

Article

Towards Understanding the Food Consumer Behavior–Food Safety–Sustainability Triangle: A Bibliometric Approach

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Abstract: Academic research on food consumer behavior related to food safety has developed extremely rapidly in the last decades, and a sizable amount of knowledge has been accumulated in this interdisciplinary field. This information set, as big data, lends itself to bibliometric analysis. Based on the Web of Science database and on a statistical analysis of more than 26.6 thousand articles containing more than 3.4 million bibliometric pieces of information, the current article offers a systematic analysis of these statistical data. The dynamics of relevant publications show an exponential character. The field is dominated by researchers from welfare states; however, food safety is a more important problem in developing states. There are dynamic changes in the portfolio of journals, but Bradford's law cannot be proven. The explanatory power of Lotka's law has been decreasing, proving the de-concentration of relevant authors. Besides traditional disciplines like consumer science, food chemistry, microbiology, and technology, new disciplines, e.g., sociology, cultural anthropology, postmodern techniques, and the real-life study of consumer behavior, going beyond the application of traditional techniques, are gaining importance. There are three key challenges for further research: (1) contribution to a deeper understanding of inherent laws governing the food-consumer-environment system; (2) quantification of results for decision-makers to enhance the efficiency of policy preparation; (3) widening the scope of research in geographical terms, better involving the developing world, and in sociological terms, focusing on the specific needs of vulnerable groups.

Keywords: big data; keyword analysis; ontology; networks; policy; science development; scientometrics; topics analysis



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1. Introduction

The desire to consume food without getting ill is one of the most basic and ancient motives of human activity and regulation [1]. It is well documented that food hygiene was a focal point of interest already in antiquity [2]. The development of contemporary food safety research can be traced back to food hygiene-related investigation [3] and legislation [4]. As a result of centuries of research efforts, an extensive mass of knowledge has been accumulated on food hygiene, but the systematic, methodologically well-founded research of food consumer behavior–food safety relationship has a much shorter history [5]; however, there is a wide consensus that this information is essential to the enhancement of the food safety level [6], further sophistication of the regulatory and consumer education system [7], and the decrease in foodborne diseases [8].

Sustainability and food safety are closely related concepts because food safety means a direct contribution to the achievement of the Sustainable Development Goals of the UN [9]. Analyzing Table 1, it is obvious that the enhancement of food safety is tightly related to the practical realization of the sustainable development goals.

Table 1. Interactions of UN Sustainable Development Goals and food safety.

UN Sustainable Development Goals	Food Safety Related Aspects
End poverty	Decreasing poverty could contribute to the enhancement of food safety [10]
Zero Hunger	Increasing food security may affect food safety risks negatively (e.g., application of agrochemicals [11])
Ensure healthy lives and promotion of well-being	Foodborne diseases are important factors of global public health [12,13]
Improvement of quality of education	Food safety must be better integrated into the public education curricula [14]
Achievement of gender equality and empowering of women	Increasing attention towards food safety promote gender equality [15]
Access to water and sanitation	Significant, positive correlation between water quality and food safety [16]
Access to energy	Energy supply systems are necessary preconditions of food safety [17]
Economic growth	Safe food promotes economic growth [18]
Resilient infrastructure, industrialization, and innovation	Technology development (specifically the info-communication innovations) enhances food safety [19]
Inequality reduction	Inequalities lead to higher food insecurity [20]
Sustainable cities and communities	Urbanization, longer supply chain means new challenges for logistics and food safety [7]
Responsible production and consumption	It is essential to find a balance between food waste and safety [21–23]
Climate actions	Climate change has an impact on food safety [24,25]
Sustainable use of marine resources	Aquatic food is extremely perishable; Biological, chemical and radiation risks should be minimized [26]
Sustainable use of terrestrial ecosystems	Incoherent organic farming systems can jeopardize food safety [27]
Peace, justice, and strong institutions	There is an urgent need for further development of global food safety regulation systems [28]
Revitalization of global partnership	Improvement of international food safety culture contributes to the enhancement of food safety performance [29]

The aim of the current article is to uncover the development of research on food safety-consumer behavior interactions (hereinafter: FSCBI), as attested in the academic literature, and to analyze the basic features of food safety. The paper is structured as follows: in the first part, we outline the hypotheses, which will be tested in the framework of bibliometric analysis. The second part offers an overview of the methods applied, then the results and their interpretation will be presented. The last part of the article—based on

our results—determines the basic direction of the development of food science–consumer science–food safety interactions, and some suggestions will be offered for further research.

In the framework of the current study, we will answer three research questions:

RQ1: How can global research on the problematics of the food safety-sustainability nexus be evaluated based on bibliometrics?

RQ2: What kind of patterns can be detected in the research of this nexus on the basis of different bibliometric indicators?

RQ3: How have the focal points of research been evaluated in the last decades, how has the science reacted to the changing socio-technological-cultural environment?

The current research provides information on the applicability of bibliometrics in the research of sustainability–environment nexus and can be considered as a guided tour into the realm of modern bibliometrics, with insights into the spatio-temporal dynamics of the research ecosystem and its thematic evaluation.

Hypothesis Development

Based on preliminary, exploratory, and heuristic literature research and our own experiences gained as public servants, researchers, and extension service experts, we have developed hypotheses on consumer-food safety relationship literature.

H1: There is a rapidly increasing interest towards the FSCBI-related topics of research all over the world [30]. This is not a linear process, but rather exponential, which is considerably influenced by food safety crises and scandals [31].

H2: Foodborne diseases cause much more severe losses in developing countries (first of all in Africa) than in welfare states (e.g., in Europe) [32] but, as a consequence of higher material resources, the majority of research is realized in developed countries.

H3: Although a relatively young field of science, the FSCBI research follows the general laws established by Lotka [33] to describe the individual academic productivity distribution and by Bradford [34] to characterize the academic source distribution.

H4: The FSCBI field is highly complex, and can be divided into different, relatively well separable intellectual trends and clusters, which have their ontological roots in knowledge piled up in different natural and social sciences in the last decades.

H5: In the last decades, there have been considerable changes in the social [35], technological [36], economic [37], political [38], legal [39], environmental [40], and ethical [41] conditions of food safety in general and safety-related consumer behavior in particular; as a consequence, the FSCBI-related research has constantly been reflecting these changes in academic and public interest.

To the best of our knowledge, the current paper is the first attempt to analyze this problem in such complexity. Previous studies have analyzed only one aspect of the question, e.g., the relationship between the Internet of things and food safety [19], food safety of Halal products [42], or the connection between sustainability and food chain, e.g., from the point of view of the water-energy-food nexus [43] or food waste [44].

2. Materials and Methods

In our data collection, we applied the traditional, generally accepted workflow of bibliometric analysis [45]. The most important steps applied in our research are depicted in Figure 1.

The first decision point was to select the database. Characteristic features of different databases, candidates to be data sources for the current research, are summarized in Table 2.

