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The impact of Brazilian food science over the past two decades. A critical review and meta-analysis

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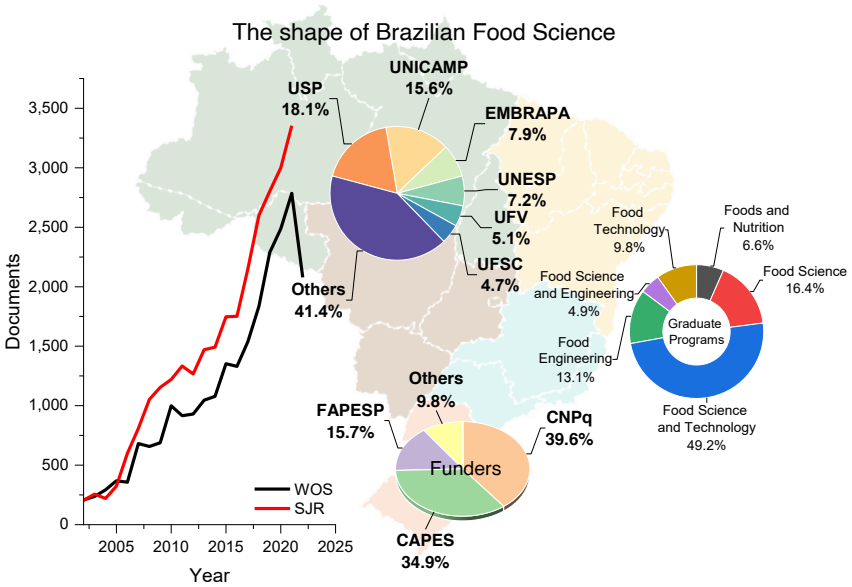
Abstract

Among the many research areas that have significantly leveraged science in Brazil over the last two decades, food science stood out as one of the most prominent subgroups in agricultural sciences. Studies involving chemistry, biochemistry, nutritional, physicochemical, biological, microbiological, safety, digestibility, preservation, bioactivity, toxicity, processing effects, regulations, authentication, and other properties of food emerged as critical topics and proved to be of great relevance along with other fields of science. Although most developed countries count on massive budgets and public investment in research, Brazil still faces considerable challenges in adequately funding studies in this vital area. However, despite low budgets and a few public policies to leverage the food science area, Brazil reached the sixth position amongst the most relevant worldwide and the most prominent Latin American country in the field over the past 20 years. This review critically discusses the advances and relevance of Brazilian food science research and its overall impact worldwide, highlighting the most researched topics, the higher-producing universities, investments in the field, and the challenges of continuing to grow.

Keywords: Agricultural sciences; food chemistry; Brazilian research; quality of science; scientific production; VOSviewer.

Graphical Abstract



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ROYALDATASET

1. Introduction

Scientific production worldwide has been increasingly growing over the last decades, and the impact of research studies can be noticed through the various modern technologies and the numerous products currently available to consumers daily. Most metrics used to evaluate the performance of each country's science include calculating the scientific documents, citations, and h-index. **Fig. 1** shows the most relevant countries in terms of overall scientific production in the period comprising between 1996 and 2021. According to the Scimago Journal & Country Rank – SJR, the United States (USA) is ranked as the first country with the highest number of documents, corresponding to 21% of total items in the database, followed by China and the United Kingdom (UK), which accounts for 12 and 6% of total documents, respectively. A similar ranking was observed regarding the number of citations and h-index (SCImago, 2022).

Brazil ranks 14th worldwide with 2% of documents and is the leading country in Latin America concerning the overall number of documents (48%), citations (44%) and the h-index (690), followed by Mexico (16% 16%, and 536, respectively) and Argentina (10%, 12% and 510, respectively). Such indicators suggest Brazil's impact and importance in worldwide science and indicate that the country has significantly contributed to scientific production over the past decades. Furthermore, Brazil ranks fifth in the worldwide number of documents and citations among agricultural sciences and is also the leading nation among Latin American countries on the topic. The same pattern was observed for the food science subcategory (Clarivate, 2023; SCImago, 2022).

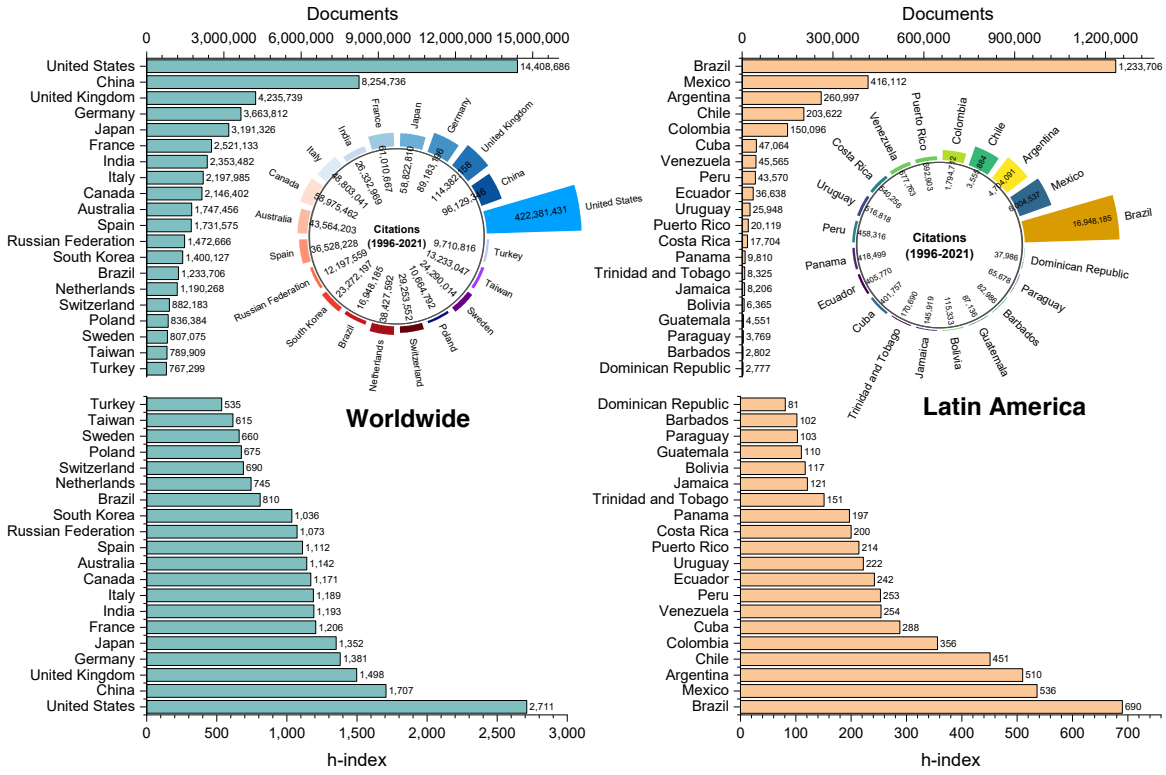

Fig. 1 Top 20 countries with the highest number of documents, citations, and h-index (left) compared to the top 20 Latin Americas countries (right) from 1996 to 2021. Source: Scimago Journal & Country Rank (2022).

Food science is a field of study that has a significant role in agricultural sciences, whose related research has been improved yearly in the last decades. The Institute of Food Technologists (2023) describes food science as a category that gathers many disciplines, such as biochemistry, biology, and chemical engineering, aiming to improve food products for consumers. Consequently, many research areas are intrinsically linked to food science. This research area is also concerned with understanding the principles underlying the physical, chemical, and biochemical nature of food and how to manipulate it (Potter & Hotchkiss, 2012). Additionally, food science is a discipline in which those subjects evaluate the causes of food deterioration (Owusu-Apenten & Vieira, 2023). According to Scimago Journal & Country Rank – SJR, food science is a key topic category among

agricultural and biological sciences, along with animal science and zoology, agronomy and crop science, and ecology, evolution behavior, and systematics (SCImago, 2022).

Research on the Web of Science Core Collection (WOS) platform retrieves 820,684 documents from the main category "Food Science and Technology" (FST) dated between 1945 and 2023, also showing increasing trends in the number of documents yearly, confirming that such a field of study has global importance (Clarivate, 2023). Similarly, the timeline on the SJR database retrieves 170 documents between 2001-2002 related to food science in Brazil while returning 3,353 in the period ranging from 2021 to 2022, indicating a 20-fold increase in the number of yearly publications after two decades (SCImago, 2022). Furthermore, the same trend has been verified in the WOS and Scopus databases, confirming that such a field of study has significant relevance among other science areas (Clarivate, 2023; Elsevier, 2023).

Although presenting increasing trends in items related to FST published over the last years to 2021, due to the overwhelming impacts of COVID-19 on research worldwide (Harper et al., 2020; Omary et al., 2020; Rashid & Yadav, 2020; Tuttle, 2020), documents in this field had an approximate 17% decrease in 2022 concerning the previous year (Clarivate, 2023). However, considering the main indicators regarding scientific production, it is believed that this scenario may return to show increasing trends soon.

Most of the documents in the WOS collection in FST subcategories are related to chemistry (26.3%), agriculture (23.2%), nutrition and dietetics (9.4%), biotechnology and applied microbiology (8.4%), biochemistry and molecular biology (4.1%), toxicology (3.5%) and engineering (2.9%). However, FST research includes more than 60 subcategories in the WOS database. The main meso-topics include the primary subject of food science and technology (14.6%), followed by phytochemicals (8.7%), dairy and animal sciences (7.2%), smell and taste science (4.1%), lipids (3.7%) and crop science (3.4%) (Clarivate, 2023). The leading countries with the highest number of published items between 2002 and 2022 are China, the United States, Spain, Japan, Italy, and Brazil (Clarivate, 2023; Elsevier, 2023; SCImago, 2022). These data suggest that the Latin American country has a notable role in leveraging global food science due to the substantial numbers and high-quality research in the field in recent years.

Thus, this critical review aimed to evaluate the leading indicators of quality regarding Brazilian food science and its performance compared to other nations worldwide over the past two decades. We have also assessed the importance of funding agencies, Brazil's government's role in higher education personnel, and the impact of food science graduate programs on the metrics for general quality.

2. Methodology

This review and meta-analysis have been performed using different databases named Scopus (https://www.scopus.com/), Web of Science Core Collection – WOS (https://www.webofscience.com/), Scimago Journal & Country Rank – SJR (https://www.scimagojr.com/), and Sistema de Informações Georreferenciadas – GEOCAPES (https://geocapes.capes.gov.br/geocapes/).

According to data availability, documents and other related information were surveyed, considering a 20-year gap from 2001 to 2021 for SJR and from 2002 to 2022 for the other databases. A meta-analysis was performed using VOSviewer (https://www.vosviewer.com/) (van Eck & Waltman, 2010) with data from the WOS platform choosing "food science & Technology" as the main category, retrieving 24,158 results from January 1, 2002, to December 31, 2022 (date of publication), restricting the country/region to Brazil. In addition, an analysis of coauthorship and cooccurrence of keywords was performed. The data was evaluated on VOSviewer using a full counting method and employing the association strength method for normalization. The clustering was based on a resolution of 1.00, and the weights to show grouping among keywords were based on occurrences. Graphs and images were produced using VOSviewer (van Eck & Waltman, 2010), OriginPro 2022 (OriginLab, Northampton, USA), and CorelDRAW v. 24 (Corel Corporation, Ottawa, Canada).

3. Food Science worldwide

According to the Web of Science Core Collection (WOS), there are 524,560 documents in the 'food science and technology' category in the period ranging between 2002 and 2022 (Clarivate, 2023). On the other hand, Scimago Journal & Country Rank (SJR) retrieves 685,753 documents in the "food science" subgroup (SCImago, 2022). The discrepancies in the number of items are expected since each platform has its own algorithm and uses specific topics to assemble documents from each area. However, both platforms reveal that food

science is among the most relevant agricultural sciences worldwide.

Fig. 2 shows the evolution of food science documents over the last 20 years according to the WOS and SJR databases. The chart highlights an increasing trend in worldwide (**Fig. 2a**) and Brazilian (**Fig. 2b**) documents over two decades.

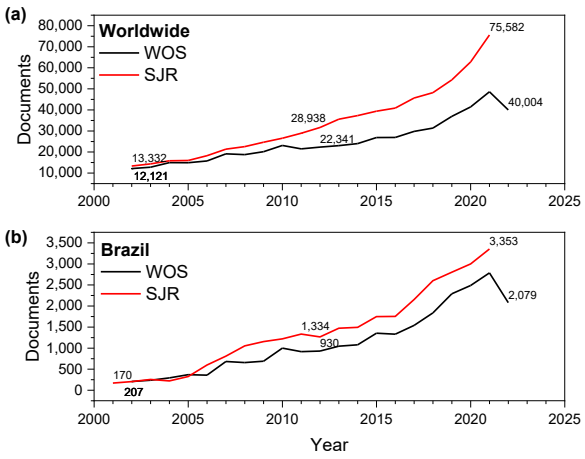

Fig. 2 Comparison of the evolution of (a) worldwide and (b) Brazilian documents in the food science area over 20 years (2001-2021 for SJR and 2002-2022 for WOS). Source: Scimago Journal & Country Rank (2022) and Web of Science Core Collection (Clarivate, 2023).

Although presenting the same increasing behavior in the number of documents, a significant difference has been observed in the last two years for WOS data, which reveals a decrease in food science items after 2021. This reduction may be an effect of the COVID-19 pandemic, which caused harmful impacts on general science worldwide (Rashid & Yadav, 2020), mainly in higher education students who are the main responsible for publishing academic scientific documents (Aristovnik et al., 2020). While some research areas (such as health sciences) presented a massive increase in the number of publications due to the coronavirus outbreak (Harper et al., 2020; Omary et al., 2020; Rashid & Yadav, 2020; Tuttle, 2020), a decrease in the worldwide production of agricultural science documents, including food science has been verified.

Due to many lockdowns over the last few years, most researchers were unable to go to the laboratories to perform and continue their studies, which caused a significant decline in published works. As a result, worldwide scientific production in food science suffered a substantial drop in 2022, representing about an 18% decrease in the number of documents in 2022 compared with 2021 (**Fig. 2a**). The same trend has been observed in Brazil, whose production in the topic reached its main peak in 2021, exhibiting a 25% decrease on the number of published items in 2022 as compared to the previous year (**Fig. 2b**).

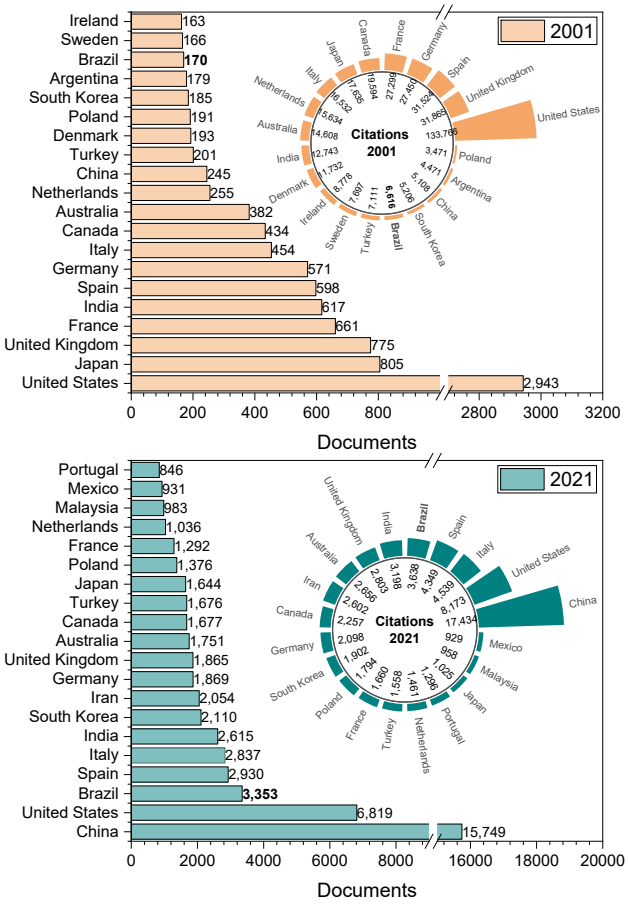

Fig. 3 Comparison of the top 20 countries with the highest number of documents and citations in the food science area in 2001 and 2021. Source: Scimago Journal & Country Rank (2022).

A comparison of the global scenario related to the number of documents in food science over 20 years has been performed, and the 20 most relevant nations in each year were ranked (**Fig. 3**). The USA had the highest number of publications and citations in 2001. Interestingly, Japan was the second most productive country on the topic but ranked seventh on the citations list. The United Kingdom (UK) was third in the number of published items and second in the number of cited items. However, the ranking has completely changed after twenty years; China outperformed all countries in the number of publications and citations, taking the top global ranking. The USA ranked second (documents and citations), and Brazil currently figures as the third most relevant country regarding the number of publications and shows the fifth position in the list concerning citations in food science.

