

Trends and hotspots of global ultra-processed food research (2010-2023): A scientometric study

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Author contributions

Cuncun Lu designed this study. Ziyi Wang and Cuncun Lu performed the search. Ziyi Wang, Wendi Liu, and Lu Cui collected data. Xiuxiu Deng, Zhijiang Bi, and Fenfen E rechecked data. Cuncun Lu and Ziyi Wang performed analysis. Ziyi Wang and Cuncun Lu drafted the manuscript. All authors revised and approved the final version of this manuscript.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data availability statement

The datasets used and analyzed in the current scientometric study are presented in the text.

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Peer review information

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Abbreviations

BC: Betweenness centrality; IF: Impact factor; LBY: Look back years; LRF: Link retaining factor; LLR: Log-likelihood rate; MD: Minimum duration; N/n: number; Q: Modularity score; S: Silhouette score; SCIE: Science Citation Index Expanded; SSCI: Social Sciences Citation Index; T: Threshold; UPF(s): Ultra-processed food(s); WoSCC: Web of Science Core Collection.

Citation

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Abstract

Background: Recently, ultra-processed foods (UPFs) have attracted considerable attention, leading to numerous studies worldwide. Scientometrics is currently gaining popularity among scientific communities, offering advantage of providing critical references to scholars of specific fields. **Methods:** This scientometric study aimed to analyze trends and hotspots of UPF research using English articles or reviews related to UPFs retrieved from the Web of Science Core Collection on March 5, 2023. Two independent researchers selected the identified records on titles, abstracts, and author's keywords, and the data were analyzed using R-bibliometrix, CiteSpace, and VOSviewer. **Results:** A total of 1018 publications (901 articles and 117 reviews) published from 2010 to 2023 were included. The result showed a significant increase in UPF publications over the past decades. Brazil published the highest number of papers (n = 473), with over half of the top 10 active institutions were located in Brazil. The University of São Paulo contributed the most publications (n = 206) and the 10 most productive authors belonged to this institution, with Monteiro CA and Levy RB contributing the most publications. The main research foundations included the NOVA system, the definition of UPFs, the prevalence of UPFs, and the impact of UPFs on dietary quality and health status. The main research frontiers included topics such as “systematic review,” “NOVA food classification,” “COVID-19,” “diabetes,” “pregnancy,” “food addiction,” “warning labels,” “plant-based diet,” and “commercial determinants of health”. **Conclusions:** This study provided a comprehensive overview of development trends and research hotspots of global UPF studies.

Keywords: scientometrics, ultra-processed foods, VOSviewer, CiteSpace, health

Background

As the most processed group of NOVA classification, ultra-processed foods (UPFs) contain industrial substances not usually found in domestic kitchens, flavoring agents, and cosmetic additives [1]. Generally, UPFs include all foods subjected to intense industrial physical, chemical, or biological processes, including hydrogenation, hydrolysis, extruding, and pre-processing, aiming to develop convenient (ready-to-eat), durable (long shelf-life), and palatable food products [1, 2]. Meanwhile, industrialization and technological innovation brought by UPFs also strengthen the power of large corporations to shape food systems across the globe, contributing to a substantial increase in the type and quantity of UPFs in high-income countries, followed by middle-income countries [3]. Recent evidence suggests that excessive UPF intake pattern is mediated by its highly reinforcing characteristic, which might trigger addictive biological and behavioral responses [4]. For instance, a recent narrative review by Elizabeth et al., [5] showed that of the 43 studies investigating the association between UPF consumption and multiple health outcomes, 37 showed that UPF consumption was associated with at least one adverse health outcome, such as overweight/obesity, cardio-metabolic risks, and depression. Besides the unhealthy effects, UPF from farm to fork, including the processing, packaging, and distribution stages has detrimental impacts on the environment and climate [6, 7]. According to a recent study [7], about 19% of UPF in the diet accounted for 24% of the diet's greenhouse gas emissions, 23% of water use, 23% of land use, and 26% of energy demand. Furthermore, households from more disadvantaged socio-economic backgrounds purchased the highest amount of UPFs to obtain the basic nutrients, exacerbating the occurrence and development of unhealthy outcomes further [8]. Subsequently, more peer-reviewed publications related to UPFs have been reported recently, possibly due to the global trend of UPF intake, combined with the multiple harmful influences of UPFs (e.g., health, environment, and climate), and the characteristics of the consumers. However, no comprehensive study has quantitatively mapped the status quo and development trends in this field so far.

