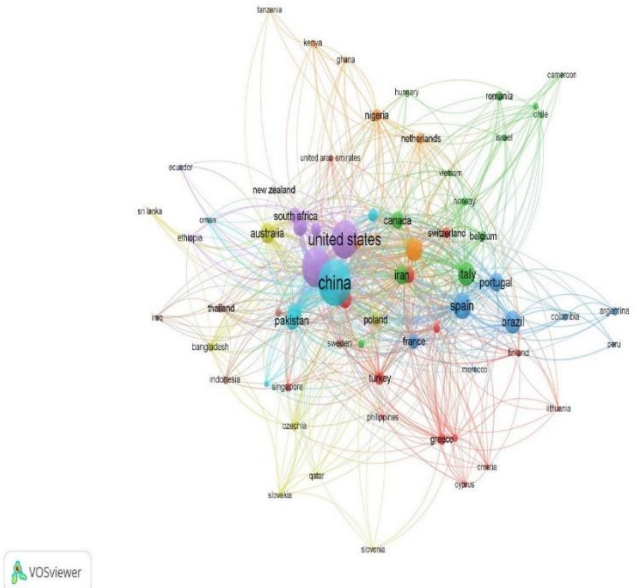


Figure 3
Publication Output of Food Safety and Food Security by (a) Country Collaboration (b) Institutes

a)



b)

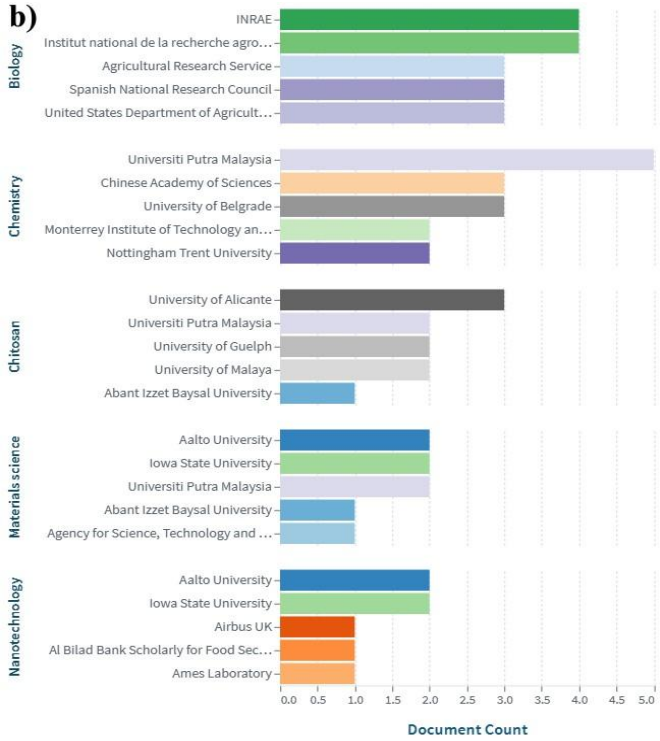


Figure 4

Publications on Nano-Fertilizers by (a) Document Count Per Year (b) by Publishers