The charts in **Fig. 4** compare the yearly scores (documents and citations) of the five most relevant countries on the food science topic: China, the USA, Brazil, Spain, and Italy. The graph reveals that all of them presented the same increasing trend in the number of documents (**Fig. 4a**), contrasting with a decreasing tendency in the number of citations (**Fig. 4b**) over the last few years. It is worth mentioning that the USA had the best scores for documents and citations from 2001 to 2012, when China overpassed the American country in the number of documents, also presenting the highest citations peak after 2016.

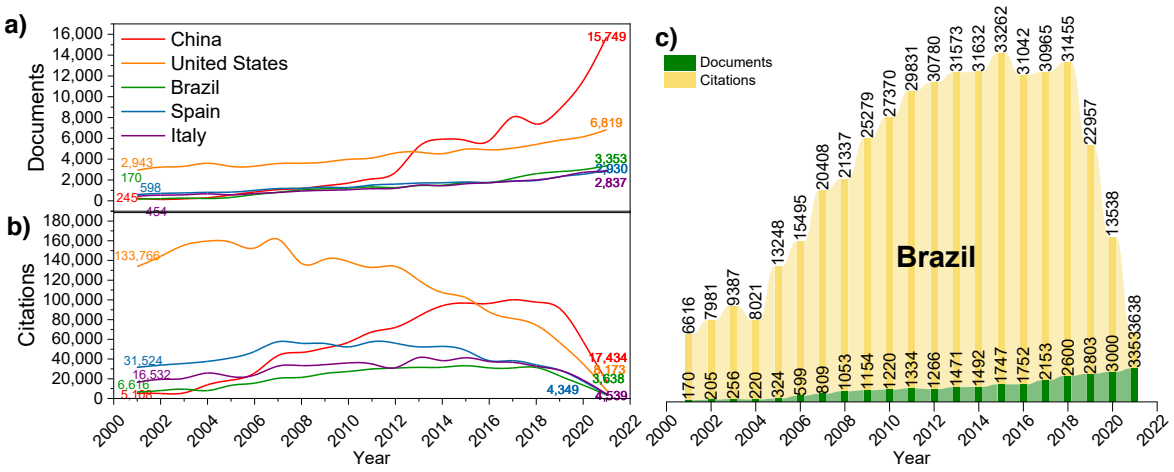

Fig. 4 Comparison of the yearly evolution of (a) documents and (b) citations of the top 5 countries with the most relevant production in the food science area from 2001 to 2021 and (c) a highlight of Brazil's scores. Source: Scimago Journal & Country Rank (2022).

The highlight for Brazil in **Fig. 4c** also demonstrates that after years of increasing productivity associated with a high number of citations, whose major peak was observed in 2014, such records started to decline, presenting an 88% decrease in citations in 2021 compared to 2014. As previously commented, this decreasing behavior can be associated with many factors as the decrease in investment in science and technology during the last decade (Daré, 2021; IPEA, 2021; Shalders, 2021) and the effects of the COVID-19 outbreak, which caused significant negative impacts on worldwide scientific production (Harper et al., 2020; Omary et al., 2020; Tuttle, 2020).

According to data from the 2021 UNESCO Science Report, 80% of worldwide countries invest less than 1% of their gross domestic product (GDP) in research and development (R&D). Despite a 20% increase in global investments in science and technology between 2013 and 2018, there is a dissimilarity marked by excessive concentration in some countries. Of these 20%, 63% represent combined investments from China and the United States. Brazil allocates around 1.15% of its GDP to R&D. Between 2014 and 2018, the period analyzed in the Report, the total invested in science decreased by almost 16%, with a 50% drop in the Ministry of Science, Technology, Innovations and Communications (MCTI) budget (UNESCO, 2021). However, the resilience of researchers has allowed the number of scientific works and the world contribution of Brazilian science not to decrease (Daré, 2021).

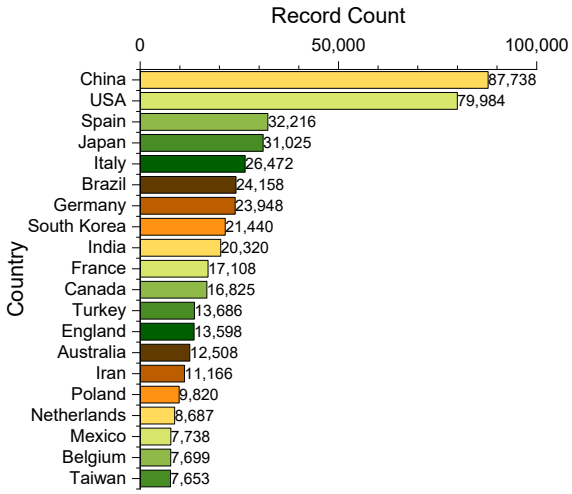

Fig. 5 The ranking of 20 main countries publishing in food science and technology based on the number of documents from 2002 to 2022 (b). Source: Web of Science Core Collection (Clarivate, 2023).

As illustrated in **Fig. 5a**, the WOS database shows that over the last 20 years, most publications on food science came from China (16.7%), the USA

(15.2%), Spain (6.1%), Japan (5.9%), Italy (5.0%), and Brazil (4.6%). In addition, the data reveal that the high number of Brazilian documents in the field surpasses developed countries such as Germany, South Korea, France, Canada, and England, confirming its relevance on the global stage.

Fig. 6 depicts the document types, main subject categories, and languages of published literature worldwide in the last 20 years. Most documents in the field are original articles (81.5%), review articles (5.5%), and proceeding papers (4.4%). Other types of documents account for 9.2% of documents (**Fig. 6a**). Among the main WOS categories of published items, chemistry applied is the leading topic (21.8%), followed by nutrition dietetics (10.7%), agriculture multidisciplinary (8.9%), biotechnology applied microbiology (8.1%), agriculture dairy animal science (5.4%), biochemistry molecular biology (4.8%), and toxicology (4.2%)(**Fig. 6b**). The remaining documents are distributed in more than 60 other WOS categories.

More than 96% of the documents are published in English, and the remaining documents are available in other languages, such as German, Japanese, Czech, Polish, and Portuguese (**Fig. 6c**). WOS also indicates 87,743 entries regarding the authors' affiliations publishing in FST worldwide. As shown in **Fig. 7**, most affiliations are from the United States Department of Agriculture - USDA (USA) (1.96%), followed by Consejo Superior de Investigaciones Cientificas - CSIC (Spain) (1.67%), INRAE (France) (1.45%), and Jiangnan University (China) (1.21%). The database reveals that among the top 30 affiliations, China has 9 institutions, while the USA shows 5 organizations, followed by France with 4 institutions. On the other hand, Brazil, Canada, and India have 2 affiliations on the list. It is worth mentioning that from more than 80 thousand entries in the WOS, 31,030 records do not contain data regarding the affiliation in the field analyzed, making it difficult for the algorithm to evaluate the documents accurately.

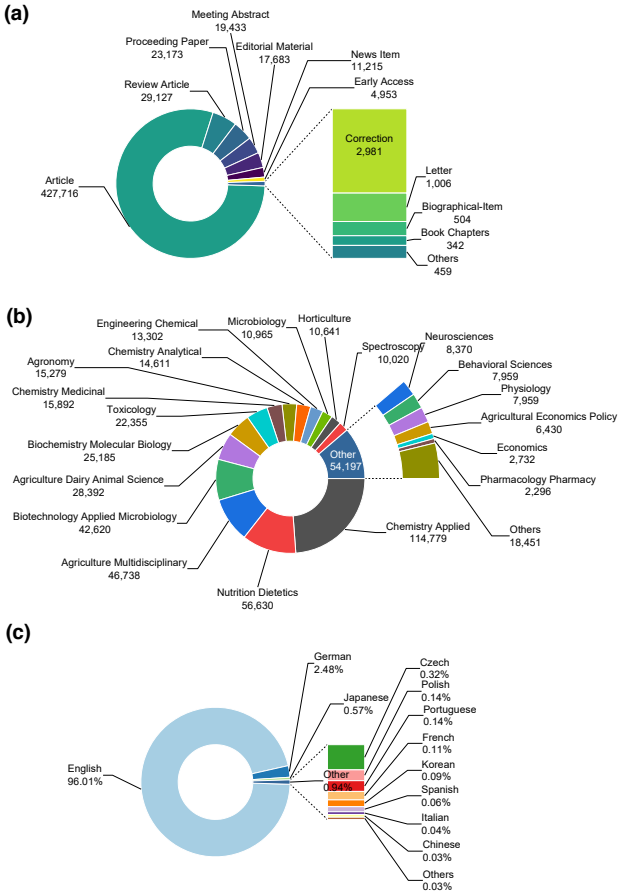

Fig. 6 Main types (a), WOS categories (b), and languages (c) of worldwide documents published in food science and technology from 2002 to 2022. Source: Web of Science Core Collection (Clarivate, 2023).

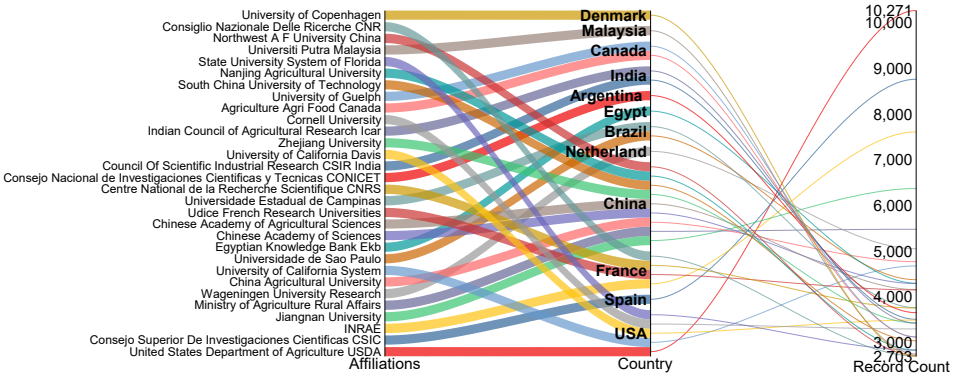

Fig. 7 Top 20 affiliations from worldwide food science and technology documents published between 2002 and 2022 linked to their countries. Source: Web of Science Core Collection (Clarivate, 2023).

Fig. 8 depicts the top 100 list of the primary authors publishing in FST and their major affiliation countries. Analyzing authorship, the Web of Science database reveals that 17,794 entries associated with publications from China, corresponding to 3.9% of the number of documents, are grouped as 'anonymous.' Most of them are news items (9,868), followed by editorial material (6,425), articles (1,053), and meeting abstracts (259). Those documents are enlisted as "anonymous" probably because such publications come from organizations, governmental agencies, and other related institutions, as scientific documents cannot be published anonymously.

The list in **Fig. 8** also shows that there are 49 authors from China, while 27 are affiliated with USA-based institutions, 9 are from South Korea, and Spain has 4 organizations ranked as well. Brazil has a single author in the top 100 with the highest number of documents in the field, Maria Lucia Zaidan Dagli (Universidade de São Paulo), whose studies are mostly related to FST and toxicology.

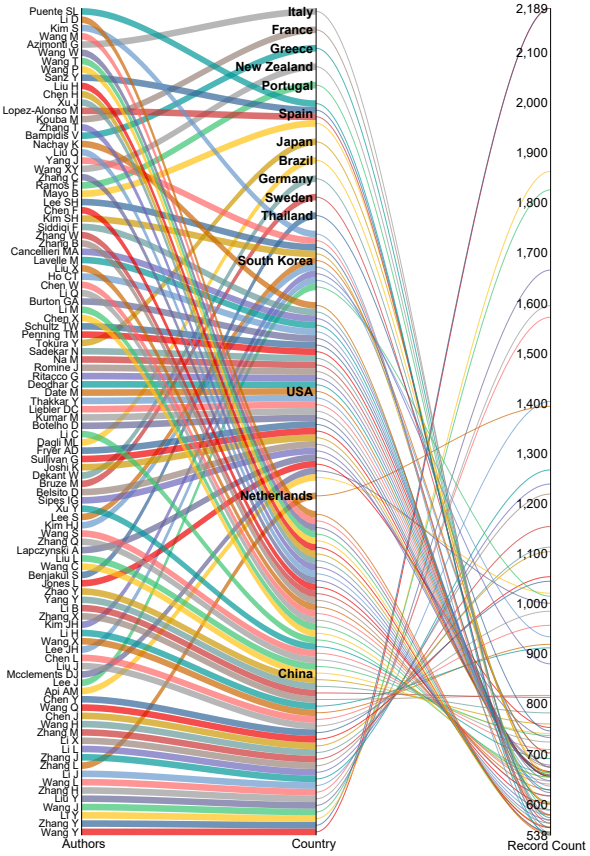

Fig. 8 Top 100 authors from worldwide documents published in food science and technology between 2002 and 2022 linked to their countries. Source: Web of Science Core Collection (Clarivate, 2023).

The leading publishers of food science documents are highlighted in **Fig. 9**. Like most research fields, Elsevier ranks first and shares 30.4% of documents in the WOS database. In second place is John Wiley and Sons (Wiley) with 13.5% items. The list also includes the American Chemical Society – ACS (6.2%), Springer Nature (5.2%), Taylor & Francis (5.1%) and MDPI (5.2%) among the most prominent publishers. Also, there are about 214 publishers whose documents are cataloged in the database. Sociedade Brasileira de Ciência e Tecnologia de Alimentos (SBCTA), which issues a single journal on the topic (Food Science and Technology), is in the 22nd place in the list.

Clarivate (2023) provides citation topics with algorithmically derived citation clusters based on a three-level hierarchical document-level classification system. The three levels of the hierarchy and their content according to the 2021 clustering include macro-topics (10), meso-topics (326), and micro-topics (2444). For example, as shown in **Fig. 10**, the meso-topics in the food science and technology main area (15%) are segmented into phytochemicals (11.5%), dairy and animal sciences (6.7%), smell and taste sciences (4.6%) and lipids (3.9%). However, the FST documents on the WOS platform are divided into more than 320 topics.

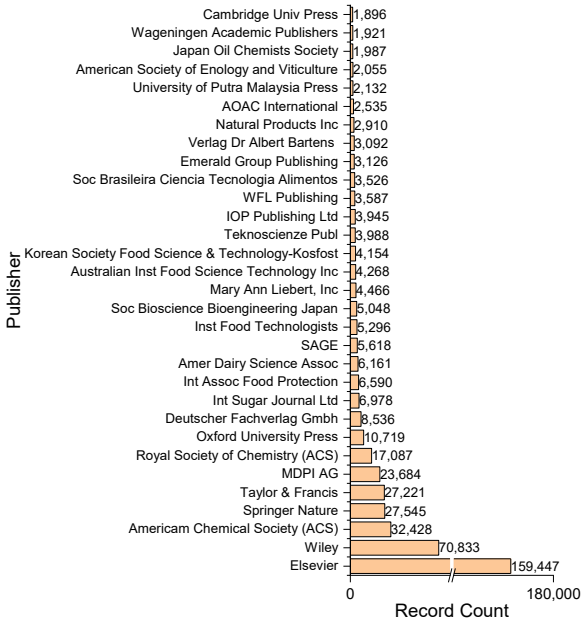

Fig. 9 Main publishers and the corresponding number of worldwide documents published in food science and technology from 2002 to 2022. Source: Web of Science Core Collection (Clarivate, 2023).

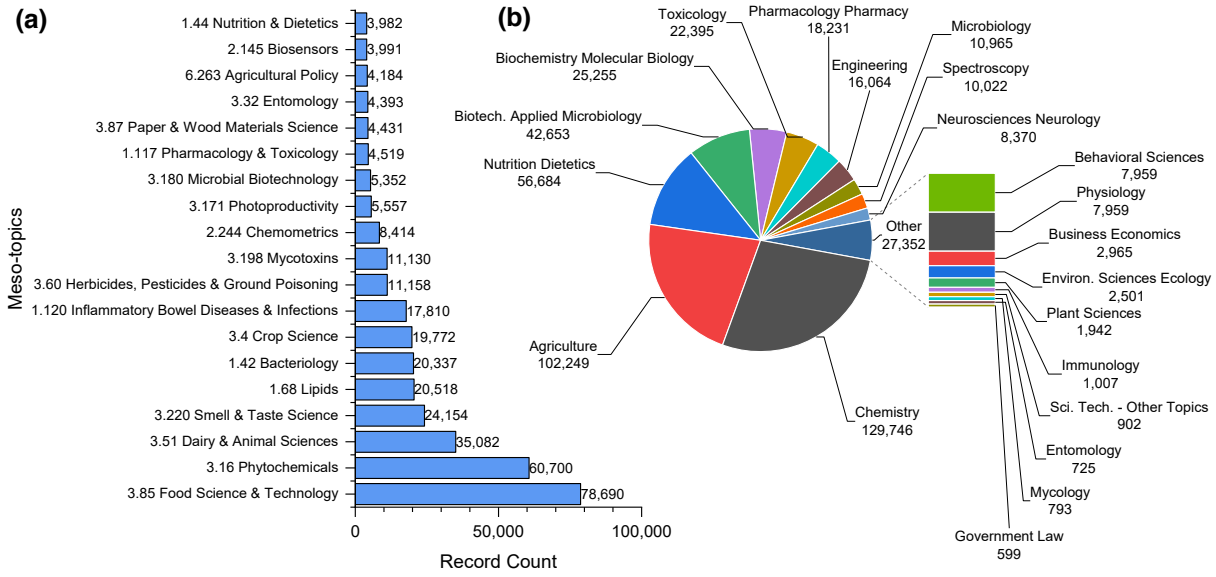

Fig. 10 Main meso-topics (a) and research areas (b) from worldwide documents published in food science and technology from 2002 to 2022. Source: Web of Science Core Collection (Clarivate, 2023).