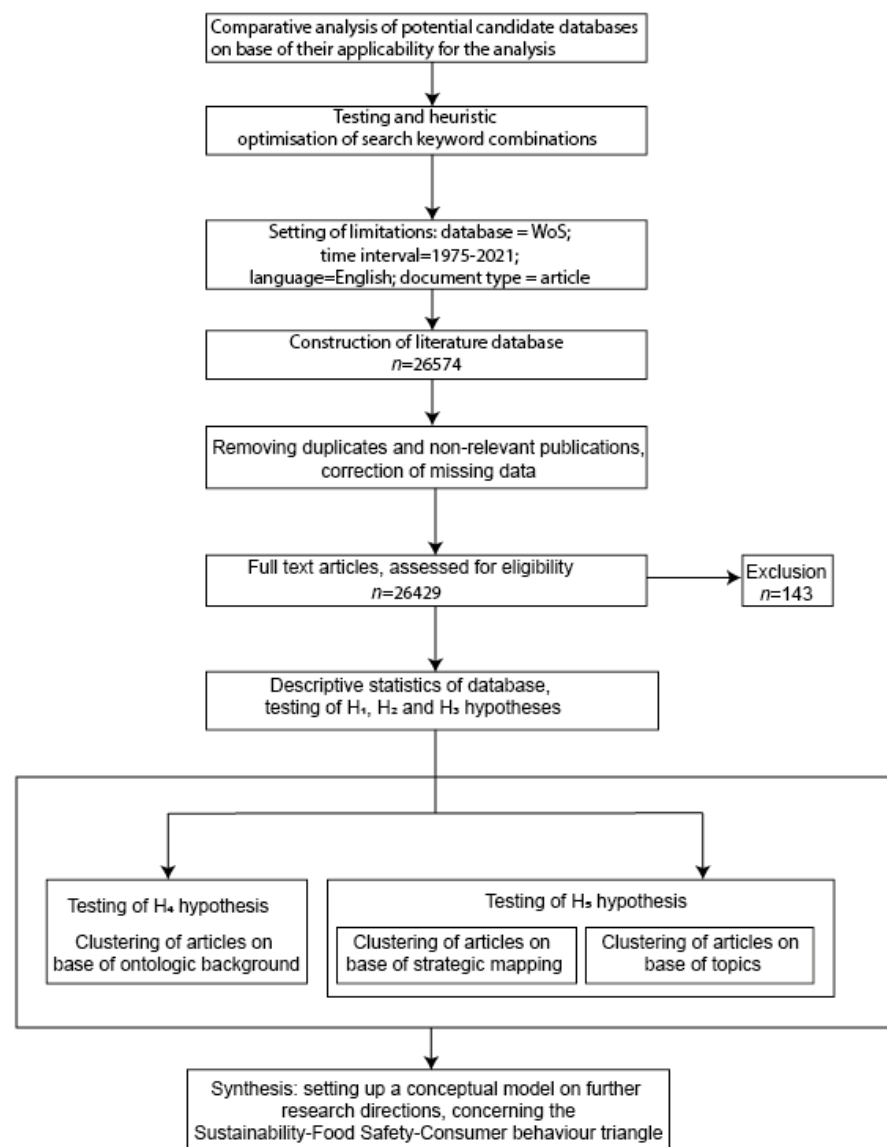


Figure 1. Flowchart of investigations.

Table 2. Comparative analysis of different databases from the point of view of suitability for our research purposes.

Name of the Database	Characteristic Feature (Advantage/Disadvantage)
PubMed	Sophisticated database, but focusing only on medical aspects of food safety [46]
Google scholar	Rapidly developing, but lack of quality control [47]
Altmetrics	Considerable overlapping with Scopus, quality control challenges [48]
Scopus	Wide range of coverage, but high level of duplications [49]
Web of Science	Relatively narrow scope, but high quality of data

Based on the considerations outlined in Table 2 we chose the Web of Science (hereinafter: WoS) system as the basis of the analysis. Our decision is supported by a comparative analysis of different databases [50]. For simplicity, to avoid the duplications, we limited

our results to journal articles, published in English language. The time window has been set from 1975 to 24th of January 2021.

We have detected structural breaks in how the number of publications has changed over time; therefore, the analysis of pooled data offers a rather limited possibility to uncover the structural changes and characteristic features of food safety development. The structural breaks in the time series have been determined by COSUM and MOUSM algorithms of Strucchange R-package [51] and expert-estimation. The experts in this process were A.K. G.K. and Z.L. Based on this, four periods have been identified: up to 2004, between 2005 and 2009, between 2010 and 2018, and the last three years. The interpretation and justification of these four periods—beside the results of the mathematical methods—are as follows: the year 2004 is a milestone, because this is the year of the enlargement of the EU by ten new member states and the beginning of a considerable increase in publications from China. The world economic crisis in 2008 has shown the vulnerability of modern societies to shocks and highlighted the importance of nation-states. Over the last years, numerous new paradigms have emerged (e.g., big data concept, network analysis), increasing the importance of data analysis.

In the first phase of our research, we determined the optimal combination of search expressions. After some trial-based heuristics, we found that the optimal choice of search word combination is as follows:

(TS = (("Food") AND(((("safe*")) OR (("Hyg" Or ("Hig*")))) AND ("Consumer*")) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC

The statistical analysis was carried out by three software: CitnetExplorer [52], Bibliometrics R-package [53] and VOS viewer [54]. All of these tools are widely applied in the quantitative analysis of academic publications [55,56].

The VOS viewer software is widely applied for the classification of different publications based on authors, literature sources and keywords. On this basis, it is relatively easy to construct and visualise clusters of authors as well as publications based on their sources and topics.

The CiteNet explorer has been designed to uncover the pathways of ontological and epistemological development of different fields of science. This approach is especially suitable to determine the intellectual development of different fields of academic research.

The Bibliometrics R package can be considered as a "Swiss army knife" of bibliometric analysis, because this tool offers a wide and sophisticated set of tools for in-depth bibliometric research.

The descriptive statistics of the corpus has been analyzed based on the home-country of the corresponding author of the articles. The distribution of academic journals has been analyzed by the application of Bradford's law [57]. This is practically an application of the Pareto distribution to the academic world, postulating that if journals in a given field of science are assorted by the number of articles relevant from the point of view of a given search criterion, then the number of journals in each third will be proportional to $1:n:n^2$.

Lotka's law [58] characterizes the frequency of publications by authors, stating that the relative frequency of authors (y) with x publications can be described as $y = c/x^n$, where c is constant, and n approximately equals 2.

The intellectual roots and background of research have been analyzed by the CitnetExplorer [52] software. This tool has been developed for the analysis of direct citation networks. This way we have been able to analyze the knowledge base of different articles. The algorithm underlying the software has been built on clustering the articles on the basis of their resources.

Another important tool for research has been the Bibliometrics R-package [53]. This complex system of different algorithms has offered a convenient way to calculate a wide range of bibliographic indicators. The Bibliometrics R-package contains an algorithm for the calculation of the bibliometric mapping method, developed by Cobo et al. [59]. By

clustering the articles based on their network position, identifying the clusters, and putting them into a two-dimensional coordinate system according to centrality (connection of members of a cluster with other clusters) and density (connections within the clusters), this approach divides the different topics into four groups: the first group of publications can be characterized by high density and centrality. These are the so-called motor themes. The basic or transversal themes are situated in the right lower quarter of the coordinate system. These topics can be characterized by a high level of centrality (these are often cited) and a low level of density (they are relatively separated from each other). There are some topics that are highly developed. Thus they are characterized by high density, but relatively separated from each other, therefore, the centrality level is rather low. These are in the upper right part of the coordinate system, depicted in figures. The emerging and declining topics can be characterized by a low level of centrality and density because they are not yet integrated into the corpus of the research field.