Traditional reviews often describe the present situation and analyze the development of knowledge in a certain field, but their comments are prone to subjectivity and are affected by the authors' expertise and intellectuality [9]. Scientometrics is a key approach to using sophisticated statistical metrics to reveal the directions and current topics discussed by scientists, thereby objectively presenting an overview of the knowledge landscape and providing critical references for relevant studies [10, 11]. Scientometrics can measure the interconnectedness of evidence and the impact of research using two different aspects: performance analysis (i.e., impact analysis of countries/regions, institutions, authors, or journals based on citation analysis) and visualization of research trends (i.e., an evidence synthesis method used to collect, collate, and produce knowledge maps and identify clusters and gaps in knowledge based on links between citations, countries/regions, institutions, journals, authors, or keywords) [12, 13]. Generally, obtaining reliable datasets from accessible databases in the first place is essential for analysis through software tools in scientometric analysis. As a high-level scientific and technological literature database, Web of Science Core Collection (WoSCC) is the most preferred database for scientometric analysis [14], and the current key software for scientometric analysis including VOSviewer [15], CiteSpace [16], and R-bibliometrix [17]. Currently, scientometrics is becoming popular among scientific communities, and has been widely applied in many scientific fields for reviewing and analyzing trends and hotspots [18]. For example, Sabe et al. [19] used this method to synthesize changes over time and measure networks and scientific productivity on antipsychotics in schizophrenia, and found that antipsychotic efficacy, cognition in schizophrenia, and side effects of antipsychotics were the main research topics. Grammes et al. [20] conducted a scientometric analysis to correlate the severity of the COVID-19 outbreak with its related scientific output per country. They found that the USA, China, and Italy were the top 3 countries involved in COVID-19 research,

with the USA being the most active in terms of collaborative efforts [20].

Therefore, the present scientometric study aimed to provide a comprehensive overview of global UPF research by analyzing the annual output, countries/regions, institutions, authors, journals, references, and keywords, thereby identifying the research gaps and highlighting the areas demanding more attention. The present study results will provide the critical reference for relevant researchers in the field of UPFs.

Methods

Data source and literature selection

The publications related to UPFs were retrieved from WoSCC on March 5, 2023. The database source was limited to the Science Citation Index Expanded (SCIE) and the Social Sciences Citation Index (SSCI), with no time limitation. A high-specificity search strategy was adopted to increase the relevance of the identified records: Topic = "ultra-processed food" OR "ultra-processed foods" OR "ultraprocessed food" OR "ultraprocessed foods".

Due to the frequent updates of the database, two researchers selected literature as quickly as possible from the website. The UPF-related publications were selected through a three-step process. Firstly, the language of identified records was limited to English. Secondly, the publications with paper types of "Article" or "Review Article" were retained. Thirdly, publications including UPF terms in titles, abstracts, or author's keywords were identified and included. The full records with cited references were downloaded from WoSCC in plain text files on the same day, that is, March 5, 2023, to ensure data accuracy. In addition, the top 10 highly-cited papers were identified and downloaded from WoSCC.

Statistical analysis

Several common scientometric tools were used for statistical analysis in this study, including CiteSpace (6.1.6), VOSviewer (1.6.19) and R-bibliometrix (4.1.0). CiteSpace was developed by Chaomei Chen, for visualizing structural and temporal patterns in scientific papers [16]. A series of structural metrics can be produced by CiteSpace, including betweenness centrality (BC), modularity (Q) and silhouette (S) score. BC is a critical parameter that measures the scientific importance of the nodes, and nodes with high betweenness centrality ($BC \geq 0.1$) are usually highlighted using purple rings [21]. The Q score measures the extent to which a network can be divided into modules, with the score ranging from 0 to +1. The S score is the approach to estimate the degree of uncertainty in interpreting clusters of data, with scores ranging from -1 to +1. When the scores are close to +1, they represent the best structured clustering model. The cluster structure is considered acceptable when the Q score is above 0.3. When the S score exceed 0.3, 0.5, or 0.7, the cluster labeling is considered homogenous, reasonable, or highly credible, respectively [19]. In this study, CiteSpace was used to analyze the intellectual landscape by conducting co-citations analysis and identifying the emerging topics in terms of publications with strong citation burstness [16]. Additionally, CiteSpace was used to construct the cluster map of document co-citation, its timeline visualization, and the dual-map overlay of journals [22]. The main parameters of CiteSpace were as follows: link retaining factor (LRF = 3), look back years (LBY = -1), e for top N ($e = 1$), time span (2010-2023), years per slice (1), links (strength: cosine, scope: within slices), selection criteria (g-index: $k = 20$), and minimum duration (MD = 1).