The leading funding agencies for food science research are displayed in **Fig. 11**. The dataset shows that the National Natural Science Foundation of China (NSFC) is the principal funding organization corresponding to 7.5% of all 524,560 documents in the WOS database. The second agency is the European Commission, with 2.5% of items. The dataset reveals that Brazil's National Council for Scientific and Technological Development (CNPq) and the Coordination for the Improvement of Higher Education Personnel (CAPES) figure in the third and fourth places in the ranking, responsible for funding 1.8 and 1.6% of documents, respectively. The database also shows that the Fundação de Amparo a Pesquisa do Estado de São Paulo (FAPESP) ranks fifteenth and contribute to 0.73% of all documents in this category. This data confirms the major role of Brazilian funding agencies in the development and leverage of global food science.

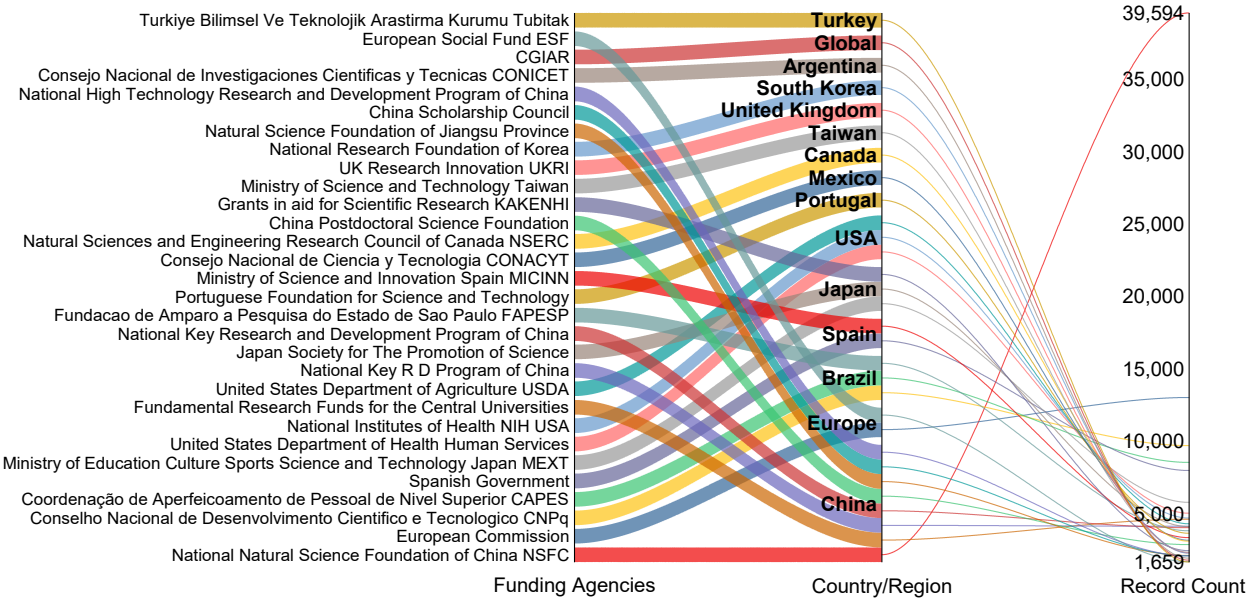

Fig. 11 Main funding agencies from worldwide documents published in food science and technology from 2002 to 2022. Source: Web of Science Core Collection (Clarivate, 2023).

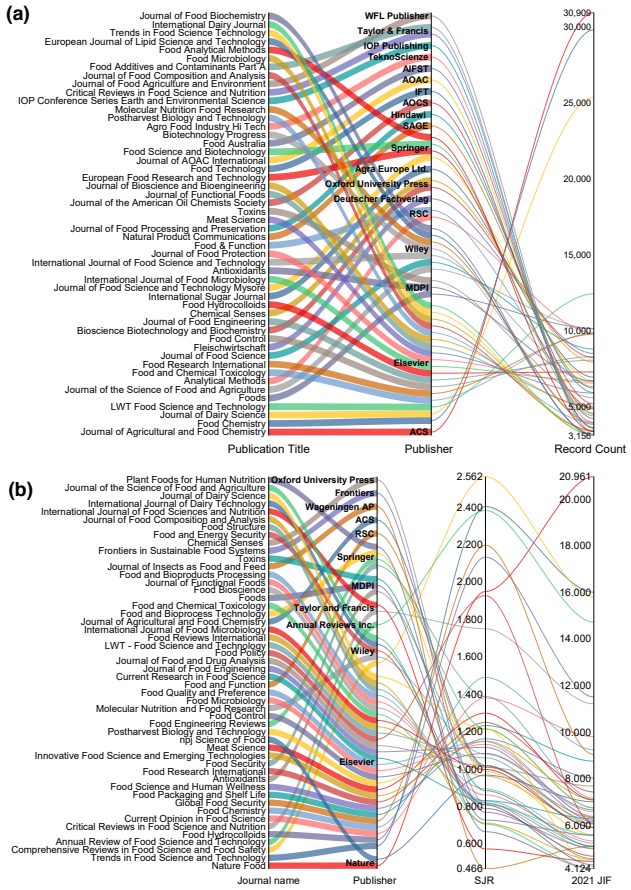

Fig. 12 Ranking of the top 50 publication titles based on the number of publications from 2002 to 2022 (a) and according to SJR and JCR impact factor – JIF (b). Source: Web of Science Core Collection (Clarivate, 2023) and Scimago Journal & Country Rank (2022).

The ranking of the major journals publishing in FST based on the number of documents from 2002 to 2022 is illustrated in **Fig. 12a**, while **Fig. 12b** depicts the Impact Factor of ranking based on the 2021 Journal Citation Reports Impact Factor (JIF) and 2021 SJR. The core title is the Journal of Agricultural and Food Chemistry, issued by the ACS, which has 5.89% of documents in the Web of Science database. Next on the list is Food Chemistry (5.67%), Journal of Dairy Science (4.83%), and LWT (2.37%), issued by Elsevier. Finally, Foods published by MDPI figures in the fifth place in the list, contributing 1.94% of all FST documents. The ranking indicates that there are 19 different publishers on the top 50 list, led by Elsevier, which issues 18 journals, followed by Wiley (7) and Springer (4).

Taking into account the ranking based on the impact factor, the main journal is Nature Food (JIF = 20.961), a recent journal launched by Springer Nature, followed by Trends in Food Science and Technology (JIF =16.002), Comprehensive Reviews in Food Science and Food Safety (15.786) and Annual Review of Food Science and Technology (14.714), which are journals dedicated to publishing only reviews (**Fig. 12b**). On the other hand, the SJR list shows Nature Sustainability (SJR = 5.789) as the leading publication title in food science; however, this journal is not grouped to food science in the Journal Citation Reports platform. The second highest qualified title in the SJR database is Comprehensive Reviews in Food Science and Food Safety (SJR = 2.562), followed by Trends in Food Science and Technology (SJR = 2.402) and Annual Review of Food Science and Technology (SJR = 2.381).

4. Food Science in Latin America

From 524,560 documents related to food science and technology available in the WOS Core Collection, the platform retrieves 43,651 documents when filtering the results to Latin America. Of them, 32.2% are all open access, 14.2% are gold open access, 5.7% are “gold-hybrid,” 4.7% are “free to read,” 16.8% are green published, 1.05% are green accepted, and 6.1% are green submitted. WOS indicates that there are 90,485 authors in those documents. Brazil (55%) is the leading nation among Latin American countries publishing in FST, followed by Mexico (17%), Argentina (13%), and Chile (6%) (**Fig. 13a**). The database shows an increasing trend in the number of publications over the past 20 years, whose peak was observed in 2021. It also demonstrates that 10.6% of all documents issued in the last two decades were published in 2021, while 7.9% were issued in 2022 (**Fig. 13b**).

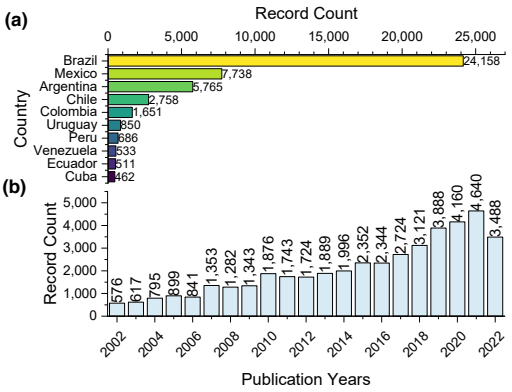

Fig. 13 Top 10 Latin American countries with the highest number of documents published in food science and technology between 2002 and 2022 (a), and the evolution of publications in the same period (b). Source: Web of Science Core Collection (Clarivate, 2023).

The leading publisher of those documents is Elsevier (40%), followed by Wiley (14%), Springer Nature (6.7%), and Taylor & Francis (5%). The primary language used in Latin American publications is English (97.9%); documents written in Portuguese and Spanish represent 1.5 and 0.4% of documents. Less than 1% of documents are written in French, German, and Italian.

Fig. 14 shows that Brazil is the most relevant country regarding the number of published documents and citations, followed by Mexico, Argentina, Chile, and Colombia. The h-index, proposed by John Hirsch, was defined as the number of articles with citation number ≥ h and can be a valuable metric to describe a researcher's scientific output (Kelly & Jennions, 2006). Although initially created to evaluate researchers, the h-index is also used as a measure of quality regarding the scientific production of journals and countries (Mester, 2016; Montazerian et al., 2019). As a result of the high rates regarding documents and citations, Brazil also has the highest h-index among Latin American countries (161), followed by Mexico (135) and Argentina (127), proving the relevance of its research.

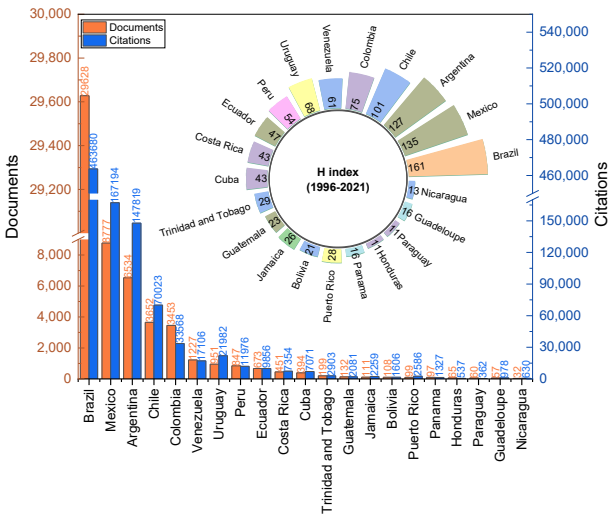

Fig. 14 Comparison of the top 20 Latin American countries with the highest number of documents and citations in the food science area between 1996 and 2021 and their corresponding h-index. Source: Scimago Journal & Country Rank (2022).

Fig. 15 shows the top 100 authors of documents associated with Latin America in the WOS database. The illustration indicates that most Latin American authorships are from Brazil (41). However, the WOS database shows that the second country of affiliation in the group is the USA (35), which belongs to North America. It also shows authors from non-Latin American countries such as Germany, Sweden, Poland, Japan, and Spain. This may be associated with coauthorship and international cooperation on studies between authors from those countries and Latin American ones. Mexico (11), Argentina, Chile, and Uruguay (2), are the following countries with the highest number of authors.

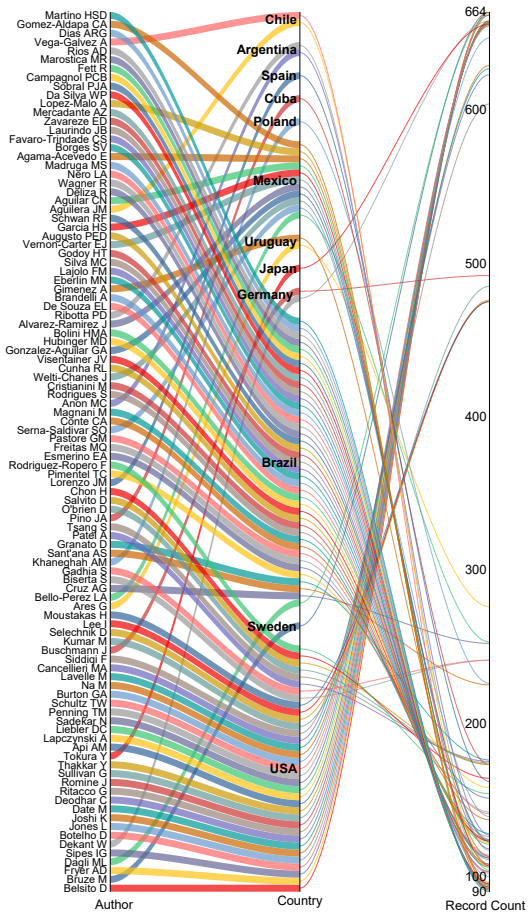

Fig. 15 Top 100 authors from documents published from 2002 to 2022 in food science and technology from Latin America (a) linked to their main countries and a highlight to the main affiliation countries. Source: Web of Science Core Collection (Clarivate, 2023).

5. Food Science in Brazil

From 43,651 documents linked to Latin America, Brazil accounts for 24,158 research items in the period ranging from 2001-2022, including research with cooperation with other non-Brazilian countries. Of them, 23,117 are from Brazilian institutions. The WOS data indicate that Brazil cooperates with 128 countries worldwide, mainly with the USA (9.2%), followed by Spain (4.1%), Germany (3.6%), Japan (3.1%), Sweden (3%), Portugal

(2.5%), Italy (1.8%), France (1.8%), Canada (1.6%), and Argentina (1%).

Fig. 16a reveals that more than 87% of the documents published from Brazil are original articles, followed by review articles (7.9%), proceeding papers (2.8%) and meeting abstracts (2.7%).

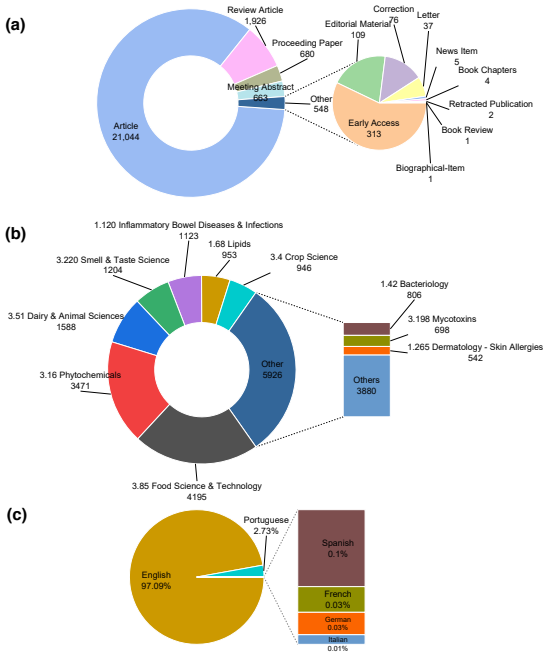

Fig. 16 Main types (a), WOS categories (b) and language (c) of documents from Brazil published in food science and technology between 2002 and 2022. Source: Web of Science Core Collection (Clarivate, 2023).

As depicted in **Fig. 16b**, the main WOS categories are chemistry applied (18%), nutrition and dietetics (11%), toxicology (7%), multidisciplinary agriculture (5.8%) and agriculture dairy animal science (5.5%). Of the 24,158 documents dating from 2002-2022 available in the WOS database related to food science and technology associated with Brazil, more than 97% are published in English (23,456), while 2.7% were issued in Portuguese (660). Less than 1% of the documents were published in other languages, such as Spanish, French, German, and Italian (**Fig. 16c**).Regarding the Open Access publications, the report also indicates that about 35% of the documents are 'all open access' (8,501), 17% are 'green published,' 15% are ϕgoldô(3,732), 8% are gold-hybrid (1,943), 7% are 'green submitted' (1,697), 5% are free to read (1,125), and 0.6% are 'green accepted' (153). Furthermore, the WOS database reveals that 65% (about 15,667 records) do not have data in the field being analyzed, indicating that those documents may be accessed under a subscription.