Based on the co-occurrence of different keywords and expressions, applying a combination of cluster and principal component analysis the VOS viewer is suitable [60] and widely applied [61] for the classification and visualization of different fields of science.

3. Results

3.1. General Characteristic Features of the Corpus

In the first part of the investigation, we analyzed our corpus by descriptive statistical methods. The most important indicators of analysis are summarized in Table 3.

Table 3. The cumulative share of the most important 20 countries in FSCBI related publications (%) (Countries indicated by three-digit ISO Codes).

1975–2004		2005–2009		2010–2018		2019–2021	
Country	Cum.share in Publications (%)	Country	Cum.share in Publications (%)	Country	Cum.share in Publications (%)	Country	Cum.share in Publications (%)
USA	38.2	USA	28.5	USA	38.2	USA	28.5
GBR	49.2	GBR	35.8	GBR	49.2	GBR	35.8
CAN	53.7	CAN	40.8	CAN	53.7	CAN	40.8
NLD	57.8	ITA	45.7	NLD	57.8	ITA	45.7
DEU	62	ESP	50.0	DEU	62	ESP	50.0
AUS	65.9	DEU	54.2	AUS	65.9	DEU	54.2
ITA	69.5	FRA	57.9	ITA	69.5	FRA	57.9
FRA	72.5	NLD	61.5	FRA	72.5	NLD	61.5
ESP	75.3	AUS	64.9	ESP	75.3	AUS	64.9
IRL	77.8	BEL	67.5	IRL	77.8	BEL	67.5
SWE	79.6	BRA	69.5	SWE	79.6	BRA	69.5
CHE	81.4	NZL	71.5	CHE	81.4	NZL	71.5
BEL	82.9	JAP	73.1	BEL	82.9	JAP	73.1
DNK	84.2	NOR	74.6	DNK	84.2	NOR	74.6
JAP	85.6	TUR	76.2	JAP	85.6	TUR	76.2
NOR	87	CHN	77.7	NOR	87	CHN	77.7
FIN	88.2	IND	79.2	FIN	88.2	IND	79.2
BRA	89.3	GRC	80.5	BRA	89.3	GRC	80.5
NZL	90.5	IRL	81.8	NZL	90.5	IRL	81.8
ZAF	91.4	ARG	83	ZAF	91.4	ARG	83

As it was supposed, the number of publications has increased in an exponential way (Figure 2), supporting the H1 hypothesis.

In the first years of the development of the FSCBI field, this sphere was dominated by welfare states (Figure 3). At this time, three-quarters of the publications had been written by US, Canadian, and Western European authors, and nearly 90% of all publications had been prepared in workshops of welfare states. At this time, only the Brazilian authors appeared in the international arena, preparing more than 1% of all publications. The situation did not considerably change up to 2009; nevertheless, some new emerging and developing countries appeared. From 2010, we see a rapid increase in the share of China, Brazil, and India, and from the former Eastern Bloc country of Poland. In recent years, we could see an even more rapidly increasing ratio of developing and emerging countries: six countries are among the most productive 20 states. Another important process that can be observed

is the decreasing of the concentration of the states active in this field. Before 2004, six countries produced two-thirds of the publications; in the last few years this number has increased to 14. The concentration ratio of the top-twenty countries has been declining from 91 to 74.6%. All of these facts highlight the global character of the FSCBI problem.

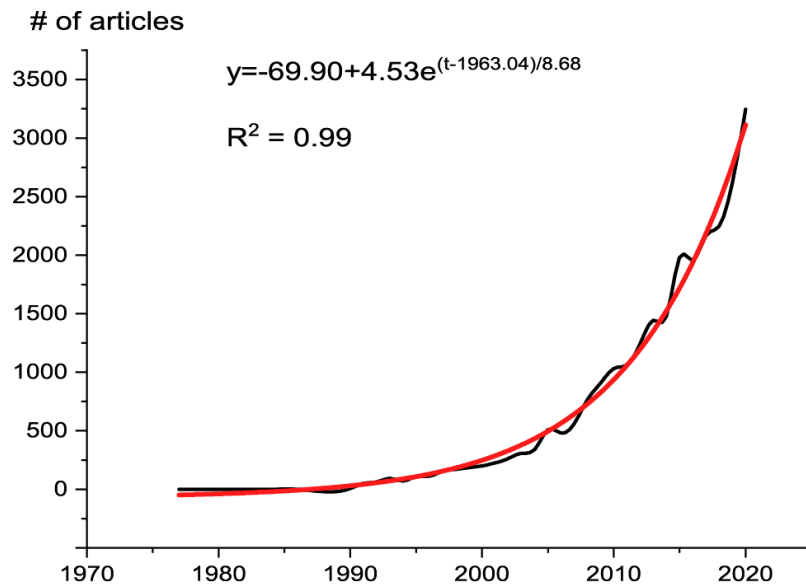


Figure 2. Yearly academic production in FSCBI domain.