VOSviewer, developed by Nees Jan van Eck and Ludo Waltman, is a freely available computer software to conduct bibliometric maps [15]. In this study, VOSviewer was used to identify productive countries/regions, institutions, journals, and authors, as well as main co-cited references and author's keywords, and related visual networks were constructed [15]. In the network maps, different nodes indicate components, such as countries/regions, institutions, and journals. The size of the nodes reflects the number (N/n) of studies or cooccurrence frequencies. The links between the nodes represent the

cooccurrence relationships, and the size of the links indicates the cooccurrence frequencies of the two nodes [21]. VOSviewer settings were as follows: counting method (full counting), while, thresholds (T) of items (i.e., countries/regions, institutions, authors, journals, references, and keywords) were used according to special circumstances.

In additional, R-bibliometrix was used to construct the network of regions distribution for UPF-related publications [17]. Microsoft Office Excel 2016 was used to manage the data and create the chart of annual research output. The impact factor (IF) of the academic journals were collected from the Journal Citation Report 2022 (Clarivate Analytics, Philadelphia, USA), and the publishers' information was be obtained from WoSCC.

Results and discussion

Results of search and selection

A flow diagram of the literature selection process is presented in Figure 1A. A total of 1488 relevant records were initially identified after searching the WoSCC. Five different languages were used by the identified publications, including English (n = 1440, 96.77%), Portuguese (n = 30, 2.02%), Spanish (n = 14, 0.94%), French (n = 2, 0.13%), and German (n = 2, 0.13%). Of 1440 English publications, 201 published records were excluded further due to the ineligible type (e.g., abstract, editorial, correction). Furthermore, the titles, abstracts, and author's keywords were screened to exclude the records without any mention of the UPF term. Finally, 1018 records [901 (88.51%) articles and 117 (11.49%) reviews] were included in this scientometric study.

Analysis of annual output

All the included 1018 UPF studies were published from 2010 to 2023. As shown in Figure 1B, the number of publications significantly increased in the past decades, reflecting the increased interest of scholars in this research area. From 2010 to 2016, the number of publications per year was relatively stable and < 20, probably indicating that the initial UPF study was in an exploratory period. Over 100 papers have been published annually since 2020 (n = 125, 12.28%), reaching a peak of 340 publications (33.40%) in 2022. The publication number increased gradually after 2020, accounting for 76.52% (n = 779) of all the included papers, indicating that the UPF field may be in a period of rapid growth. These were basically

consistent with four stages of the evolutionary process of a new discipline proposed by Shneider [23].

The first article, entitled "A new classification of foods based on the extent and purpose of their processing" on record in WoSCC, was published in *Cadernos de Saude Publica* by Monterio et al. [24]. They defined three main groups of foods, including unprocessed or minimally processed foods, processed culinary and food industry ingredients, and UPFs [24]. However, several systematic reviews reported that the NOVA classification system was first introduced in 2009, and the concept of UPFs began to spread among people [25, 26]. Herein, the reference was traced to discover the earliest article entitled "Nutrition and health. The issue is not food, nor nutrients, so much as processing", which was published in *Public Health Nutrition* by Monterio et al. [27], but this paper could not be retrieved from WoSCC. However, this paper had the highest betweenness centrality (BC = 0.18) in the document co-citation analysis (see "Analysis of research topics"), demonstrating that this node has a purple ring in the timeline visualization of the cluster map. This observation highlighted that the publication is a pivot node and has scientific importance in the field of UPFs.

Analysis of countries/regions

The productive 10 countries/regions are shown in Table 1 according to the number of publications. The country/regions with the highest number of papers is Brazil (n = 473), indicating that Brazil might take the dominant position in research in the field of UPFs. The USA was the second most productive country, with the total publications accounting for about half of Brazil (n = 230), followed by Australia (n = 102). In addition, all the other countries/regions are less than 100 publications, such as England (n = 85), Spain (n = 75), and France (n = 59).

The number of scientific papers is an important indicator in scientific evaluation, reflecting the comprehensive research capacity to some extent [14]. Generally, the economic and technological power of the countries contributes to more authoritative scholars, thereby increasing scientific production [28]. Additionally, the output of countries/regions can be influenced by other factors, such as the popularity and influence of research topics in their areas. For example, in 2021, the USA had the highest UPFs consumption, with the percentage of energy intake from UPFs exceeding 50% of the total energy intake [29], which may, to some extent, explain why the USA published the second largest number of UPF research.