The WOS database shows that publications from Brazil are distributed to 127 publishers. Nevertheless, that number shows conflicting results, as different names for the same publishers were observed in the dataset. Most of the documents of Brazilian authors (42%) were published in Elsevier-issued journals, followed by Wiley (13%), SBCTA (7.7%), Springer (6.2%), Taylor & Francis (4.8%), Royal Society of Chemistry – RSC (3.2%), MDPI (2.9%) and ACS (2.8%) (**Fig. 17**).

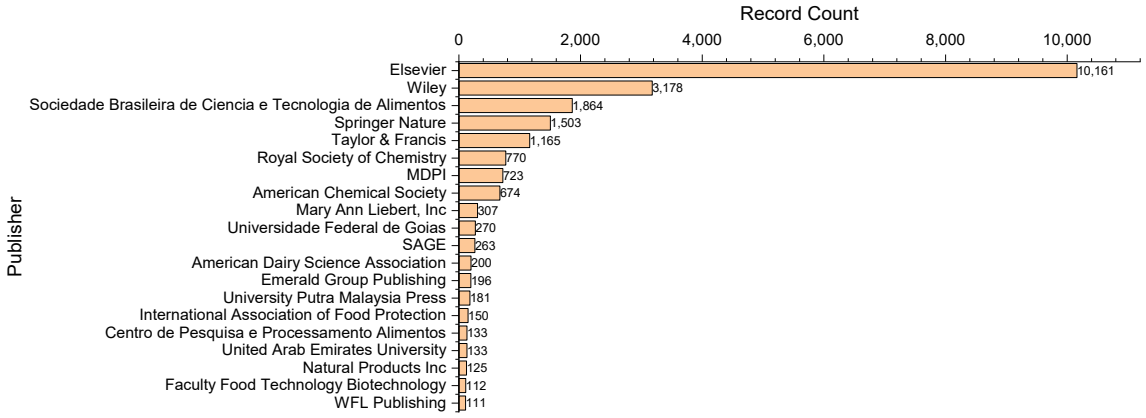

Fig. 17 Main publishers of documents from Brazil in food science and technology from 2002 to 2022. Source: Web of Science Core Collection (Clarivate, 2023).

The WOS platform classifies their main subject topics into different categories as meso-topics and research areas. As illustrated in **Fig. 18a**, in addition to food science and technology (17.4%), the documents published in this field are mainly associated with phytochemicals (14.4%), dairy & animal sciences (6.6%), smell and taste science (4.9%), inflammatory bowel diseases and infections (4.6%) and lipids (3.9%). The main research area of Brazilian research is chemistry, which contributes to

21.6% of total items, followed by agriculture (14.3%), nutrition and dietetics (11.4%), and toxicology (7.2%).

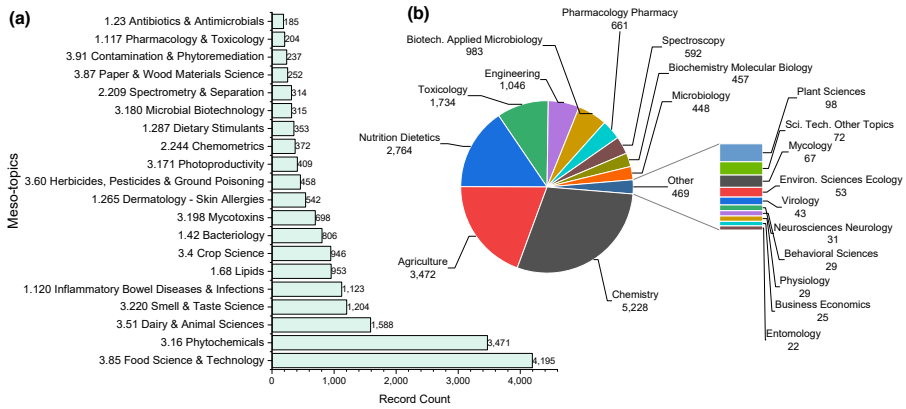

Fig. 18 Top 20 meso-topics (a) and research areas (b) from documents published in food science and technology from 2002 to 2022 in Brazil. Source: Web of Science Core Collection (Clarivate, 2023).

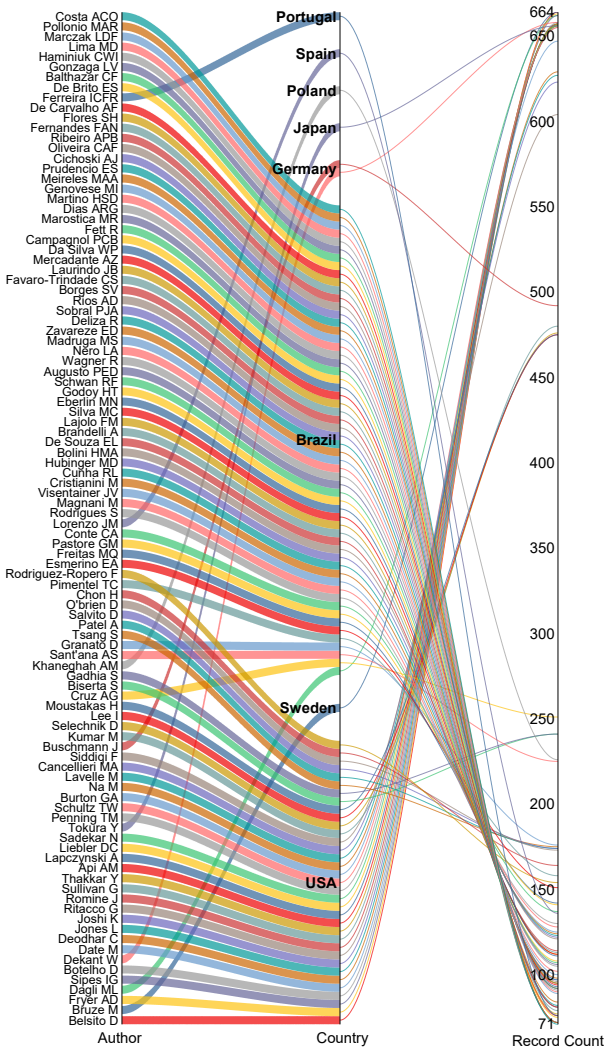

Fig. 19 Top 100 authors from documents published from 2002 to 2022 in food science and technology from Brazil (a) linked to their countries. Source: Web of Science Core Collection (Clarivate, 2023).

As shown in **Fig. 18b**, other relevant research areas also include engineering (4.3%), biotechnology and applied microbiology (4.1%), pharmacology and pharmacy (2.7%), and spectroscopy (2.4%).

Conflicting results were detected after grouping documents from Brazil to verify their authorship. As depicted in **Fig. 19**, the data analysis revealed that of 100 authors ranked in a list from the WOS database, only 59 belong to Brazilian institutions, while 33 are affiliated with the USA. Other affiliations from Germany, Sweden, Japan, Poland, Portugal, and Spain were also observed. In fact, the highest number of document records come from Donald Vincent Belsito, a researcher from Columbia University who collaborates with Brazilian authors.

The second and third listed authors, Magnus Bruze and Allison D. Fryer, are affiliated with Lund University (Sweden) and Oregon Health and Science University (USA), respectively. Finally, the fourth author on the list is Maria Lucia Zaidan Dagli, a Brazilian from the University of São Paulo. Other Brazilian authors include Adriano G. Cruz (IFRJ), Anderson A. Sant'ana (Universidade Estadual de Campinas - Unicamp), Daniel Granato (formerly from Universidade Estadual de Ponta Grossa), and Tatiana C. Pimentel (IFPR). As in the Latin American documents, the same pattern is observed in Brazilian publications whose authors are from different countries due to coauthorship with other researchers from around the world.

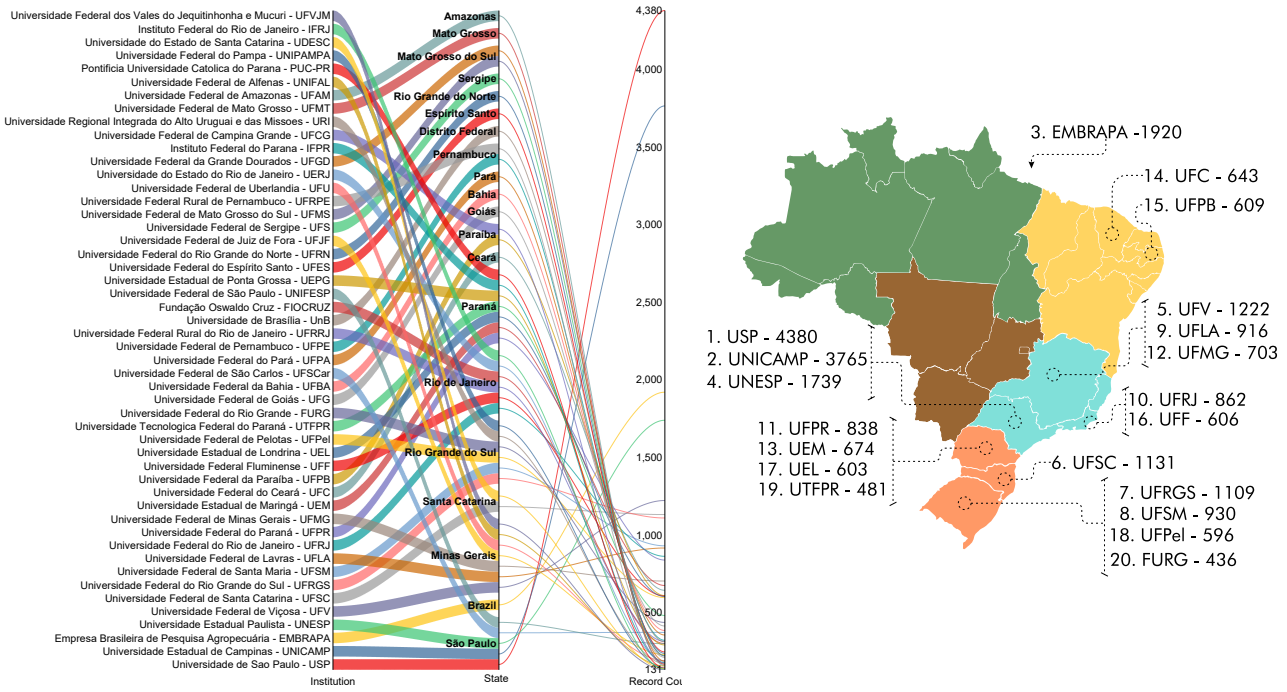

Fig. 20 Main Brazilian institutions with the highest number of publications from 2002 to 2022 in food science and technology linked to their leading states (a) the ranking of the top 20 institutions (b). Source: Web of Science Core Collection (Clarivate, 2023).

As observed in **Fig. 20**, Paraná and Minas Gerais are the leading states with the highest number of institutions (7) publishing in FST among the top 50 Brazilian organizations. The next on the list, Rio Grande do Sul and Rio de Janeiro have 6 public institutions contributing to this area, while São Paulo has 5 of them. Finally, Mato Grosso do Sul, Pernambuco, and Santa Catarina, have 2 institutions in the ranking. The other 12 states have a single institution on the list. The top 20 most relevant institutions publishing in food science in Brazil and their number of articles published between 2002 and 2022 are highlighted in the map on the right side in **Fig. 20**.

The Brazilian institutions with the highest number of documents are the Universidade de São Paulo – USP, and the Universidade Estadual de Campinas – UNICAMP contributing with 18.13 and 15.59% of documents, respectively. Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA (7.95%), a federal government agency distributed across the country, is in the third position, while Universidade Estadual Paulista – UNESP (7.20%), Universidade Federal de Viçosa – UFV (5.01%), and Universidade Federal de Santa Catarina – UFSC (4.68%) ranks fourth, fifth and sixth positions, respectively.

Due to many factors, including typos and duplicated entries related to the funding agencies on the documents in the WOS platform, conflicting results were observed, and the exact values concerning the contribution of each foundation could be over- or underestimated, as more than 7,300 funding organizations were correlated to Brazilian documents. However, it was possible to rank the major agencies, as shown in **Fig. 21**. The illustration reveals that many agencies fund studies from Brazilian authors across the globe. Most of them are supported by Brazilian institutions such as CNPq (39.5%), CAPES (34.8%), and the Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP (15.7%). The other funding organizations are mostly state foundations that leverage science and technology throughout the country. Though, funding for Brazilian research over the last 20 years also came from Europe (mainly Portugal, Spain, and UK), the USA, Canada, Argentina, Mexico, Chile, and Uruguay. Such a variety in the number of funding agencies also reflects international collaboration, which has increased in recent years.

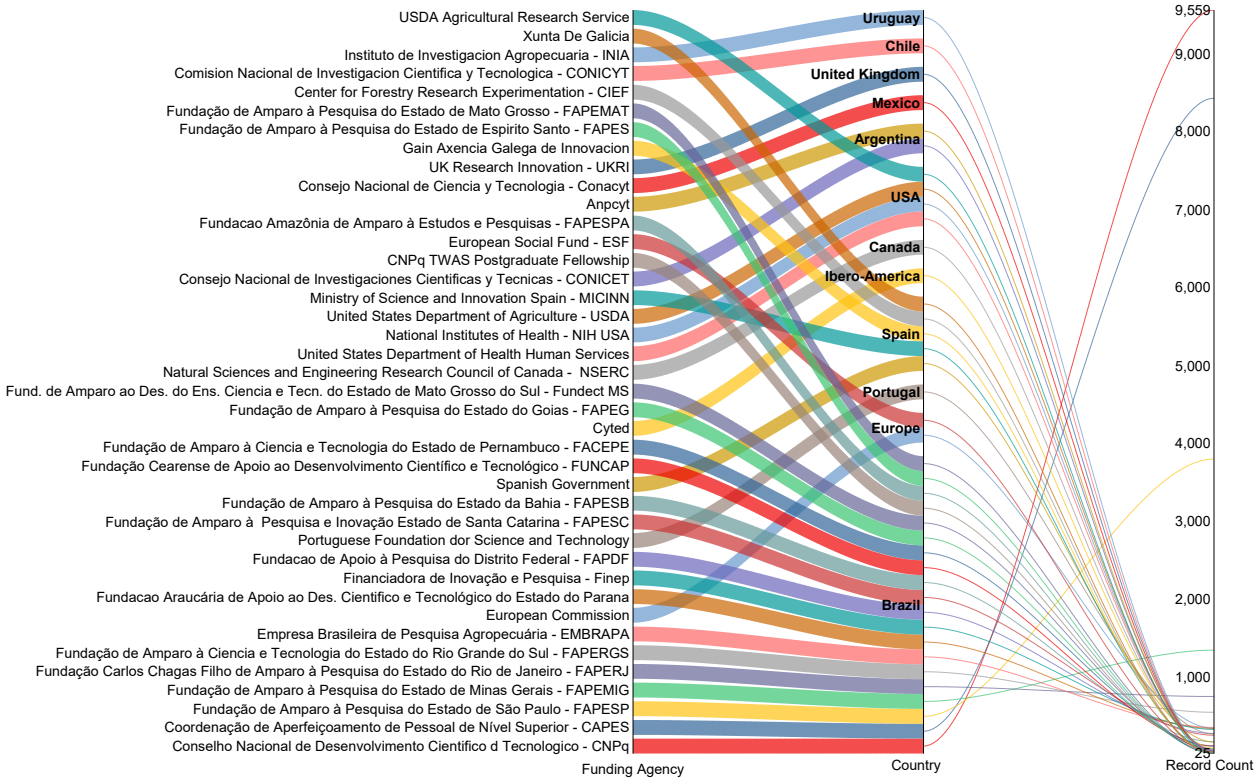

Fig. 21 Top 40 funding agencies for food science Brazilian publications and their countries. Source: Web of Science Core Collection (Clarivate, 2023).

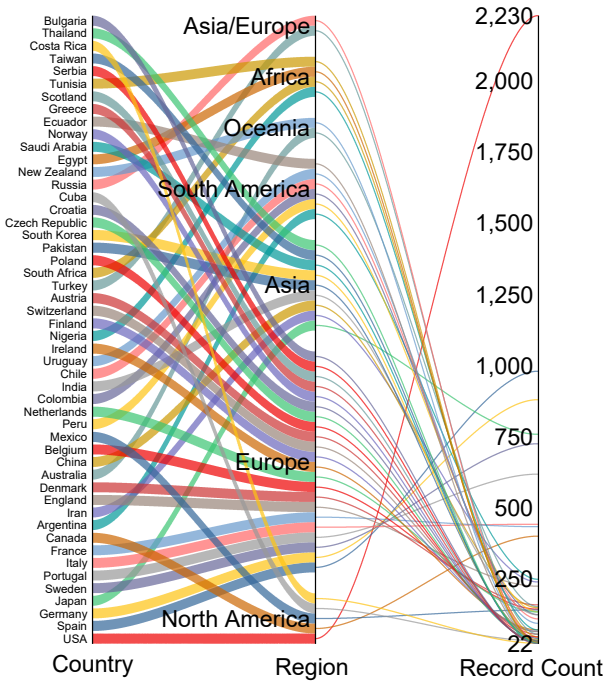

Fig. 22 Main countries publishing in collaboration with Brazil in food science from 2002 to 2022: Web of Science Core Collection (Clarivate, 2023).