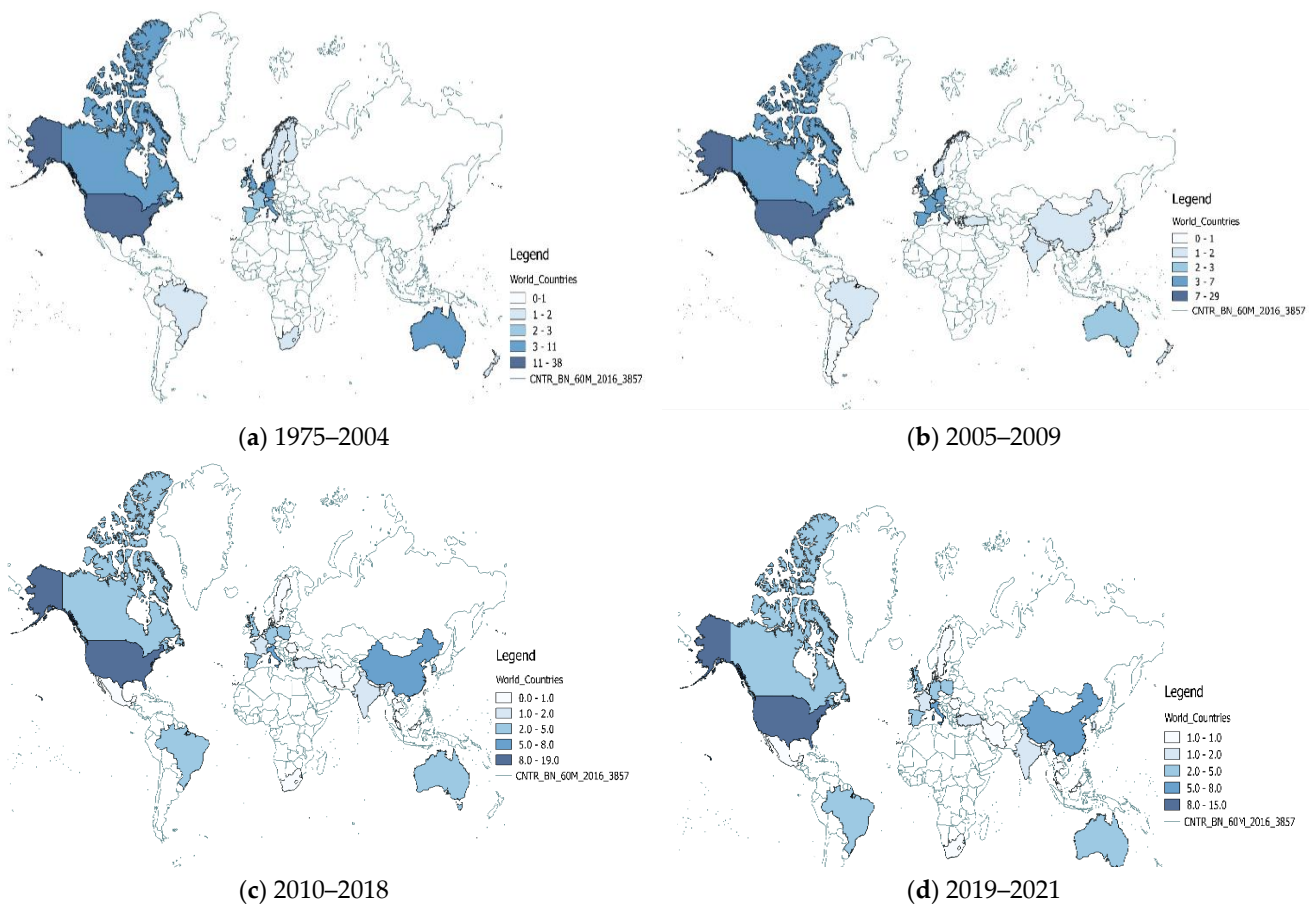


Figure 3. Temporal changes of the spatial distribution of FSCBI related publications (%).

Bradford's law could not be proven in the case of journals (Table 4). This fact highlights that the concentration of the keynote periodicals in this field is relatively low.

Table 4. Ratios between different journals, calculated by the Bradford method.

Zones	–2004		2005–2009		2010–2018		2019–	
	# of Journals	Ratio	# of Journals	Ratio	# of Journals	Ratio	# of Journals	
1st zone	27	1.00	19	1.00	1st zone	27	1.00	19
2nd zone	120	4.44	116	6.10	2nd zone	120	4.44	116
3rd zone	583	4.86	582	5.02	3rd zone	583	4.86	582

Analyzing the structure of journals (Table 5), it is interesting that in the first period, articles were published in a rather wide spectrum of journals, and a high number of journals made up the first third of the journals published on the subject. This fact can be explained by a lack of specialized publication possibilities on FSCBI topics. Over the last years, journals offering a suitable publication possibility on FSCBI topics have appeared. From the point of view of publication policy, it is worth noting that among the first six journals, three are open access, relatively new organs of academic communication.

Table 5. Academic journals in first third of periodicals, relevant in the field of FSCBI topics.

1975–2004	2005–2009	2010–2018	2019–2021
Journal of Food Protection	EFSA Journal	EFSA Journal	EFSA Journal
Ecology	British Food Journal;	British Food Journal	Foods
Food Quality and Preference;	Journal of Food Protection;	Food Control	Sustainability
Food Additives and Contaminants;	Food Quality and Preference;	Food Quality and Preference;	Food Control
Food Control	Food Additives and Contaminants: Part A–Chemistry Analysis Control Exposure and Risk Assessment;	PLoS One	Nutrients
International Journal of Food Microbiology;	Food Control	Appetite	Food Quality and Preference
Journal of the American Dietetic Association	Appetite	Food Additives and Contaminants: Part A–Chemistry Analysis Control Exposure and Risk Assessment;	British Food Journal
Marine Ecology Progress Series	Marine Ecology Progress Series	Journal of Food Protection	Journal of Food Processing and Preservation
Oecologia	Ecology	Journal of Food Science;	Food Research International
Food Policy	Meat Science	Innovative Food Science and emerging technologies	International Journal of Environmental Research and Public Health

Table 5. *Cont.*

1975–2004	2005–2009	2010–2018	2019–2021
European Journal of Clinical Nutrition	Journal of Food Science	Journal of the Science of Food and Agriculture;	Journal of Food Science
Limnology and Oceanography	Journal of Agricultural and Food Chemistry;	Food Policy	PLoS One
Public Health Nutrition	Journal of the Science of Food and Agriculture;	Public Health Nutrition	Science of the Total Environment
Trends in Food Science and Technology;	Food Policy	Food Chemistry	LWT–Food Science and Technology
British Journal of Nutrition	Food Chemistry	International Journal of Food Microbiology	Journal of Cleaner Production
Appetite	LWT–Food Science and Technology;	Marine Ecology Progress Series;	Journal of Food Protection;
American Journal of Clinical Nutrition	Risk analysis	Food Research International	Appetite
Food Australia	International Journal of Food Science and Technology	Nutrients	Journal of the Science of Food and Agriculture;
Journal of Agricultural and Food Chemistry;		Journal of Food Composition and Analysis;	Animals
Journal of Nutrition		Journal of Food Processing and Preservation;	
Journal of Nutrition Education		LWT–Food Science and Technology;	
Regulatory Toxicology and Pharmacology		Sustainability	
Journal of Food Science		International Journal of Consumer Studies;	
Food Additives and Contaminants: Part A–Chemistry Analysis Control Exposure and Risk Assessment;		Journal of Food Safety	
Food and Chemical Toxicology;			
Hydrobiologia			
Freshwater Biology			

The results of the analysis of the distribution of authors based on Lotka’s law (Table 6) show a continuous decrease in the concentration of authors. In the first period, the beta coefficient was higher than the “benchmark” value of 2; now it is below it. The fitting of the “classic” regression equation is highly significant, but the value of R square has been continuously decreasing. These processes can be explained by two facts: on the one hand,

by the increasing interest in the problems of the FSCBI continuum, and on the other hand, by the increasing diversity within this realm.

Table 6. Changes in coefficients and the fitting of the Lotka-equation in different periods.

Coefficients	1975–2004	2005–2009	2010–2018	2019–2021
n	3.57	1.68	1.32	1.603
C	0.94	0.082	0.02	0.05
R ²	0.98	0.72	0.69	0.67

3.2. Changes of Research Focus, Reflected in Keywords

The dynamics of the appearance of different keywords over time highlights the changes in the focus of research (Figure 4). Analyzing Figure 4, it is obvious that gender-related aspects have constantly played an important role in the publications in this field of science; the appearance of the word “women”, parallel with the word “home”, has been increasing linearly. The importance of functional food and risk assessment has increased exponentially, showing the relevance of these concepts.

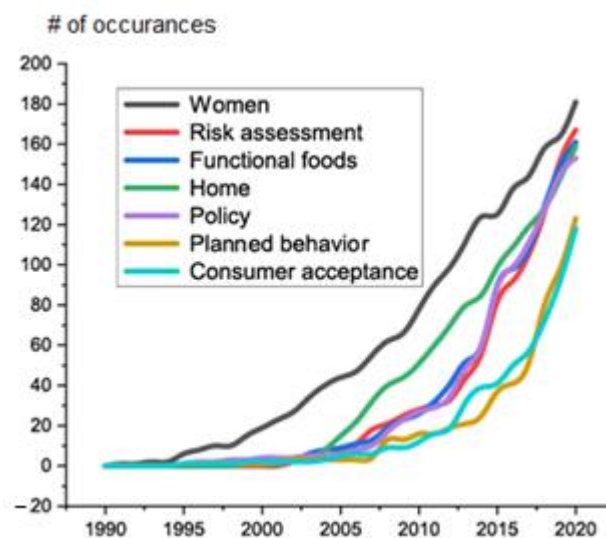


Figure 4. Occurrence of some frequent keywords and key terms in the corpus—1.