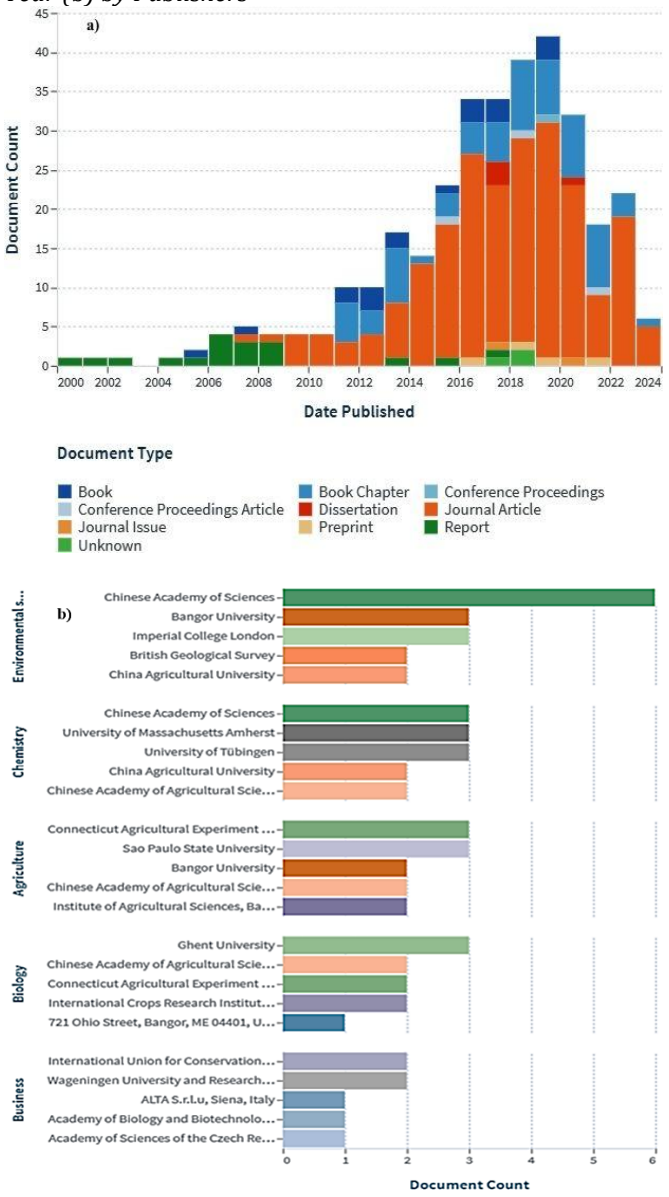


Figure 5

Publication Output of Phenolic Compounds by Journal Category.