WOS database indicates 127 countries with coauthorship for food science publications from Brazil. **Fig. 22** shows that most international collaboration between Brazil and other countries has been made with Europe, North America, and Asia; the primary country with a partnership with Brazil is the United States (9.23%), followed by Spain (4.06%), Germany (3.64%), Japan (3.14%), Sweden (3.00%), and Portugal (2.55%).

6. Bibliometric Analysis of Food Science in Brazil

A bibliometric analysis aided by VOSviewer has been performed using the WOS dataset of 24,158 documents published between 2002 and 2022 (van Eck & Waltman, 2010). For coauthorship, the analysis retrieved 68,308 authors. Using a minimum of five documents of an author, the software showed that 4,504 meet the thresholds. Then, for each of the 4,504 authors, the total strength of the coauthorship links with other authors was calculated. Finally, the authors with the highest total link strength were selected. Of the authors chosen to appear in the clustering cloud, only 4,205 were connected to others. The software indicated 42 clusters for coauthorship, 26,699 links and a total link strength of 68,336.

Fig. 23 shows the main network grouping for coauthorship of documents published from Brazil

based on the total link strength (TLS) as weights. **Table 1** shows the overall ranking of the most prominent authors based on TLS, their main affiliations, and h-index, while **Fig. 24** illustrates the ranking based on TLS. The analysis revealed that Adriano G. Cruz from the Instituto Federal do Rio de Janeiro (IFRJ) is the most prominent author, whose main subject topics include food science & technology, agriculture, chemistry, nutrition & dietetics, biotechnology & applied microbiology. The following authors on the list are Monica Q. Freitas (Universidade Federal Fluminense - UFF), Anderson S. Sant'ana (Unicamp), Erick. A. Esmerino (IFRJ), Daniel Granato (currently affiliated with the University of Limerick, Ireland), Silva MC (IFRJ), Tatiana C. Pimentel (Instituto Federal do Paraná - IFPR), Celso F. Balthazar (Unicamp), Jonas T. Guimarães (UFF), and Renata S. L. Raices (IFRJ).

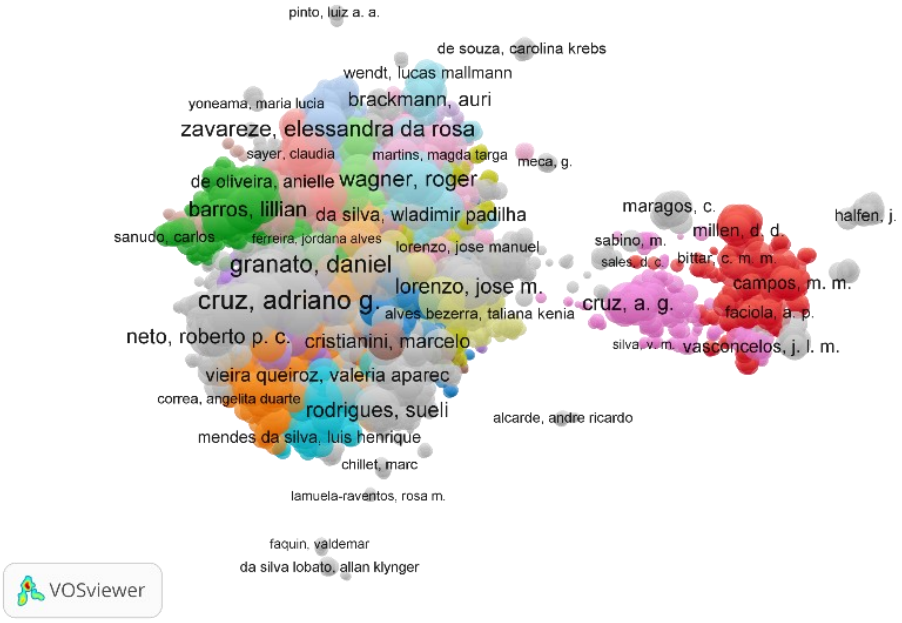

Fig. 23 Coauthorship network from Brazilian publications in food science from 2002 to 2022 from VOSviewer analysis of coauthorship based on total link strength. Source: Web of Science Core Collection (Clarivate, 2023).

As illustrated in **Fig. 24**, IFRJ has 5 authors among the 20 most prominent researchers, Unicamp has 3, and Universidade Federal de Santa Catarina (UFSC), Universidade Federal de Santa Maria (UFSM) and UFF have 2 authors each. Important to note that most institutions publishing in food science are from southern and southeastern Brazil. However, the ranking count on 2 authors from northeastern universities, Sueli Rodrigues from Universidade Federal do Ceará (UFC) and Marciane Magnani, affiliated with Universidade Federal da Paraíba (UFPB).

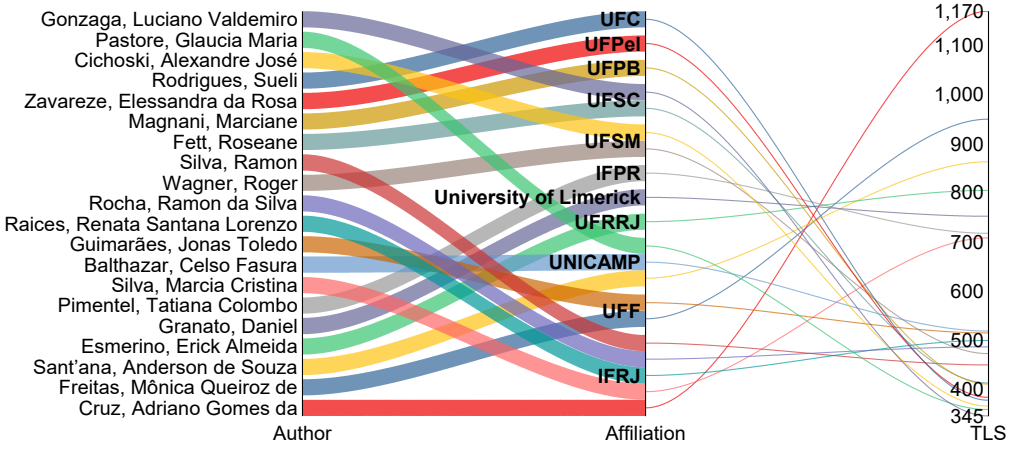

Fig. 24 Ranking of the most relevant Brazilian authors in food science (2002 to 2022) from VOSviewer analysis of coauthorship based on total link strength. Source: Web of Science Core Collection (Clarivate, 2023).

Table 1. Overall ranking of main authors of Brazilian food science and technology studies from 2002 and 2022 based on the VOSviewer meta-analysis.

Author	Current Affiliation*	TLS	Doc.	Cit.	Ranking per			h-index		
					TLS	Doc.	Cit.	S	W	G
Cruz, Adriano Gomes da	Instituto Federal do Rio de Janeiro (IFRJ)	1170	162	5579	1st	2nd	3rd	**65**	58	37
Freitas, Mônica Queiroz de	Universidade Federal Fluminense (UFF)	950	108	3080	2nd	7th	12th	**50**	47	**
Sant'ana, Anderson de Souza	Universidade Estadual de Campinas (UNICAMP)	863	213	6139	3rd	1st	2nd	54	51	**62**
Esmerino, Erick Almeida	Universidade Federal Rural do Rio de Janeiro (UFRRJ)	805	96	2503	4th	12th	20th	**48**	40	**48**
Granato, Daniel	University of Limerick, Ireland	752	159	8004	5th	3rd	1st	56	53	**66**
Pimentel, Tatiana Colombo	Instituto Federal do Paraná (IFPR)	717	82	1630	6th	19th	52nd	34	32	**39**
Silva, Marcia Cristina***	Instituto Federal do Rio de Janeiro (IFRJ)	708	70	2319	7th	25th	24th	**40**	32	6
Balthazar, Celso Fasura	Universidade Estadual de Campinas (UNICAMP)	518	54	1353	8th	53rd	80th	33	24	**35**
Guimarães, Jonas Toledo	Universidade Federal Fluminense (UFF)	514	60	1305	9th	43rd	88th	29	21	**32**
Raices, Renata Santana Lorenzo	Instituto Federal do Rio de Janeiro (IFRJ)	499	45	1632	10th	90th	51st	37	35	**40**
Rocha, Ramon da Silva	Instituto Federal do Rio de Janeiro (IFRJ)	486	47	1282	11th	78th	92nd	**27**	24	**
Wagner, Roger	Universidade Federal de Santa Maria (UFSM)	472	97	1605	12th	11th	54th	33	30	**37**
Silva, Ramon	Instituto Federal do Rio de Janeiro (IFRJ)	449	57	1314	13th	50th	86th	23	26	**32**
Fett, Roseane	Universidade Federal de Santa Catarina (UFSC)	412	88	3071	14th	15th	12th	40	25	**51**
Magnani, Marciane	Universidade Federal da Paraíba (UFPB)	410	127	2175	15th	4th	27th	27	33	**41**
Zavareze, Elessandra da Rosa	Universidade Federal de Pelotas (UFPel)	383	94	2821	16th	13th	14th	38	41	**48**
Rodrigues, Sueli	Universidade Federal do Ceará (UFC)	377	114	3850	17th	6th	4th	45	42	**55**
Cichoski, Alexandre José	Universidade Federal de Santa Maria (UFSM)	365	70	1503	18th	26th	64th	28	25	**30**
Pastore, Glaucia Maria	Universidade Estadual de Campinas (UNICAMP)	358	106	2812	19th	8th	15th	53	49	**68**
Gonzaga, Luciano Valdemiro	Universidade Federal de Santa Catarina (UFSC)	345	63	2533	20th	39th	18th	32	31	**38**

TLS, Total link strength; Doc., documents; Cit., citations; S, Scopus; W, Web of Science; G, Google Scholar. *All institutions from Brazil, except that of D. Granato. **h-index/profile not available/unconfirmed in that platform. ***This author has conflicting names with other homonymous persons, and the algorithm gathers all documents from them to calculate data generating conflicting results. Source: Web of Science Core Collection (Clarivate, 2023).

The authors with the highest h-index (highlighted in bold in **Table 1**) in the ranking are Glaucia M. Pastore (68), Daniel Granato (66), Adriano G. Cruz (65), and Anderson S. Sant'ana (62). Due to differences in the platforms that calculate the h-index, a wide variation has been observed in those values for each author, while the profile of some of them was not available in Google Scholar, for instance. Although widely used as a helpful tool and valuable metric to evaluate performance (Hirsch, 2005; Kelly & Jennions, 2006; Mester, 2016; Thomaz et al., 2011), the literature reposts inconsistencies and critics on the use and calculation of the h-index, which has also been the subject of several studies seeking to update and make the calculation of the index more efficient (Gaster & Gaster, 2012; Montazerian et al., 2019; Waltman & van Eck, 2012). Most inconsistencies and dissimilarities in the h-index of Brazilian scientists may also be ascribed to outdated or unconfirmed authorship and incomplete profiles in each platform (Scopus, Web of Science, or Google Scholar).

It should be noted that the list has conflicting data on documents and citations due to duplicated authorship data caused by the abbreviation of author names in some documents. For instance, "Adriano G. Cruz" appears twice in the list, either as "Cruz, Adriano G. or "Cruz, A. G." causing conflicting results on the TLS, sum of documents, and citations. Furthermore, the same behavior occurs in many other authors, causing the appearance of separated clouds in the cooccurrence network.

Considering the number of documents per author in **Table 1**, the ranking changes to Anderson S. Sant'ana as the most prominent author, followed by Adriano G. Cruz, Daniel Granato, and Marciane Magnani. The list based on citations in the last 20 years shows that Daniel Granato was the first with 8,004 citations, followed by Anderson Sant'ana (6,139) and Adriano G. Cruz (5,579); however, the total citations for Adriano G. Cruz may be higher due to conflicting names in the dataset, as he appears twice in the list as previously commented, and probably his number of citations has been split. **Table 2** shows the main clusters and authors from the coauthorship analysis. The dataset confirms the presence of the authors indicated in the ranking from **Table 1**, as well as other authors with a relationship with others based on TLS.

Table 2. Top 10 clusters from the VOSviewer meta-analysis of coauthorship based on data from Brazilian food science and technology studies from 2002 and 2022.

Cluster	Items	Main authors
Cluster 1	224	Campos, M. M.; Arrigoni, M. D. B.; Millen, D.D.; Fonseca, L. M.; Cerqueira, M. M. O. P.;
Cluster 2	222	Ferreira, I. C. F. R.; Barros, L. Visentainer, J. V.; Leimann, F. V.; Calhelha, R. C.; Demiate, I. M.; Haminiuk, C. W. I.; Matsushita, M.
Cluster 3	205	Sant'ana, A. S.; Magnani, M.; Cristianini, M.; Pastore, G. M.; Barba, F. J.; Ribeiro, A. P. B.; Lajolo, F. M.; Nero, L. A.; Madruga, M. S.;
Cluster 4	191	Cruz, G. A.; Wagner, R.; Rios, A. O.; Campagnol, P. C. B.; Prudêncio, E. S.;
Cluster 5	180	Freitas, M. Q.; Guimaraes, J. T.; Schwan, R. F.; Conte-Junior, C. A.; Queiroz, V. A. V.; Caliari, M.; Genovese, M. I.; Marsico, E. T.;
Cluster 6	177	Borges, S. V.; Martino, H. S. D.; Minim, V. P. R.; Fernandes, F. A. N.;
Cluster 7	170	Neto, R. P.C.; Stringheta, P. C.; Rodrigues, S.; Coutinho, N. M.;
Cluster 8	150	Godoy, H. T.; Hermosin-Gutierrez, E.; Sobral, P. J. A.; dos Santos, B. A.; Lorenzo, J. M.;
Cluster 9	143	Esmerino, E. A.; Silva, M. C.; Vasconcelos, J. L. M.; Faria, J. A. F.
Cluster 10	138	Fett, R.; Gonzaga, L. V.; Zavareze, E. R.; Valduga, E.; Vitali, L.; Cansiam, R. L.; Verruck, S.; Dis, A. R. G.; Treichen, H.

Minimum number of documents per author = 5. Source: Web of Science Core Collection (Clarivate, 2023).

Another problem related to data calculation could be verified for Maria Cristina Silva, which has conflicting names with another homonymous person, and the algorithm gathers all documents from those authors, suggesting overestimated results for that author. For instance, the WOS platform assembles documents from 'Silva, Marcia Cristina Freitas' (Universidade Federal do Pará - UFPA), 'Silva, Marcia Cristina' (Universidade Federal do ABC - UFABC), and 'Silva, Marcia Cristina Delgado da' (Instituto Federal de Educação, Ciência e Tecnologia do Rio de Janeiro - IFRJ), as authored by the same person (Silva, MC). This problem is associated with unconfirmed authorship in the WOS and Scopus platforms. Therefore, considering the oldest publications and the higher number of documents available and confirmed in the Scopus database, we believe that this author is Marcia Cristina Delgado da Silva from IFRJ.

The analysis of cooccurrence with data from the WOS related to food science in Brazil retrieved 53,503 keywords; of them, 7,035 meet the threshold when using 5 as the minimum number of occurrences of a keyword. The TLS of the cooccurrence with other keywords was calculated. All 7,035 keywords were connected to others. The algorithm returned 7 main clusters from the cooccurrence, showing 120,196 links and a total link strength of 375,386. The main keywords network is depicted in **Fig. 25**. The main items from each cluster are shown in **Table 3**. The keyword cloud shows that the main research topics are related to quality, food, identification, and extraction. Furthermore, stability, temperature, and physicochemical properties are also highlighted in the clusters. A high significance of studies on antioxidant activity, bioactive compounds, and oxidative stress has also been verified. Model, absorption, consumer exposure, and personal care were highlighted among the core topics associated with food science documents.