The results of consumer-related food safety research have been integrated into policy-making. This tendency is highlighted by the increasing frequency of the appearance of the word “policy”. It is important to see that the word “consumer acceptance” appears more and more frequently. This tendency underlines that researchers are increasingly interested in the feedback from consumers on different food related innovations.

Some keywords (in some cases, this *terminus technicus* actually means “key terms”) appear with an exponential frequency (Figure 5), showing the increasing sensibility of the academic environment towards climate change and obesity. Interestingly, the rapid increasing of the appearance of willingness-to-pay shows a paradigm shift in consumer research- the paper and pencil type, questionnaire-based research is at least partially replaced by experimental methods, simulating non-theoretical consumer decisions.

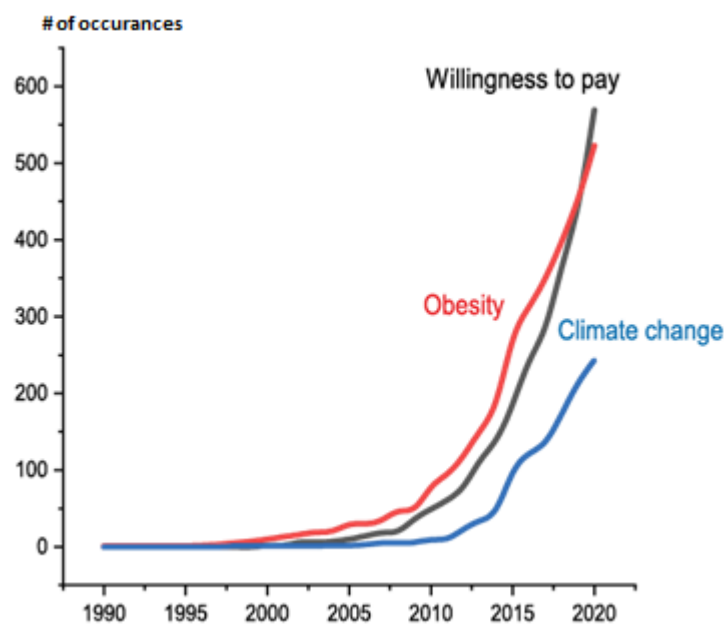


Figure 5. Occurrence of some frequent keywords and key terms in the corpus—2.

3.3. Ontology of FSCBI

The FSCBI field has developed in an organic way. It can be characterized by an extremely high level of complexity, integrating a wide range of knowledge. The analysis of literature sources, based on which the different sub-sets of the discipline have been developed, can help to understand the intellectual roots of the different spheres of FSCBI and to have a more accurate picture of the internal structure of the field (Table 7). Nearly 80% of the articles could be categorized according to their knowledge base.

Table 7. Clustering of publications in the corpus based on cited references.

Topics	Number of Publications in the Topics
Consumer behavior models to understand	5954
food safety related behavior (I/1)	4074
Food chain (I/2)	2720
Information, labelling (I/3)	2422
Kitchen technologies (I/4)	1612
Biochemistry (I/5)	1457
Toxicology (I/6)	687
Genotoxicity assessment (I/7)	647
Food safety regulation (I/8)	511
Food risk assessment (I/9)	403
Food allergy (I/10)	296
Food safety and security (I/11)	67
Acrylamid (I/12)	62
Dietary supplements (I/13)	24
Political economy of food safety (I/14)	13
Drug advertisement (I/15)	12
Food safety and animal welfare (I/16)	11
Sustainability and food safety (I/17)	

The citation chart collects sets of publications that have been divided into distinct thematic clusters. The largest cluster ($n = 5954$) focuses on the development and application of consumer behavior models. The intellectual forerunner of this cluster was Lancaster's seminal paper on consumer theory [62]. Ajzen's classic study on the Theory of Planned Behavior [63] has served as an intellectual underpinning of the most cited paper in this cluster: Grunert's theory, explaining food consumer behavior [64].

The second-largest cluster analyses the problems of food chains from the point of view of ecology and food safety. This cluster of publications considers the food chain as a succession of biological agents in a given ecosystem. A third cluster analyses consumer response to nutrition-related pieces of information, focusing on food labels. Seminal papers on this topic are Grunert and Wills [65] as well as Cowburn and Stockley [66].

An important cluster examines the importance of consumer behavior from home hygiene, kitchen techniques, and storage practices [67]. The seminal paper in this field as a source of information was written by Redmond [68]. Statistical data highlighting the importance of food-related illness were collected and presented by [69]; this paper offers important proof of the weight of food-related diseases.

A relatively large number of articles analyze different aspects of food safety from the point of view of microbiology or food chemistry, but they try to establish a connection with food consumer behavior, while only a relatively low number of publications deal with problems of the political economy of food safety.

3.4. Mapping of Topic-Evaluation

Based on Cobo et al.'s [70] approach, the thematic evaluation map of different research problems has been analyzed by a two-dimensional graph for each time slice.

The first period of the development of the FSCBI field can be characterized by a dominance of classic problems of food safety (Figure 6). At the time, the motor theme was protein research; other topics, such as fish consumption and their food safety consequences, and the migration of different chemical components had been highly developed, but as rather isolated themes. The “classic” consumer research, along with policy and information procession analysis, were among the emerging topics. This fact highlights that this was the era of the formulation of food consumer science. The most important basic theme was the survival analysis of microbes. In summary, it can be concluded that the first period of FSCBI developments was characterized by classic food hygiene research aspects, but the basis of the modern food consumer science was laid down at this time also.

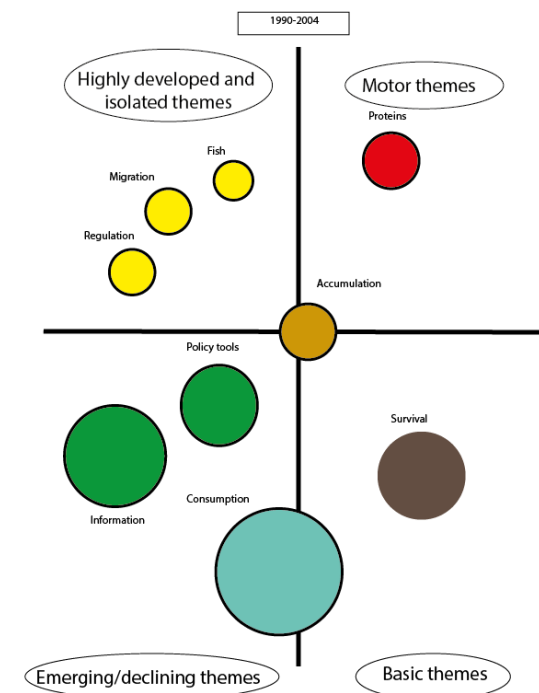


Figure 6. Science map of research topics of FSCBI 1990–2004.