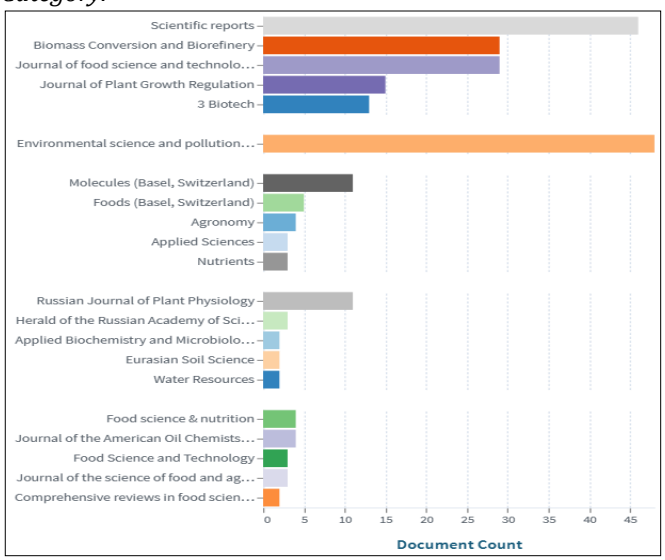


Figure 6

Publication Output Performance of Shelf Life by (a) Research Category (b) Year

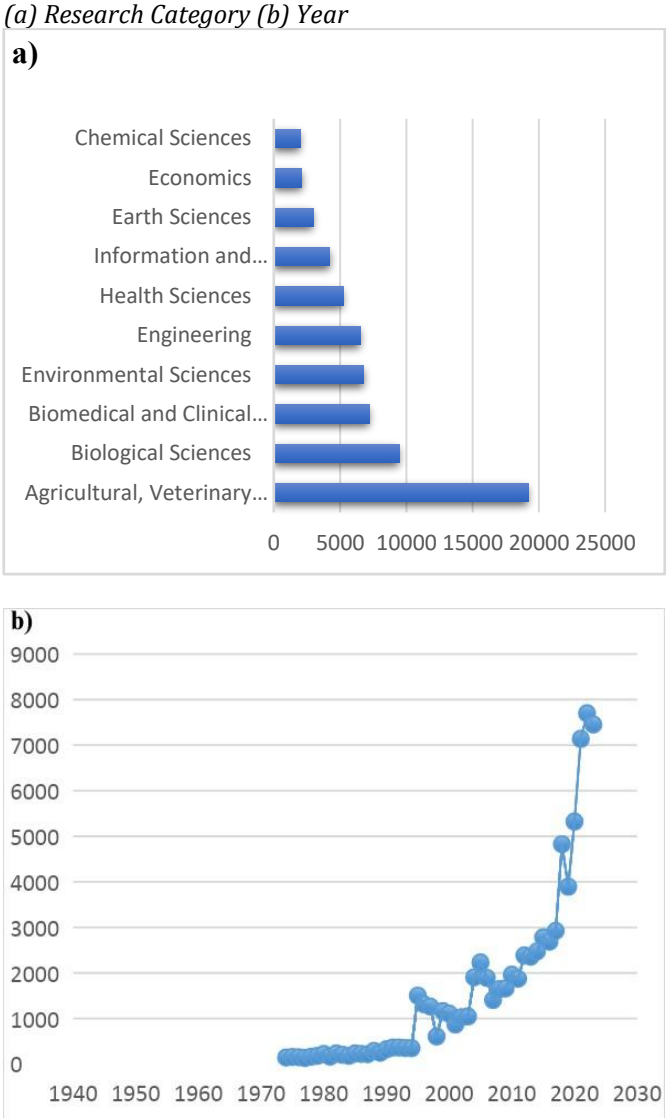


Figure 7

Advanced Technological Trend for Food Safety and Food Security

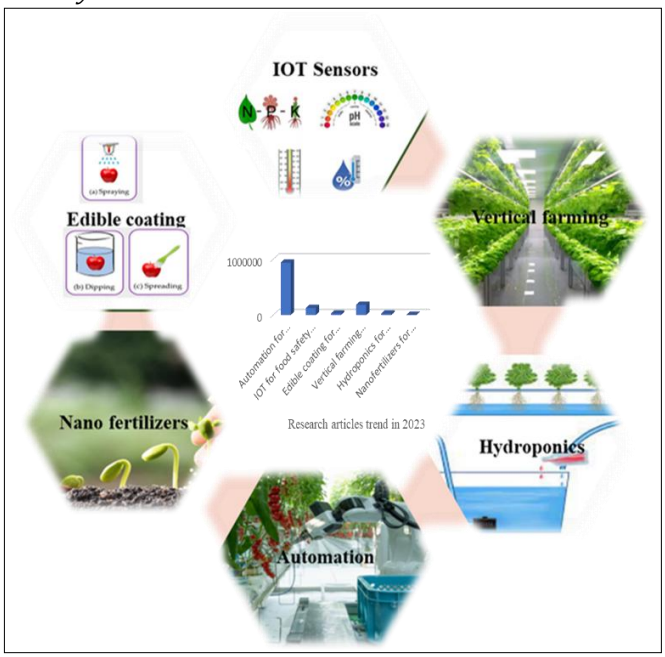


Figure 8
Publication Output Performance in IOT by Year

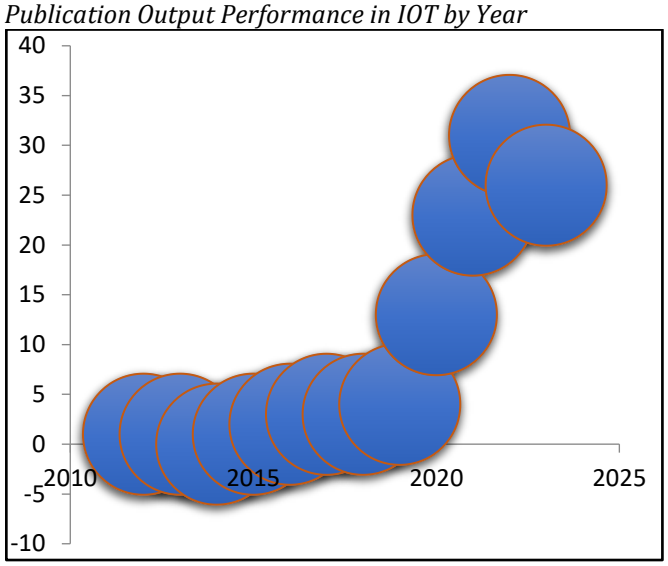


Figure 9
The Network of the Authors in Food Safety and Food Security from 2000-2023