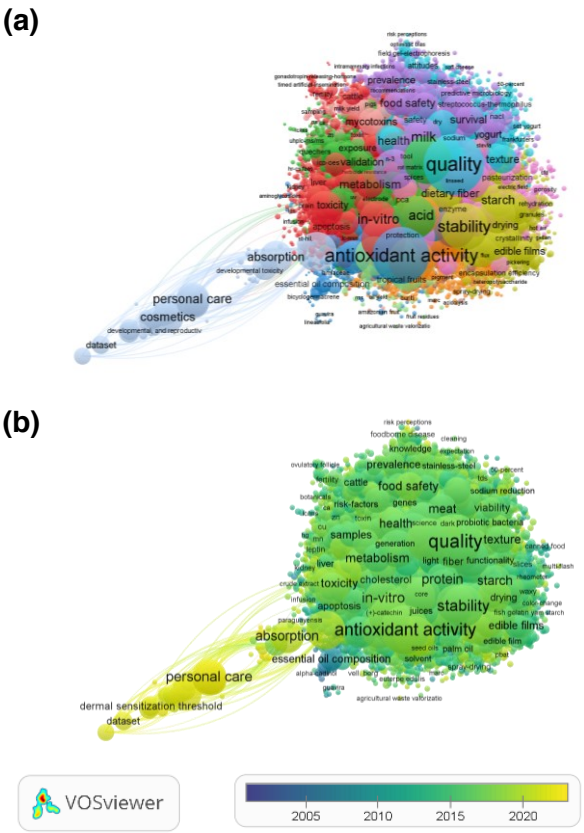

Fig. 25 Cooccurrence network of the most frequent authors' keywords related to documents in food science from Brazil between 2002 and 2022. (a) Term map based on different clusters whose colors represent similar subjects, and connected lines indicate the strongest connections. (b) Map of the average year of the term. Source: Web of Science Core Collection (Clarivate, 2023).

Fig. 25b shows the most recent topics in yellow, while the oldest may appear in blue. The image reveals that the most recent topics from the cloud may have been exhaustively studied in the last 5 years. For example, studies on personal care, cosmetics, and genotoxicity are trending topics in current research. This could be associated with recent trends in the application of bioactive compounds extracted from vegetable matrixes, whose applications extend from food to pharmaceutical and cosmetics (Liu, 2022; Pavlić et

al., 2023; Zhao et al., 2022). Taking into account the TLS as a classification factor, quality (17,189) was first as the main keyword associated with food science in the last 20 years, followed by antioxidant activity (14,726), food (10,432), stability (10,029) and bioactive compounds (9,365). Other important topics included extraction (8,159), phenolic compounds (8,061), optimization (7,195), and identification.

Table 3. Clusters from the meta-analysis of the cooccurrence of keywords based on data from Brazilian food science and technology studies from 2002 and 2022.

Cluster	Items	Main item
Cluster 1	1,227	Quality, food, identification, extraction
Cluster 2	1,089	Metabolism, chemical composition, *in vitro*, vegetables, validation, chemometrics, health
Cluster 3	815	Antioxidant activity, antioxidant, bioactive compounds, extraction, oxidative stress, flavonoids, anthocyanins, oil, fruits, encapsulation, optimization
Cluster 4	753	Stability, physicochemical properties, mechanical properties, rheological properties, texture, starch, kinetics, oxidative stability
Cluster 5	731	Food safety, strains, growth, milk, probiotics, mycotoxins, survival, meat, lactic acid bacteria
Cluster 6	580	Sensory properties, viability, fermentation, dairy, shelf life, bacteria
Cluster 7	481	Protein, bioavailability, solubility, pulp, chitosan, juice, inhibition, plants, hydrolysis,
Cluster 8	465	Osmotic dehydration, edible films, gelatin, soybean oil, functional properties, flour, release
Cluster 9	449	By-products, polyphenols, purification, fatty acids, cholesterol
Cluster 10	208	DPPH, tropical fruits, supercritical fluid extraction, flavonols, essential oil, antibacterial activity, antimicrobial activity, extracts
Cluster 11	180	Validation, liquid chromatography, quantification, diversity, volatile compounds, nutrition
Cluster 12	57	Personal care, model, cosmetics, genotoxicity, absorption, dermal sensitization threshold, dataset, ttc

Minimum of keywords = 5. Source: Web of Science Core Collection (Clarivate, 2023).

7. Past and Present of Food Science in Brazil

The shape of food science in 2002 and 2022 has been compared to understand the trending topics over the past two decades. **Fig. 26** reveals a massive increase in the number of documents in each subarea related to food science in Brazil.

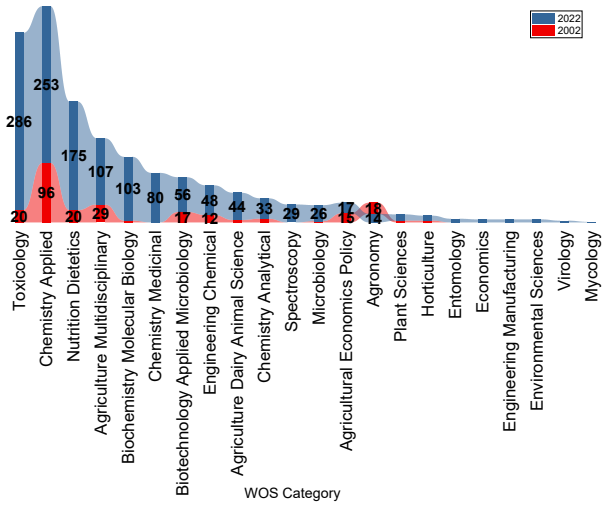

Fig. 26 Comparison of the main subject categories from Brazilian publications in food science in 2002 and 2022. Source: Web of Science Core Collection (Clarivate, 2023).

For example, the Web of Science shows 207 results from documents related to food science and technology from Brazil, which were published in 2002. Besides the main subject, other areas researched from that year included chemistry applied, agriculture multidisciplinary, nutrition dietetics, and toxicology. On the other hand, in 2022, the database revealed a 10-fold increase in publications reaching 2,095 documents.

The analysis of cooccurrences using VOSviewer with data from 2002 showed 204 items related to Brazilian food science, which were grouped into 11 clusters, 858 links, and a TLS of 1,099 (**Fig. 27a**). At that year, the main research topics based on TLS were essential oil composition, beta-caryophyllene, HPLC, alpha-pinene, quality, and bicyclogermacrene. Other keywords highlighted included carotenoids, proteins, tocopherols, oxidative stability, lactic acid bacteria, and *Bifidobacterium*.

On the other hand, an analysis of authorship in 2002 revealed that only 28 authors were connected to others, and the grouping was formed by 6 clusters with 66 links and a total link strength of 70 (**Fig. 27b**). Such behavior suggests that food science was still in incipient in that period concerning collaboration with other researchers and institutions. However, massive changes have been observed in the number of documents, authors, institutions, and subjects related to FST after two decades, confirming the critical role of the subject.

The cooccurrence of 9,475 from 2022 documents assembled 717 keywords considering 5 as a limiting factor. All of them were connected to other keywords, resulting in 8 clusters, 19,992 links and a TLS of 32,992. The network with the main keywords is shown in **Fig. 27c** and indicates that model, personal care, consumer exposure, bioactive compounds, quality, antioxidant activity, absorption, cosmetics, stability, extraction, phenolic compounds, in vitro, and oxidative stress were the main topics studied in 2022.

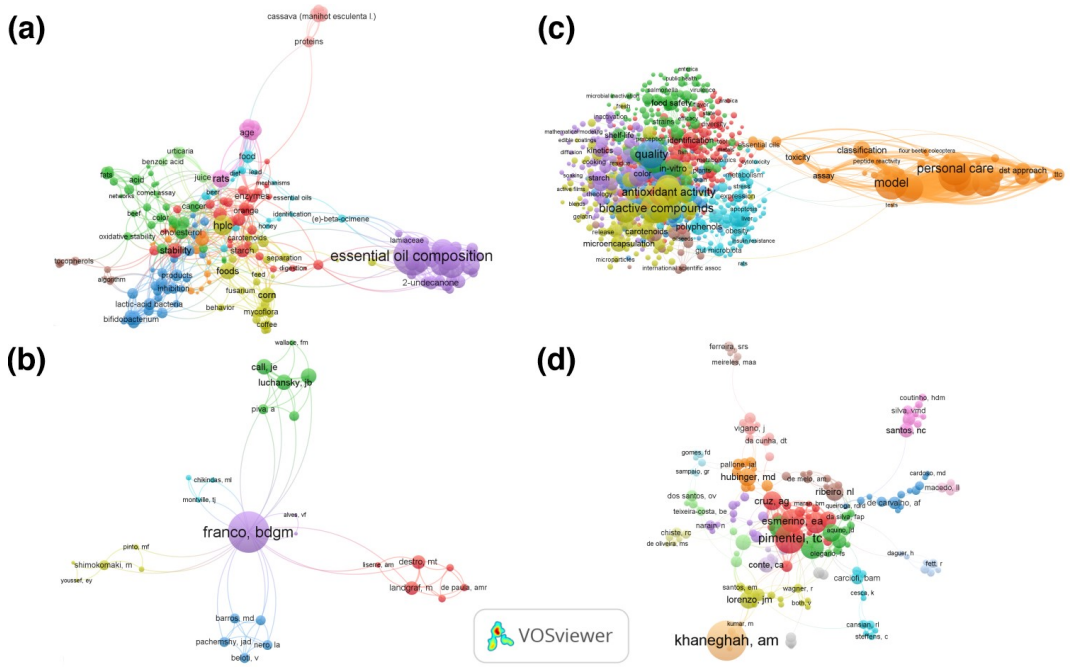

Fig. 27 Comparison of the cooccurrence of keywords from studies (a, b) and the primary Brazilian authors (c, d) from food science in 2002 (left) and 2022 (right). Source: Web of Science Core Collection (Clarivate, 2023).

The coauthorship analysis indicated 8,533 authors for documents from 2022, and 193 had at least 5 documents, which was the threshold. Of them, 164 were connected to other authors in 20 clusters, 443 links and a TLS of 1,110. The most relevant authors from Brazilian food science in 2022 are shown in **Table 4**. The analysis revealed that Erick A. Esmerino (UFRRJ) ranked first in 2022, followed by Tatiana C. Pimentel (IFPR), Adriano G. Cruz (IFPR), Elane S. Prudêncio (UFSC), Ramon Silva (IFRJ), and Silvani Verruck (UFSC).

Table 4. Top 10 most relevant authors from Brazilian food science and technology in 2022 based on the VOSviewer meta-analysis.

Author	Current Affiliation*	TLS	Doc.	Ranking per		h-index		
				TLS	Doc.	S	W	G
Esmerino, Erick Almeida	Universidade Federal Rural do Rio de Janeiro (UFRRJ)	75	18	1st	3rd	**48**	40	**48**
Pimentel, Tatiana Colombo	Instituto Federal do Paraná (IFPR)	66	23	2nd	2nd	34	32	**39**
Cruz, Adriano Gomes da	Instituto Federal do Rio de Janeiro (IFRJ)	43	15	3rd	7th	**65**	58	37
Prudêncio, Elane Schwinden	Universidade Federal de Santa Catarina (UFSC)	41	13	4th	12th	**31**	29	**
Silva, Ramon	Instituto Federal do Rio de Janeiro (IFRJ)	29	8	5th	33rd	23	26	**32**
Verruck, Silvani	Universidade Federal de Santa Catarina (UFSC)	40	16	6th	6th	16	14	**17**
Magnani, Marciane	Universidade Federal da Paraíba (UFPB)	38	18	7th	4th	33	27	**41**
Santos, Newton Carlos	Universidade Federal do Rio Grande do Norte (UFRN)	36	11	8th	8th	**5**	**5**	**
Almeida, Raphael Lucas Jacinto	Universidade Federal do Rio Grande do Norte (UFRN)	35	10	9th	15th	**7**	5	**
Campagnol, Paulo Cezar Bastianello	Universidade Federal de Santa Maria (UFSM)	31	10	10th	17th	34	25	**38**

TLS, total link strength; Doc., documents; S, Scopus; W, Web of Science; G, Google Scholar. Source: *All institutions are from Brazil **h-index/profile not available/unconfirmed in that platform. Source: Web of Science Core Collection (Clarivate, 2023).

8. Cooperation Between Institutions and the Impact on Brazilian Food Science

As previously commented, Brazil cooperates with more than 100 countries worldwide in food science studies. The improvement of Brazilian research metrics in the last few years can also be associated with international collaboration as one of the factors that helped to enhance the quality of research. An analysis of coauthorship based on organizations indicated 8,704 institutions from 24,158 documents issued from 2002 to 2022. Using a minimum of 5 documents of an organization, VOSviewer showed that 1,117 meet the thresholds. Then, for each of the 4,504 authors, the TLS of the coauthorship with other organizations was assessed. Finally, the institutions with the highest TLS were selected. Of the items chosen to appear in the clustering network, only 1,115 were connected to others. The software indicated 24 clusters, 13,855 links and a TLS of 80,797 (**Fig. 28**).

(a)

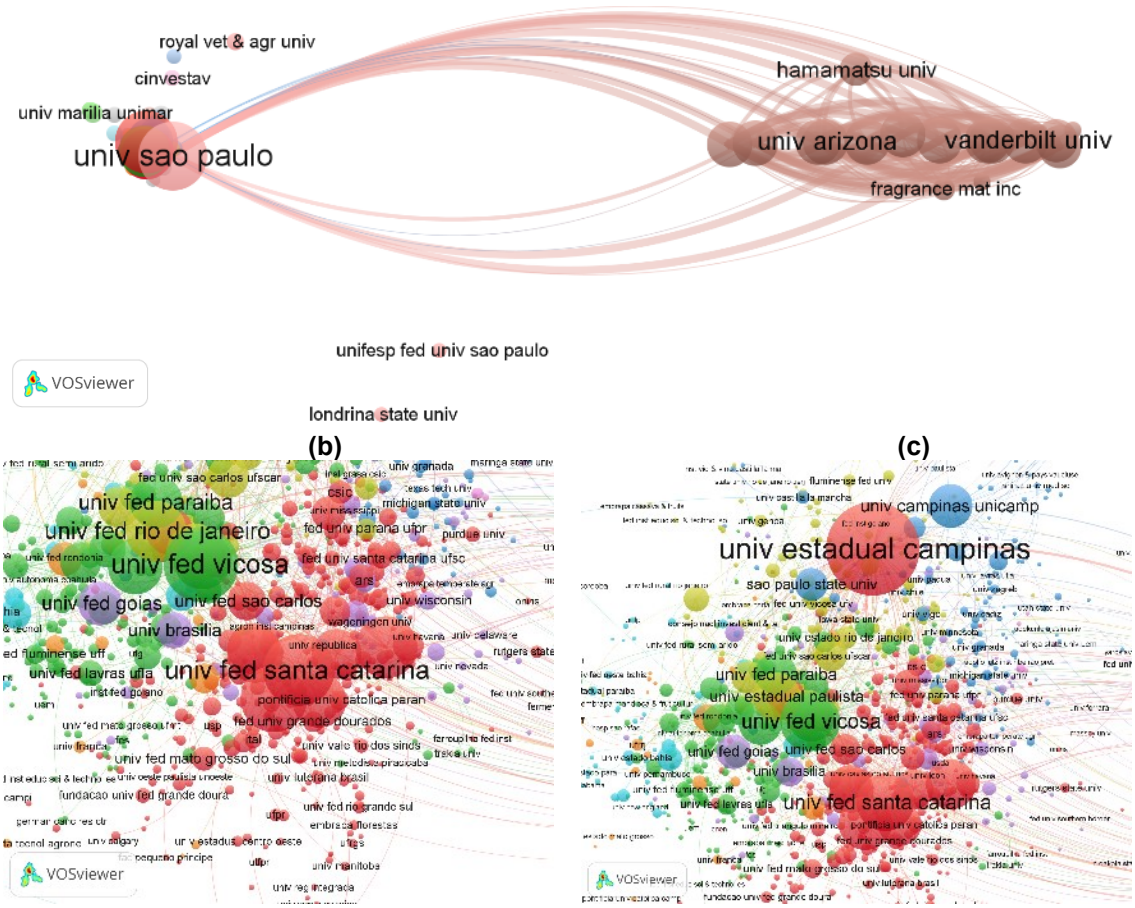

Fig. 28 Network of organizations involved in Brazilian food science studies from 2002 and 2022 (a) and the main organizations from clusters 2 (b) and 3 (c). Source: Web of Science Core Collection (Clarivate, 2023).

The clustering network in **Fig. 28a** confirms that the Universidade de São Paulo (USP) is the major contributor of Brazil to food science, with a TLS of 11,292. The analysis based on TLS shows that after USP, 12 universities outside Brazil contributed to the cloud, confirming the importance of international collaboration to leverage Brazilian food science. In order of highest TLS, there is the University of Arizona (7,774), Oregon Health & Science University (7,770), University of Pennsylvania (7,745), and Malmö University Hospital (7,744). The second Brazilian institution on the list is Unicamp, which shows a TLS of 2,845.

The first cluster has 340 items, mainly consisting of UFSC, Universidade Federal de Viçosa (UFV), Universidade Federal do Rio Grande do Sul (UFRGS), Universidade Federal de Santa Maria (UFSM) and Universidade Estadual de Maringá (UEM), Universidade Federal do Paraná, Universidade Federal da Paraíba (UFPB) and Universidade Federal do Rio de Janeiro (UFRJ) (**Fig. 28b** and **c**). Conflicting and duplicated results were also observed due to the writing style of the names of the universities in Portuguese and their corresponding version in English. Cluster 2, with 214 items, shows most institutions previously cited, along with Universidade Federal Rural do Rio de Janeiro (UFRRJ), Universidade Federal de Goiás (UFG), Universidade de Brasília (UnB), and Universidade Estadual Paulista (Unesp). Cluster 3 presented 162 items and is composed mainly of Unicamp (which forms 4 different clouds due to different typing names), Universidade do Estado do Rio de Janeiro (UERJ), and Universidade Estadual de Ponta Grossa (UEPG). The other clusters represent the link between other Brazilian institutions (**Fig. 28**).