The period between the EU-enlargement and the world economic crisis was still dominated by the welfare states, where there was an increasing health issue, with the

two most important health-related problems being cancer and cardiovascular diseases (Figure 7). Thus, the connection of food safety with these diseases had central importance. This was the time of fierce debate on consumer acceptance of foods with genetically modified organisms (GMO). Food chemistry and microbial problems became mature, highly developed topics. Legislation was a basic problem, but at this time, food-safety-related research was not incorporated into the discussion yet. The appearance of topics on cooking and storage in the research field showed the increasing importance of exploring domestic consumer behavior.

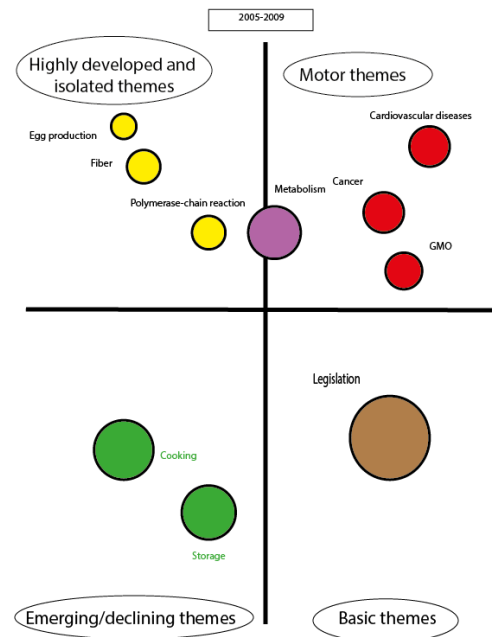


Figure 7. Science map of research topics of FSCBI 2005–2009.

In the first decades of research, the landscape (Figure 6) was dominated by problems of food chemistry and microbiology. Consumption patterns, information processing and policy formations had been relatively young and emerging fields in this period, having few ties to other fields of science. In this period, these topics were developing relatively independent from each other.

Years of economic reconstruction and continuously increasing globalization of the world economy have resulted in considerable changes in the structure of FSCBI research topics (Figure 8). There was an increasing understanding of the importance of domestic factors of food safety, therefore, the research of cooking technologies, storage methods and practice became motor themes. The emergence of new research methods based on the conceptual background of postmodern approaches [71] and participatory research [72] was a characteristic feature of these years. This explains the emergence of cultural anthropology as a basic theme. Interestingly, food-related legislation did not become a motor theme and its relative importance in academic publications diminished.

The last three years have witnessed considerable structural changes in FSCBI fields (Figure 9).

Analyzing the map of the most important research directions in the last years (Figure 9), two basic directions can be seen among the motor themes: on the one hand, the increasing importance of research methods, aimed at modelling real consumer decision-making (e.g., conjoint analysis, willingness to pay) and quantitative methods (structural equation modelling) and on the other hand, the application of cultural anthropology. Econometrics and globalisation are two topics which can be considered basic themes. The application of Artificial intelligence and nanoparticles-related food safety problems are not yet integrated into the field, but market-regulation problems, gender issues, and street food related research

are among the new topics, and, of course, Covid-19-related questions have also appeared. The survival analysis of microbes has become a rather standard technique [73].

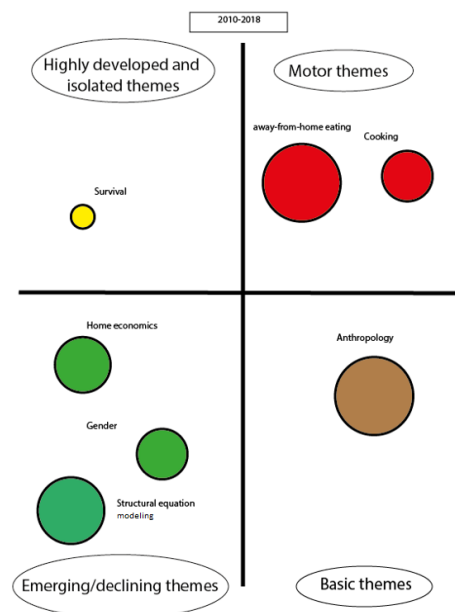


Figure 8. Science map of research topics of FSCBI 2010–2018.

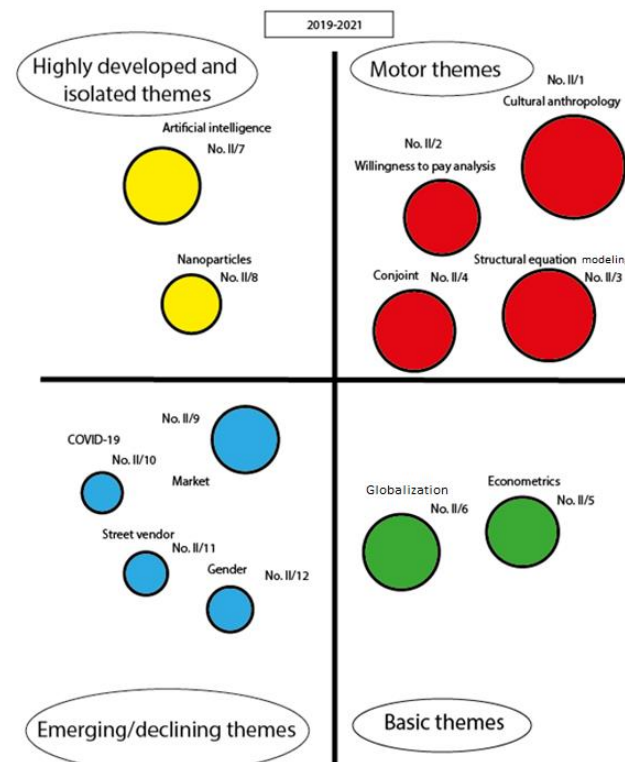


Figure 9. Science map of research topics of FSCBI 2019–2021.

3.5. Clustering of Research Topics Based on Co-Occurrence of Keywords

As we have seen, important changes have taken place in recent years in the research field, therefore, the co-occurrence-based analysis by the VOSviewer has only been applied to the period from 2018–2020. The results of the analysis are summarized in Figure 10 and Table 8.