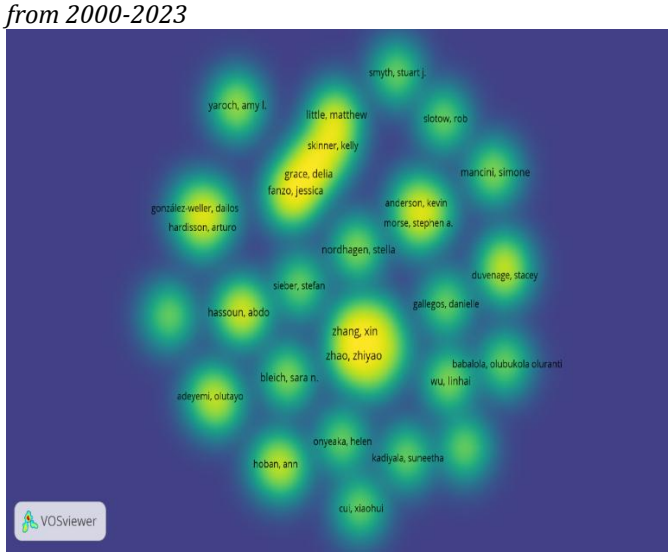
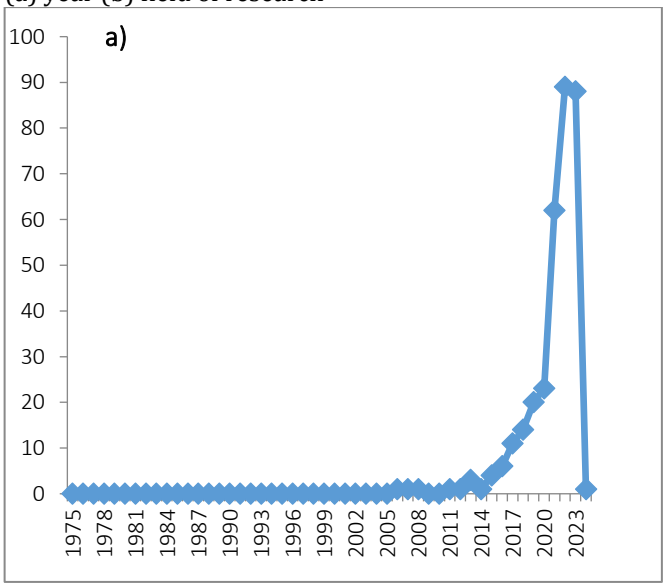


Figure 10
Publication Output Performance in Hydroponics by (a) year (b) field of research



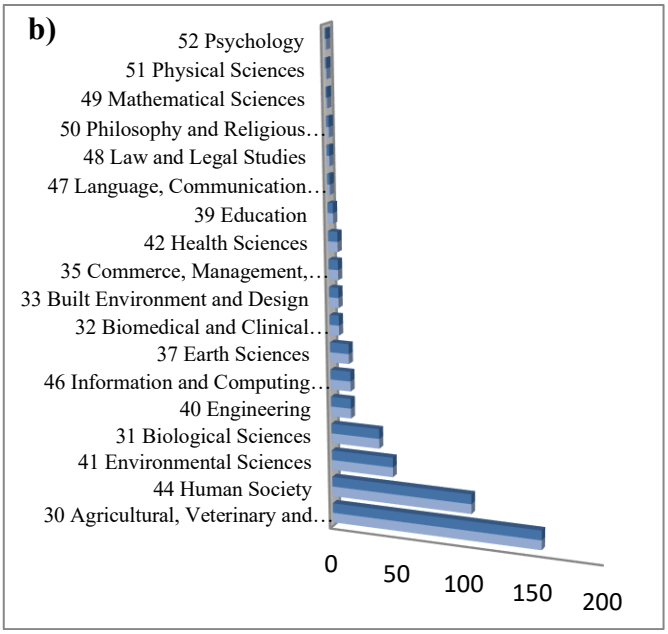
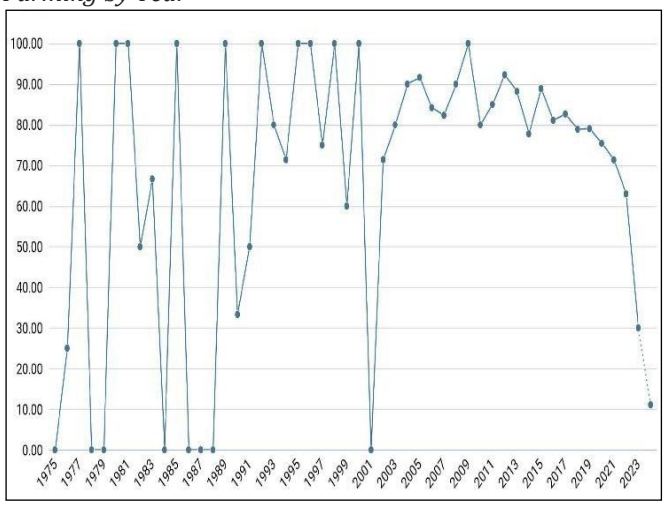