A highlight of cluster 8 (right side in **Fig. 28**) was verified, mainly formed by international institutions such as the University of Pennsylvania, the University of Arizona, the University of Michigan, and Oregon Health and Science University, all from the USA.

Considering the highest number of publications, the ranking indicates the following organizations as the leading institutions: USP (4,139), Unicamp (2,794), UFV (1,147), UFSC (1,062), UFRGS (910), UFSM (792), UFRJ (753), and Universidade Federal de Lavras – UFLA (692). When using the number of citations as a ranking parameter, the list shows that the first 25 organizations with the highest number of citations

are from Brazil. USP also ranks first (81,069), followed by Unicamp (73,190), UFSC (23,594), UFV (22,633), UFRGS (18,795), UFRJ (16,634), UFC (14,189), and UFSM (14,055).

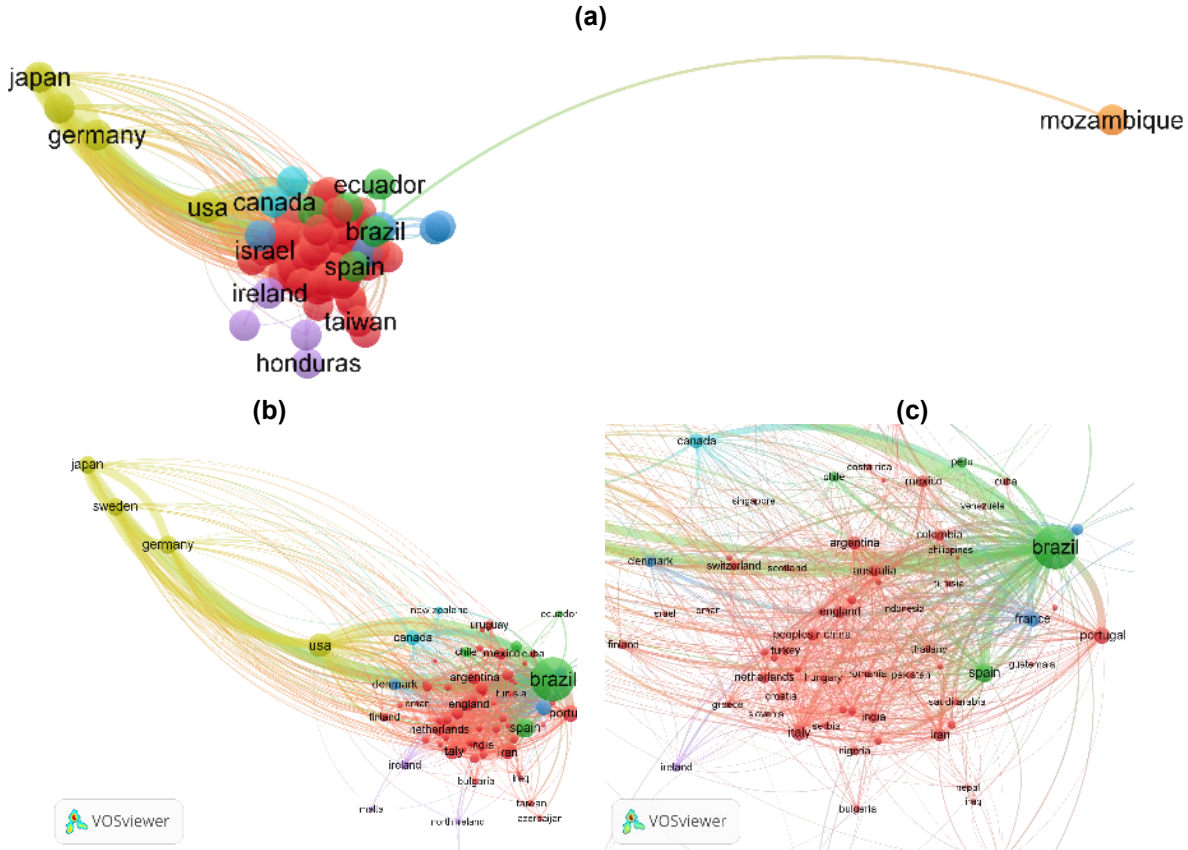

Fig. 29 Network of countries in collaboration with Brazil regarding food science studies from 2002 and 2022 (a) and the main countries from clusters 1 (b) and 4 (c). Source: Web of Science Core Collection (Clarivate, 2023).

A meta-analysis of coauthorship based on countries has also been performed on VOSviewer. Using a minimum of 5 documents of an organization, VOSviewer found 128 countries and indicated that 79 meet the thresholds. Then, the TLS of the coauthorship with other countries was calculated. Finally, the institutions with the highest TLS were selected. Finally, the 79 countries selected were connected to others. The software showed 7 clusters, 1,589 links, and a TLS of 20,505.

Fig. 29 shows the countries with cooperation in food science studies from Brazil. Cluster 1 shows links between Brazil and 57 countries (**Fig. 29a**), while clusters 2 and 3 have 5 countries each. The other 11 countries in the dataset were distributed into 4 clusters. The total link strength ranking shows that the leading countries with cooperation with Brazil were the United States (TLS = 5,232), Germany (3,158), Japan (2,878), Sweden (2,874) (**Fig. 29b**), followed by Spain (1,622), Italy (1,040) and Portugal (990) (**Fig. 29c**).

9. Brazilian Food Science Graduate Programs

Graduate programs in Brazil are primarily funded by governmental agencies, either from the Federal Government or state foundations. Two federal agencies are the main ones responsible for the highest investments and funding, the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES, which is under the responsibility of the Ministry of Education (MEC) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq, managed by the Ministry of Science, Technology, and Innovation (MCTI). In addition, each Brazilian state has specific foundations for research development with grant scholarships and budgets for graduate programs. However, most of the funding for graduate studies lies in the responsibility of CAPES and CNPq.

CAPES has a primary mission to expand and consolidate graduate programs in Brazil. Nowadays, the funding agency supports innovation, bearing in mind the continuous improvement of academic development (CAPES, 2022). On the other hand, CNPq's mission is to foster science, technology and innovation and act in formulating its

policies, contributing to advancing the frontiers of knowledge, sustainable development and national sovereignty. Due to the low availability of yearly data regarding the administration and distribution of values from CNPq and state foundations, only data from CAPES could be evaluated herein.

The overall values transferred from the Federal Government to CAPES and CNPq over the last 10 years are depicted in **Fig. 30**. According to Federal Budget Panel (Brazil, 2023a), the amounts allocated to CAPES and CNPq for the payment of the main expenses (**Fig. 30a**), as well as the values focused on investments (**Fig. 30b**) have dramatically decreased from 2015 to present. Furthermore, the money dedicated to science and technology in 2021 was considered the lowest in 21 years (Saraiva & Vasconcelos, 2021), and the budget for 2022 was also under the expectations and needs of most research institutions in Brazil (Escobar, 2021). With such a low investment in science and technology, progress in several strategic areas of the country may become increasingly difficult.

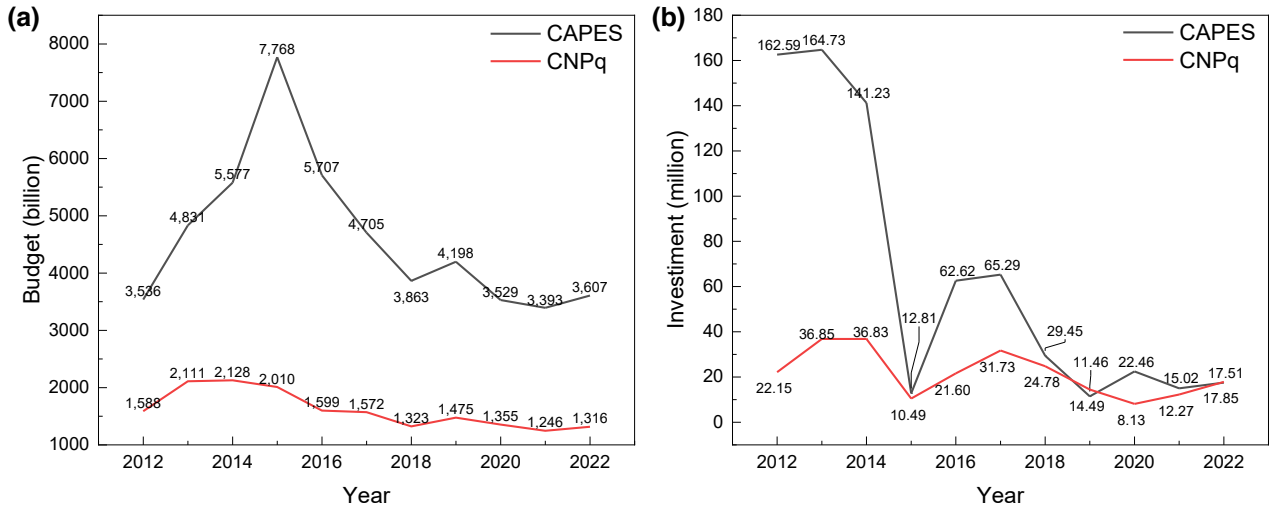

Fig. 30 Overall budget (a) and investment values of the CAPES and CNPq funding agencies between 2012 and 2022. Source: Federal Budget Panel (Brazil, 2023a)

CAPES has cataloged data regarding graduate programs in food science in Brazil since the 1990s. Such graduate programs are divided into six subareas: 'food technology,' 'food science and engineering,' 'food engineering,' 'food science and technology,' 'food science,' and 'foods and nutrition.' These categories were set according to the specificities of several universities, professors, infrastructures, and geographical locations, aiming to contribute to developing human resources to work in all stages of the food chain. **Fig. 31a** shows the number of programs within each food science sub-area. As of 1998, Brazil had 19 graduate programs in five different food science categories. The main subareas were food science and food science and technology.

Notwithstanding many social, political, and economic issues, the number of graduate programs in food science has gradually increased over the past few years from 19 to 61, representing about a 321% increase. Of them, about 65% are within the 'food science' and 'food science and technology' subcategories. In addition to continuous access to improvement and the high demand for empowered professionals that caused higher demands for graduate professionals in food science, such advances resulted from different governmental actions, including the leverage of CNPq and CAPES through the Brazilian National Graduate Program (Barreto et al., 2014).

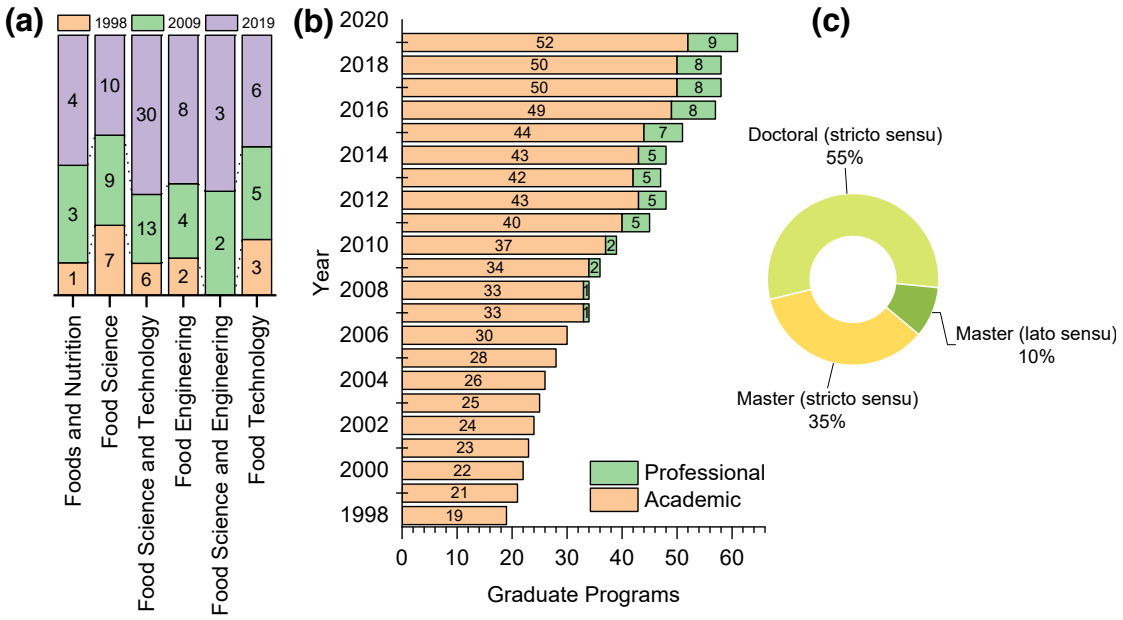

Fig. 31 Graduate courses by subarea in the main field of food science in Brazil (a), the evolution of the number of programs from 1998 to 2019 (b), and the current distribution among master and doctoral programs (c). Source: CAPES (2019).

It is possible to observe in **Fig. 31a** that since the 1990s, the number of food science graduate programs has increased; there were only 19 graduate programs in the field at the beginning of data evaluation (1998). Twelve years later (2010), the number of programs doubled; additionally, in the last evaluation (2019), the number of graduate programs reached an increase of 3.2 times (61 programs) the initial data.

Fig. 31b shows that professional graduate courses were introduced in 2007, and their number increased to 9 courses today. Differently from the academic degree, professional master's programs highlight technical training and the development of in-demand business and leadership skills and are currently at the interface between universities and enterprises.

The most recent available data from CAPES (2019) indicated that there are 94 courses classified as *stricto sensu* master, *lato sensu* master, and *stricto sensu* doctoral (**Fig. 31c**). Of them, 52 courses are *stricto sensu* master's degrees, also known as academic master degree; 9 are *lato sensu* master (professional master degree), and 33 courses are *stricto sensu* doctoral, suggesting a difficult for universities to offer and support such doctoral programs across the entire country, as it requires more advanced infrastructure, specific equipment, and qualified professors and staff. Furthermore, a professional master's degree is indicated to those who do not think exclusively in academic life but aim to work in the food industry, which is also considered a kind of specialization. According to CAPES, professional master's degree courses are only available in 5 states.

Although Brazilian universities should prepare professionals to contribute within all areas of the food science field, offering and maintaining a food science graduate program in all 26 states is challenging in a vast country like Brazil. **Fig. 32** represents the distribution of master's and doctorate graduate programs across Brazil. From the chart, it is possible to notice that only 12 states have a doctorate course in the field, representing less than 50% of all the states. On the other hand, master's degree courses are available in 18, representing almost 70% of all Brazilian states.

As illustrated in **Fig. 32**, many states as Espírito Santo, Mato Grosso do Sul, Mato Grosso, Sergipe, Pernambuco, Piauí, Tocantins and Pará, have just one graduate program in the field of food science. In contrast, São Paulo and Minas Gerais have ten courses across both states, revealing dissimilarities in the distribution of graduate courses within the Brazilian territory. Furthermore, most of the courses are concentrated in the southern and southeastern regions of Brazil, which have the higher GDP index, according to the Brazilian Institute of Geography and Statistics – IBGE (2022). However, states such as Alagoas, Rio Grande do Norte, Maranhão, Amapá, Roraima, Amazonas, Acre and Rondônia represent 30% of Brazilian states but do not have any graduate programs in food science.

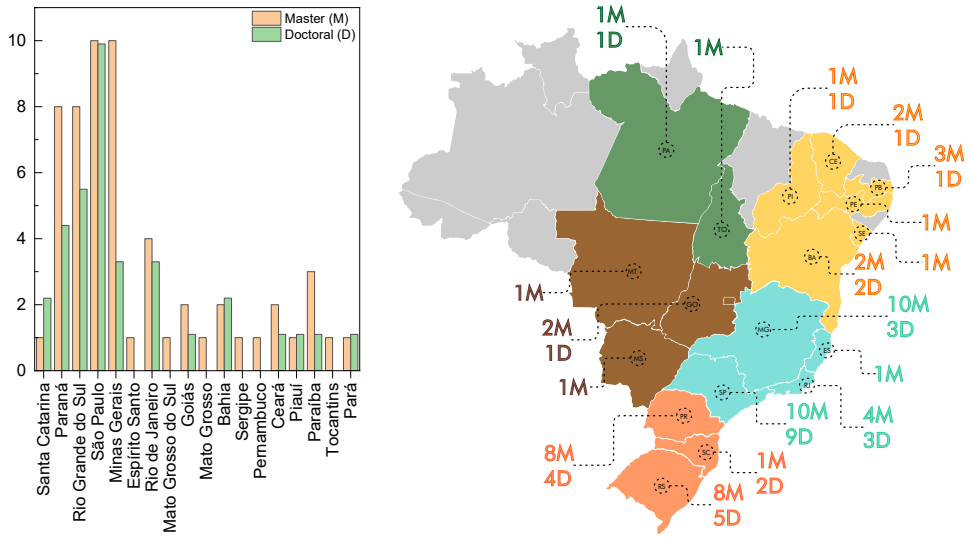

Fig. 32 Distribution of food science graduate courses across Brazilian states. The states highlighted in gray do not have courses in this field. Source: CAPES (2019).