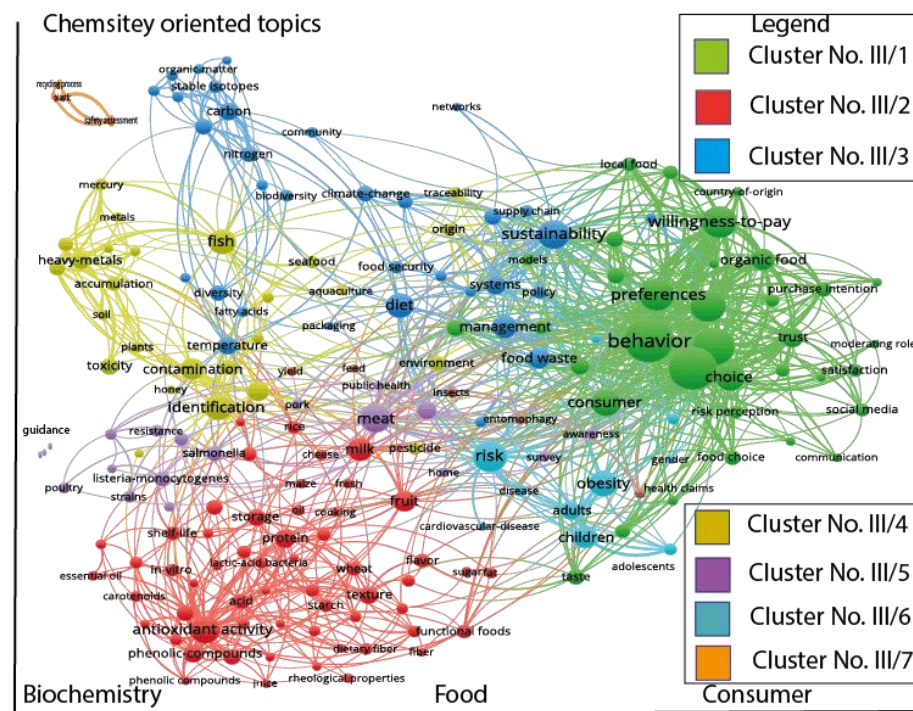


Figure 10. The key clusters of food safety and sustainability-related research.

Table 8. Clustering of publications in the corpus based on cited references.

Food technology cluster (III/1)				
acid	chemical-composition	flavonoids	lipid oxidation	probiotics
anthocyanin	components	flavor	maize	profile
antimicrobial activity	cooking	flour	milk	protein
beverage	dietary fibre	fresh	muscle	rheological properties
bio-accessibility	dough	fruit	mycotoxins	rice
bioactive compounds	essential oil	functional food	oil	sensory analysis
bread	extraction	functional properties	oxidation	sensory evaluation
by-products	fat	in-vitro	phenolic compounds	shelf-life
carotenoids	fermentation	juice	physiochemical properties	starch
cheese	fiber	lactic-acid bacteria	polyphenols	storage
sugar	texture	volatile compounds		wheat
yield	yogurt			
Consumer behavior focus cluster (III/2)				
antecedents	choice	food choice	motivations	purchase intention
attitudes	choice experiment	health claims	organic food	risk perception
attributes	communication	information	perceived risk	satisfactions
beef meat	consumer	liking	perceptions	taste
behavior	country-of-origin	local food	planned behavior	trust
benefits	demand	models	preference	willingness-to-pay
cocoa	emotions	moderating role	price	

Table 8. Cont.

Food safety and sustainability (III/3)				
agriculture	diversity	fresh-water	nitrogen	stable isotopes
biodiversity	ecology	greenhouse-gas	organic matter	supply chain
carbon	fatty acids	emission	packaging	sustainability
climate-change	food security	life-cycle	phytoplankton	sustainable
community	food waster	assessment	policy	consumption
diet	food webs	migration	prevention	system
trophic position	zooplankton	networks		temperature
Food chemistry (III/4)				
accumulation	adulteration	aquaculture	cadmium	contamination
environment	fish	heavy metals	honey	identification
lead	liquid-	mercury	metals	origin
pesticide	chromatography	pollution	quantification	seafood
soil	plants	trace-elements	traceability	vegetables
toxicity				
Food microbiology (III/5)				
antimicrobial	guidance	meat	public health	survey
resistance				
awareness	home	nutritional	resistance	United States
		additive		
bacteria	inactivation	port	salmonella	zootechnical
foodborne	listeria-	poultry	strains	additive
pathogens	monocytogenes			
Food safety of high-risk groups (III/6)				
adolescents	cardiovascular	chives	gender	obesity
	disease	disease	income	risk
adults	children			
Food safety and polyethylene (III/7)				
plastic	polyethylene	recycling process	safety assessment	
	terephthalate			
Food safety of edible insects (III/8)				
entomophagy	feed	food neophobia	insects	

Interestingly, the different clusters can be rather easily interpreted in a two-dimensional coordinate system: the ordinate differentiates between the biochemical–chemical topics, the abscissa between biochemical, food and social science-related problems.

The largest cluster in terms of word frequency, and the second largest in terms of word number comprises consumer behavior and attitude research (No. III/2). In this cluster, indicated by green color, there are three products: beef meat, and organic food, and cocoa, because these products are often used as models to study the laws governing consumer behavior. The second cluster (and the largest by the number of words) consists of 53 keywords. This cluster is indicated by red color (No. III/1). Obviously, this is the domain of traditional food science and chemistry. The majority of this cluster consists of words and expressions related to chemical aspects and products. This fact highlights that even today, food chemistry is a basic factor of the food safety domain. The third cluster (No. III/3) deals with problems of ecological and sustainability-related aspects of food safety. In the Figure, this is indicated by blue color. In this cluster are the food waste-related aspects, too. The fourth cluster (No. III/4) embraces the chemical aspect of food safety, focussing on long-range problems and accumulation in the human organism. The fifth cluster (No. III/5) focusses on microbial aspects of food safety, and the sixth (No. III/6) on foodborne risks, with special emphasis on some vulnerable groups, e.g., adolescents, children, patients with cardiovascular diseases, obesity, or those living on a relatively modest income. A small, separated cluster deals with problems of polymers and recycling (No. III/7). Interestingly, the polymer recycling cluster and one part of the food microbial cluster have no or very

weak relations with other parts of the corpus. This fact highlights the relatively weak embeddedness of some problems into the mainstream of research. A small but relatively well separable cluster deals with food safety problems of entomophagy (No. III/8). This is a rather small part of the FSCBI research, but it is situated among the realms of human aspects, foodborne risk analysis, and sustainability.

As a summary, it can be stated that FSCBI have become an extremely complex set of different disciplines. The backbone of the field is the systematic research of consumer behavior, which is tightly connected to food technology, microbiology, and chemistry. Besides these relatively traditional sciences, there is an increasing importance for sociology, and packaging technologies.

4. Discussion and Conclusions

The results of the bibliometric analysis have highlighted the importance of consumer-related food safety research. Our H1 hypothesis has been supported because the number of relevant publications has increased exponentially. The concept of food safety has gained in importance in the last decades. This fact can be explained by different factors, as the intensification of international food trade, globalization, the emergence of new technologies, food safety scandals, and the application of food safety as a non-tariff trade barrier, have all increased public interest in food safety problems. Besides the positive aspects of increasing importance, some considerable inequalities and anomalies can be seen in publications. Our research has shown that although food safety is most critical in developing states (first of all in Africa), the majority of academic publications that deal with this problem come from developed states. Thus, the H2 hypothesis has been proven, but it is a positive development that the concentration of countries producing the academic articles has decreased, and there has been an increase in the number of developing countries as producers of academic publications. The dynamics of this field are well reflected by the structure of the focal problems.

The statistical characteristics of the distribution of publications in different journals and according to authors do not follow the generally established rules of academic publications by Bradford's law. This fact can be explained by the multidisciplinary character of the domain. It is very important to see that there are dynamic changes in the portfolio of journals publishing in FSCBI realms. The most successful and important journals are the open-source types. Lotka's law is applicable, but the level of fitting of theoretical equations is decreasing. This fact highlights that there is an increasing number of important actors being active in the FSCBI field. In summary, it can be stated that we have partially been able to prove the H3 hypothesis.