Figure 11
Publication Citations Output Performance in Vertical Farming by Year



DISCUSSION

According to recent studies, global food demand will rise by 70 to 100 percent by 2050 (Bank, 2007; Baulcombe et al., 2009). Climate change-induced droughts, floods, and extreme temperatures all threaten agricultural development and productivity, compounding food security problems (Bhattacharya, 2019). A study conducted by Sweileh (2020) on food security in the context of climate change highlighted the increasing trend in publications over the last decade, with a focus on water security, crop yield, food availability, and health. Another study by Xie et al. (2021) on global trends in food security research using bibliometric techniques found that food security research is becoming more mature, extending from food security to encompassing water and land resource security. These findings resonate with the provided study's identification of emergent trends and the significant number of articles published on chemical spoilage and shelf life.

Ohlan & Ohlan (2023) examined the publication trends in the journal Global Food Security: Agriculture, Policy,

Economics and Environment (GFS), which covers a wide range of interdisciplinary topics related to food security. The study analyzed 311 scholarly documents published between 2012 and 2019 using various bibliometric tools such as the g-index, m-index, burst detection, and network analysis. The key findings indicated that GFS has shown significant growth, with an increasing number of publications and their influence rising year by year. The journal features contributions from researchers worldwide and is well-connected with other top-tier journals in the same field. The study highlighted the need for more research on ethical issues in social decisions regarding nutrition security and the impact of global seafood trade on access for low-income populations.

According to a study by Kumar et al. (2020), phenolic compounds exhibit both antimicrobial and antioxidant properties, which play crucial roles in plant defense mechanisms. The antimicrobial properties of phenolic compounds help protect crops from a variety of pathogens, thereby reducing the incidence of diseases and improving overall crop health. Additionally, their antioxidant properties contribute to enhanced plant growth and stress resistance by mitigating the harmful effects of reactive oxygen species (Ahlawat et al., 2024). This dual functionality makes phenolic compounds a valuable tool in sustainable agriculture, promoting healthier crops and more stable yields (Ahlawat et al., 2024).

Advanced technological trends are significantly enhancing food safety and food security (Albahri et al., 2023; Ashrafudoulla et al., 2023; King et al., 2017). IoT sensors are pivotal in monitoring various parameters in real-time, ensuring optimal conditions for food production and storage (da Costa et al., 2022; Lamberty and Kreyenschmidt, 2022; Parween et al., 2021).

Edible coating technology involves applying a thin, edible layer to food products, extending their shelf life and maintaining quality (Andriani and Handayani, 2023; Oduro, 2021; Suhag et al., 2020). Nano fertilizers, which are advanced fertilizers, improve nutrient delivery to plants, thereby enhancing growth and yield (Al-Juthery et al., 2021; El-Saadony et al., 2021; Seleiman et al., 2020).

Automation technologies streamline food production processes, increasing efficiency and reducing human error (Micle et al., 2021; Sachani et al., 2021). Vertical farming, a method of growing crops in vertically stacked layers, maximizes space usage and enables year-round production (Kumar et al., 2023; Mishra et al., 2024). Lastly, hydroponics, a soil-less farming technique, uses nutrient-rich water solutions to grow plants, often in controlled environments (Ragaveena et al., 2021; Rajaseger et al., 2023; Rani et al., 2022). These technologies collectively contribute to more efficient, sustainable, and safe food production systems.

Gizaw (2019) investigated public health risks in the food market, such as microbial contamination, harmful chemicals, food adulteration, misuse of additives, mislabeling, GM foods, and outdated products. It recommends risk-based food control systems, safety standards for imports, public awareness, regular inspections, and R&D to prevent contamination. Verma et al. (2022) discovered that recent trends in nano-fertilizers (NFs) have investigated suitable agri-technologies to fill gaps and ensure long-term positive agricultural policies to protect global food security.