Such a scenario may reflect state policies aiming at leveraging local food production and a result of private investment in food industries, which causes the need for qualified professionals and improved human resources to work in such fields. For decades, São Paulo has been at the forefront of development in the food sector with massive investments in the area. In addition to having the two most important universities in food science (USP and Unicamp), the state also has the Institute of Food Technology (ITAL), an important center that also contributes enormously to the evolution and development of food science for over 59 years, with increasing investments year by year (Jaqueline Harumi, 2022; Jaquelini Harumi, 2022).

In general, most graduate scholarships for the year 2020 were covered by CAPES (73%), while CNPq was responsible for 13%, and state foundations paid another 13% (Ferrari, 2022). As verified in the meta-analysis, CNPq (39.5%), CAPES (34.8%), and FAPESP (15.7%) are the main ones responsible for funding food science graduate studies (Clarivate, 2023). Besides the technical issues related to starting and maintaining a graduate course in Brazil, such graduate programs require qualified human resources with a finished undergraduate course to pursue a master's or doctoral degree. Currently, the scholarship provided to master and doctoral students ranges from 1,500 to 2,200 Brazilian Real (BRL), corresponding to about 288 and 423 USD, respectively.

Those graduate professionals granted scholarships generally sign an exclusivity contract with Brazilian research agencies. This means they cannot have other economic activities while engaged in graduate programs. However, in a country where the minimum wage fails to provide a dignified life, scholarships for graduate professionals are frequently insufficient to pay minimal bills like rent, transportation, and food. Beyond that, the lack of monetary adjustment of scholarship values is another major issue contributing negatively to the development of graduate professionals.

The evolution in the values of master's and doctoral scholarships from the main funding agencies since 1995 is depicted in **Fig. 33**. The chart shows that, in 1995, a doctoral scholarship holder earned 1,073 BRL, corresponding to ten minimum wages or twelve basic food baskets. In 2013, the value reached 2,200 BRL, equivalent to four minimum wages or six basic food baskets. Since then, without any adjustment, it is currently worth approximately 1.8 minimum wage and allows the purchase of only three basic food baskets.

The data reveal that in 2022, the CAPES and CNPq grants reached the lowest real value in three decades. As in most nations, lower salaries with no adjustment regarding inflation are critical, especially in a country with a high dollar currency, which reflects in the prices of everything we consume in Brazil. Moreover, as also demonstrated in **Fig. 33**, the value of a master's scholarship is currently almost the same as the minimum wage, which represents a major problem, as master's students have finished their undergraduate degree and usually have at least 3 minimum wage salaries in the industry. Therefore, if no change occurs, such a scenario may discourage the search for graduate courses.

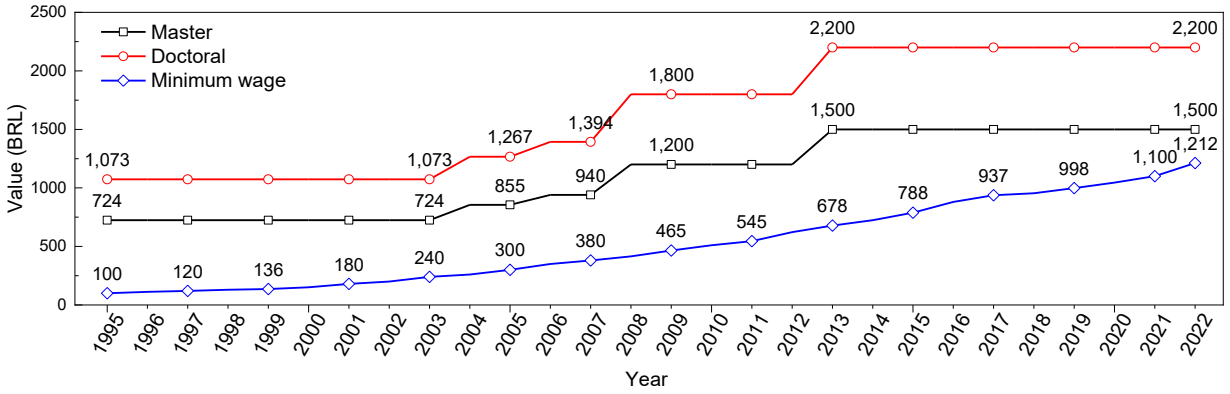

Fig. 33 Evolution of CAPES and CNPq scholarships value (in BRL) for master and doctoral students from 1995 to 2022 compared to the Brazilian minimum wage. Source: CAPES (2023a).

Such a few resources and low professional valorization led to a 'brain drain,' where several good researchers and brilliant minds fled to other countries to pursue better opportunities (Lippelt et al., 2022; Silveira, 2020). The number of Brazilians who decided to leave Brazil to live and work abroad exceeds the average for recent years. According to Fragomen, the largest and oldest immigration company worldwide, between January and November 2022, for Portugal alone, requests increased by 200% compared to the same period in 2021. About 114% growth was observed for the USA, and for Australia and New Zealand, it reached 544% (Nunes, 2022).

The low value of master and doctoral scholarships and their devaluation over the last decades has been the subject of several debates in the Brazilian press (Estadão, 2022; Ferrari, 2022; Lyra, 2022; Tokarnia, 2019; Veja, 2022). A calculation based on the IPCA (National Consumer Price Index) accumulated from January 2013 to November 2022 indicates that the values are 78.6% out of line with inflation in the case of CNPq and CAPES grants. If adjusted for inflation, the master's scholarship (currently 1,500 BRL) would rise to 2,679 BRL. The doctoral scholarship would go from 2,200 to 3,929 BRL.

According to GEOCAPES (2022), from 2019 to 2021, there was an 18% reduction in the number of graduates in *stricto sensu* graduate courses (master's or doctorate). In absolute numbers, 14,520 graduate students started their studies but did not complete them. In addition to problems related to the low values, which currently do not cover most of the expenses of graduate students, several delays in the payment of research grants have occurred in recent years, causing more inconvenience to researchers (Veja, 2022).

Aware of such devaluation on the main workforce related to scientific production in Brazil, three state foundations that also provide scholarships for graduate studies have decided to provide an adjustment on their values in 2022. The Foundations of Minas (Fapemig), Rio (Faperj), and Santa Catarina (Fapesc) announced an increase between 20-25% in the values currently paid to the researchers (Ferrari, 2022).

Former CAPES president Anderson Correia promised a review of the values of graduate scholarships in December 2019 (Tokarnia, 2019). However, the remuneration of Brazilian graduate researchers remained frozen. On the other hand, recently, at the inauguration ceremony as president of CAPES, the new head of the foundation promised to work on adjusting the scholarships. The foundation's current social media team indicated that approximately 200,000 master's, doctoral, postdoctoral and basic education teacher training program students receive a CAPES scholarship. They also highlighted that adjusting scholarships' values is one of the Foundation's priorities and concluded that CAPES is working with the Federal Government to ensure that this action takes place as soon as possible (CAPES, 2023b).

CNPq, which is under the Ministry of Science and Technology (MCTI) in Brazil, also grants many graduate scholarships. Recently, the current president of MCTI, Luciana Santos, announced that the scholarships would be updated on ~70% of their values (Estadão, 2022). Furthermore, she highlighted the importance and need for investment in science and technology, emphasizing that research grants and scholarships are an investment in the country's future (Brazil, 2023b; Brazilian Academy of Sciences, 2023).

Despite all the unpleasant situations, scholarships for graduate programs in food science have shown an increasing evolution since 1995. In that year, 145 scholarships were awarded to doctorate students, increasing to 764 in 2021, representing a 527% increase in the period. The same behavior occurred for master's degree scholarships, increasing from 194 in 1995 to 599 in 2021 (**Fig. 34**). CAPES also provides scholarships for trained doctors to start or complete their research in a post-doctoral internship currently valued at 4,100 BRL. This kind of scholarship started to be cataloged in 2002 when there were 7 postdoctoral professionals in the Brazilian graduate programs. A 14-fold increase in these grants was also observed from 2002 to 2013, when 99 scholarships were distributed. Although the average number of postdoctoral scholarships in the last six years was about 77, only 56 postdoctoral grants were available in 2021. Even though presenting increasing trends, the chart in **Fig. 34** demonstrates a decrease in master's grants since 2015, in contrast to the number of doctoral scholarships, which exceeded masters in that year. As with the other grants, postdoctoral scholarships are also frozen with no readjustment since 2013.

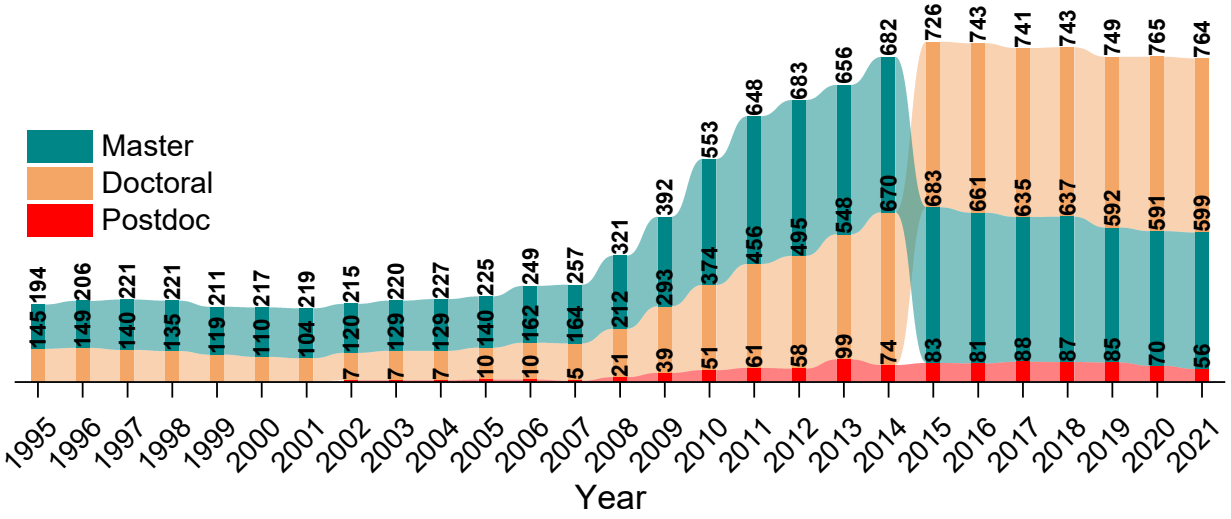

Fig. 34 Evolution of the number of master, doctoral, and postdoctoral scholarships in food science in Brazil granted by CAPES over the years. Source: GEOCAPES (2022)

It is worth observing in **Fig. 35** the distribution of scholarships from 1995 to 2021 according to each region of Brazil. As mentioned above, most food science courses are concentrated in the southern and southeastern Brazilian regions. As a result, the distribution of scholarships over the years follows the same pattern. Since 1995, more than five thousand doctoral scholarships have been distributed to the southeast region, while more than four thousand master's scholarships have been granted to students in that region. These data reveal the inequality concerning other Brazilian regions and a strategic opportunity for future investments in the field of food science.

Brazil has many social, economic, and political issues which directly impact investments in universities and research centers. However, modern technologies and industrial solutions in the food science field arise from the initiative of several brilliant minds in graduate programs across Brazil. Therefore, investment in graduate food science programs remains essential to developing the food sector. As previously remarked, food science studies in Brazil are mainly sponsored by CNPq, CAPES, and FAPESP. Thus, the role of CNPq, FAPESP and other state foundations in the development of food science may also be further evaluated. However, an appropriate assessment is almost impossible without the availability of specific databases from CNPQ and state foundations. Therefore, we highlight those platforms such as GEOCAPES simplify data checks and allow everyone to access information related to Brazilian graduate programs transparently and efficiently.

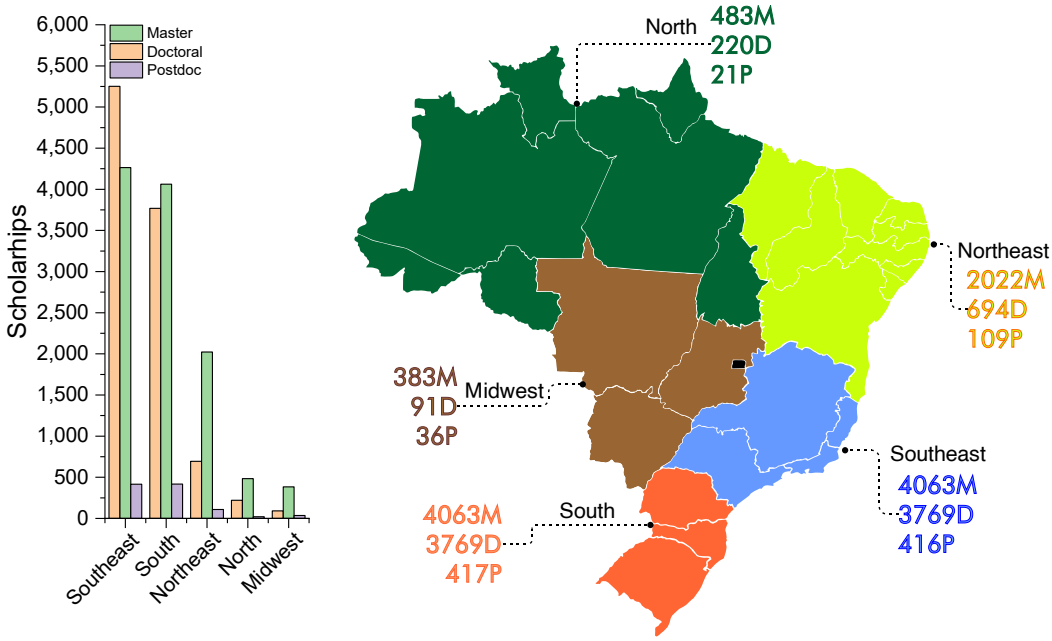

Fig. 35 Master, doctoral, and postdoctoral scholarships in food science per region in Brazil granted by CAPES between 1995 and 2021. M, master; D, doctoral; P, postdoctoral. Source: GEOCAPES (2022).

10. Concluding Remarks

As verified with a broad range of data, Brazil has been a significant player over the last decades and has become the fifth nation with the highest food science production worldwide, also ranking as the first most relevant in Latin America. It was also evidenced that the partnership between Brazil and international institutions is essential to maintain and increase the quality of food science, as the research with the highest metrics evaluated herein were those with coauthorship from all over the world. This review also shows that despite the decreasing budgets and low investments, WOS and SJR databases confirm increasing trends in the number of documents, citations, and quality of Brazilian studies in food science, while Brazilian researchers resist the most adverse conditions to maintain a significant production.

The meta-analysis concerning the relevance of Brazilian food science indicated that such a field of study has a major role among agricultural sciences due to its expressive indices. Unfortunately, such a scenario has also been severely affected in the last two years due to the impacts of the COVID-19 pandemic, which caused a significant decrease in scientific production in many countries. Nevertheless, it was verified that science and technology are not expenses but investments. Moreover, developed nations have demonstrated that supporting studies in most areas of science results in higher productivity and progress. Regarding agricultural sciences and food science, the situation would not be different.

Most topics related to food science studied across the globe have also been investigated in Brazil over the last few years, confirming its status as a powerful country in this field. Research areas such as applied chemistry, toxicology, nutrition and dietetics, biochemistry and molecular biology have been proven to be the core subjects in food science, whose studies do not stop growing. Besides, this study revealed that the current trending topics are mostly related to quality, extraction, bioactive compounds, antioxidant activity, phenolic compounds, stability, models, absorption, personal care, cosmetics, *in vitro* assays, and oxidative stress, indicating that studies in these areas may be of high relevance.

Although presenting 61 graduate programs in food science, most indicators reveal dissimilarities among their distribution across Brazilian states, as 8 (from Northern and Northeastern Brazil) do not have any courses in this field. This certainly impacts lower development and quality of those regions, considering that food science is a strategic area due to its relevance in improving food products, processes, and technologies. This review also highlights the importance of CAPES, CNPq and FAPESP funding agencies to leverage food science, showing the world that appropriate investments in the field bring good results and allow scientists to confirm that we can produce high-quality science in Brazil.

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Authors' Contributions

G. L. T: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. B. L. F: Formal Analysis, Writing – original draft, Writing – review & editing.

Availability of data and materials

Data are available under request from the corresponding author.

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Informed Consent Statement

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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