The analyses of ontological foundations and structural changes support the H4 and H5 hypotheses on the development and dynamics of the FSCBI field.

Based on the most recent years of development of the science, some future directions can be determined, all of which can be connected to the Sustainable development goals. The most important of these are summarized in Table 9.

In summary, it can be stated that food safety, consumer behavior and sustainability are inseparable and will inspire a wide range of research in the decades to come. This can be explained by the immense complexity and importance of the subject. The most important sub-regions of research are summarized in Figure 11.

Table 9. Contribution of research on food safety–consumer behavior interaction to the achievement of the Sustainable Development Goals of the UN.

Goal Number and Short Title	Cluster Numbers according to Different Classification Methods	Some Specific, Suggested Research Aspects
No. 1, No poverty	I/11; II/1; II/9; I/16	Food safety aspect of social food problems, food safety of conditional and unconditional cash transfers [74]
No. 2, Zero hunger	I/11; II/1; II/11; I/16	Increasing the food safety level in the developing world [75]
No. 8, Good health and well being	I/7; I/8; I/12 III/1	Good health and well-being/food safety aspects of the nutrition of people with diseases or elder people [76]
No. 4, Quality education	I/3; II/3; II/4	Upgrading the food safety related education at all levels of the education system, overarching the life cycle of individuals [77]
No. 5, Gender equality	I/9; I/10; II/12	Better division of food-related activities and responsibility within the families [78]
No. 6, Clean water and sanitation	III/4, III/5	Decreasing foodborne diseases by improving the water quality used in agriculture and food processing [79]
No. 7, Affordable and clean energy	I/14; I/17	The utilization of alternative, sustainable energy resources for food preservation and preparation [80]
No. 8, Decent work and economic growth	I/14; II/2	Harmonization of economic growth and food safety [18]
No. 9, Industry, innovation and infrastructure	I/2; II/7; II/8; III/2	Integration of the latest developments of information science [81], data mining [82] and nanotechnology [83] into the food chain for the enhancement of food safety
No.10, Reduced inequalities	I/11; II/5; II/6	Food safety problems in case of multiply disadvantaged groups [20]
No. 10, Sustainable cities and communities	I/17; II/11; III/3;	Increasing the food security of the urban poor, development of short supply chains [10]
Responsible consumption and production	I/1; I/4; I/12; II/3; III/3, III/6	Complex optimization of the food system aimed at decreasing food waste and increasing food security [84]
Climate action	I/17; III/3	Tackling challenges of climate change by the introduction of Genetically modified plants, taking consumer reactions into consideration [85]
Life below water	I/5; I/6; II/8; III/4	Food safety aspects of microplastic debris in marine ecosystems [86]
Life on land	I/5; I/6; II/8; III/4	Harmonization of sustainable agricultural practice with food safety demand [87]
Justice and institution building	I/8; II/6	Improvement of embeddedness of food safety-related regulation into national and international legal regulatory systems [88]

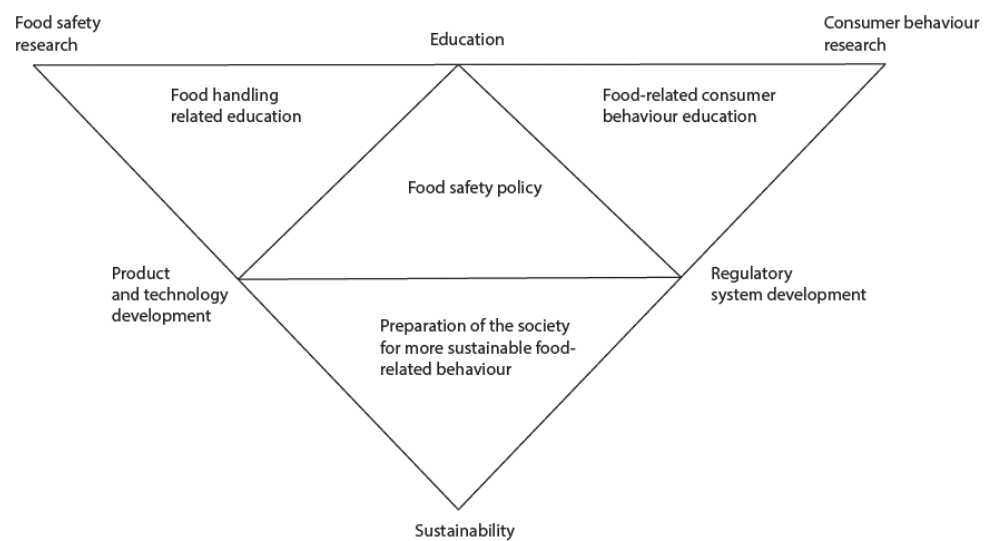


Figure 11. The food safety–consumer behavior–sustainability continuum.

This triangle model is the authors' own construction; based on numerous workshops and discussions with leading specialists on the topics, this conceptual and visual model have seemed to be the most suitable. Similar visualizations of complex systems have been applied in other fields of life, e.g., in controlling [89].

Food safety research has an important, joint set with education. Food safety, education, and product development technology are relatively well separable reigns of knowledge because the enhancement of food safety should be built on two pillars: increasing the food safety-related knowledge of each and every member of society, working in different positions in the food chain (using the evergreen commonplace: “from farm to fork”) and the consumers. On the other hand, the development of new technologies (e.g., aseptic methods of production) can enhance product safety, but new technologies (e.g., novel food preservation methods [90]) and products (e.g., insects as food in Europe [91]) also generate new problems in the field of food safety, which enhance the demand for continuous consumer education. It is well proven [92], that global food production resources would not be sufficient to offer enough food for all in the world if, as a consequence of the increasing welfare and purchasing power, the citizens of developing states wanted to follow the consumption patterns established by inhabitants of the developed states. Under these conditions, the importance of sustainability further increases. This can be achieved by product and technology development (e.g., cold plasma technologies [93]), education (e.g., consumer education to decrease waste [94,95]), as well as regulatory system development (e.g., decreasing the environmental burden by the circulatory use of packaging, promoted by the regulatory system [96]). This quadrant could be divided into two triangles: the basic pillars of food safety policy constitute the regulatory, education, and innovation component. The sustainable development of the society can be achieved by harmonizing technology development, the regulatory framework, and the long-range sustainability policy of the society. The results on consumer behavior can supply direct pieces of information for the fine-tuning of the regulatory system, goal setting, methodological development and quality controlling of the education. The Food consumer behavior, the education–product and technology development–sustainability trapezium consists of three triangles: food-related consumer behavior education, food safety policy, and the preparation of the society for more sustainable food-related behavior. In summary, we see an immense complexity of food safety-related problems. Recent decades have witnessed an unprecedented development, but there are numerous relatively lesser-known fields. The most important of these are as follows:

1. Econometric quantification of the consequences of food safety, up-and downscaled to different socioeconomic entities;
2. Food safety problems in developing countries where the food (un)safety and food (in)security go hand in hand;
3. Food safety in welfare states among vulnerable groups, first of all, ethnic minorities, handicapped people, elderly people, mentally ill consumers;
4. Food safety aspects of emerging technologies.
5. Possibilities and integration of results of food safety and sustainability research into national and international legislation framework.

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