Bouzembra et al. (2019) reviewed IoT applications in food safety, noting its emergence since 2011. They found that most studies, primarily conducted by Chinese universities, focused on food supply chain traceability and the monitoring of safety and quality. Key areas of application included food, meat, cold chain, and agricultural products, with sensors used to monitor temperature, humidity, and location. The most common communication technologies were the Internet, RFID, and WSN. The study highlights knowledge gaps that can guide future research in IoT for food safety.

IoT architectures for food monitoring from 2014 to 2019 were examined by Dias et al. (2020). They discovered that the majority of IoT applications for food safety were carried out in Asia, mostly by researchers from India. Temperature, humidity, and gas sensors are frequently used in conjunction with RFID, Wi-Fi, Bluetooth Low Energy (BLE), and ZigBee communication technologies. The study emphasised the potential of IoT to improve food safety, but it also identified obstacles including standardisation and data integration.

A review (Budiawati et al., 2024) on coping mechanisms and food security during pandemics emphasized the importance of policies to enhance individual and household food security, which is in line with the provided study's emphasis on technological advancements to improve food production and safety. The provided study's results are consistent with the broader research landscape, which shows a growing interest in technological solutions to enhance food security and safety. The study's detailed analysis of keywords, research collaborations, and publication trends provides valuable insights into the evolving field of food safety and security, highlighting the importance of technology in addressing these critical issues.

Valoppi et al. (2021) highlighted significant advances in food science and technology aimed at ensuring food security. Key points include the circular economy, which valorizes food waste to enhance sustainability, and the exploration of alternative food production technologies such as cellular agriculture, algae, insects, and wood-derived fibers. Innovative food design aims to create sustainable, nutritionally adequate diets. Digitalization, through AI, VR, and blockchain, improves food chain management and the development of novel foods. The review also addresses the impact of COVID-19 on the food supply chain, emphasizing the need for resilience. Similarly, Demirel et al. (2024) studied bio-based technologies and their potential to enhance food security and safety. Their study emphasizes the importance of sustainable practices and the integration of modern technologies to address food security challenges.

The bibliometric analysis by Erere et al. (2021) from 2008–2018 on hydroponics indicated that China, Japan, the United States, and Iran hold a strong position in research publications in this area. Acta Horticulturae was denoted as the premier journal for research on hydroponics. The main writers were Pardossi, Fabrício Ávila Rodrigues and Alberto. With 78 total employees, Chinese Academy Sciences is the most productive

organization or affiliation publishing within this field. They draw the conclusion that considerably more research on hydroponics and related fields is required. Parmeswaran (2021) examined the hydroponics publications' research output from 1989 to 2020. From 1989 until 2008, there was some variation in the distribution of publications; however, following that, there was a consistent increase in the distribution of publications. The majority of authors—95.78 percent—have submitted research publications in the English language, with the remaining 4.22% publishing in other languages. China took the place with a contribution of 20.99% publications.

In terms of literature reviews, a systematic review (Manikas et al., 2023) of indicators measuring food security found that household-level calorie adequacy and dietary diversity-based indicators are frequently used, which suggests a focus on the practical aspects of food security.

CONCLUSION

Emergent technologies in food safety and food security are edible coatings, IoT sensors, nano fertilizers, vertical farming, hydroponics, and automation. The number of articles published in food safety and food security and emergent technologies has increased over the years. It is observed that the key concerns in food safety are contamination, heavy metals, mycotoxins, and salmonella, whereas disquiets in food security are nutrition policy, agriculture, climate change, and COVID-19. Also, United States and China has a significant higher publication outputs and extensive collaborations in this field. It is noticed that the emergent technologies have significantly impacted both food security and food safety, leading to more efficient, transparent, and safer food systems and continued is resulting in a more resilient and productive agricultural industry, ensuring that the food delivered to consumers is safe and of high quality. These technologies are competing the challenges of environmental sustainability, and resource management faced by the agricultural community. With more research in these emerging fields and in new technologies such as block chain, data and predictive analytics and advanced packaging we can expect to witness further advancements that will shape the future of sustainable agriculture to enhance food safety and security.

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