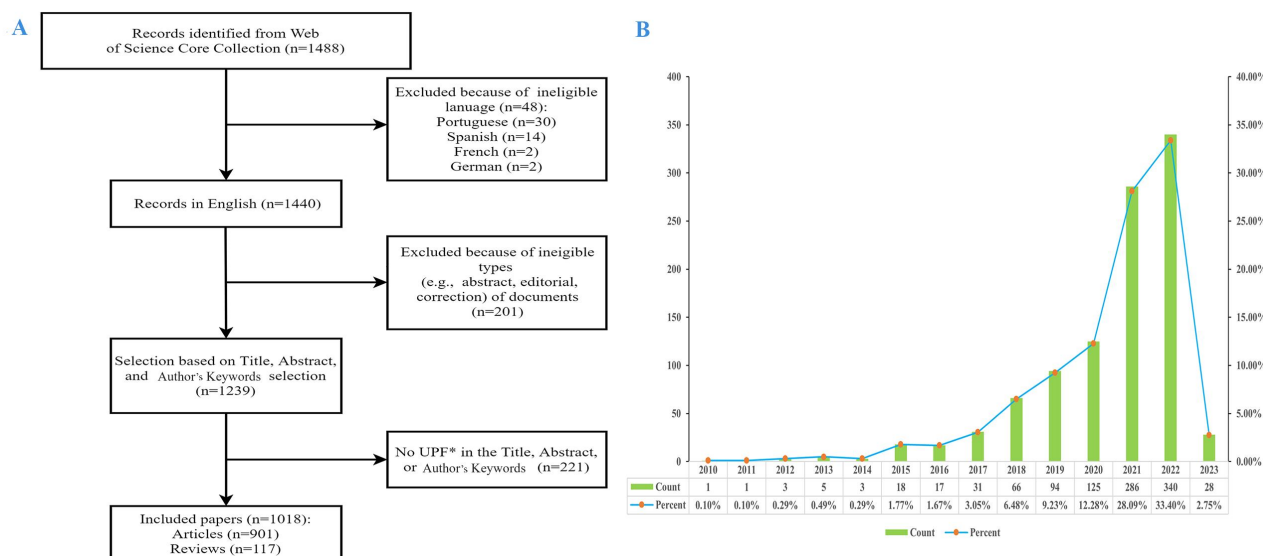


Figure 1 Flow diagram of literature selection (A) and annual output of UPF research (B).

Interestingly, Brazil and Mexico, as the developing countries, also significantly contributed to the field of UPFs. Brazil's significant advantage in the total number of publications could be attributed to various reasons. The reasons for Brazil publishing the highest number of publications may include but are not limited to the following points. Firstly, Brazil is the first country to introduce the NOVA classification system, and explain the definition of UPFs [27]. Secondly, Brazil is facing a shift away from traditional diets towards UPFs dominating dietary structure, which is associated with obesity and diet-related non-communicable diseases [3]. Thirdly, several businesses in Brazil receive government support, leading to a substantial expansion in the production and sale of UPFs [3]. Therefore, researchers should focus on the potential adverse impact of UPF industry political activities, encourage relevant practitioners to reduce conflicts of interest between policy-makers and the private sector, increase the transparency of their interactions, and monitor and educate corporate behavior to minimize industry influence on the food and nutrition policy [30]. Mexico shares similar reasons with Brazil, such as the prevalence of UPFs [31, 32].

The top 10 were distributed in four continents (Europe, North America, South America, and Oceania), and 50.00% of the top were located in Europe (Figure 2A). The 20 countries/regions with a publication number greater than or equal to 15 were used to construct the co-authorship network (Figure 2B). In this network map, Brazil, the USA, Australia and England had larger sizes of nodes, representing more publications. Brazil and the USA were at the central position in the field of UPFs, and other countries/regions (e.g., Australian, Canada) had close cooperations with them. Moreover, the strongest link within this network map of countries is between Brazil and the USA, showing the thickest link.

Analysis of institutes

According to the number of publications, the top 10 institutions were distributed in four countries/regions (Brazil, Australia, the USA, and Canada), with almost all institutions ($n = 7$, 70.00%) located in Brazil (Table 1). The Universidade de São Paulo ($n = 206$) published most papers ranked the first, followed by the Universidade Federal de Minas Gerais ($n = 79$), and the rest are less than or equal to 45 publications. Besides the number of publications, citation of publications is a critical index to evaluating the research level [14]. For instance, the first authors of the top 10 highly-cited papers and co-cited references were mostly affiliated with the Universidade de São Paulo (see "Analysis of references"). Thus, it was inferred that the UPF research conducted by the Universidade de São Paulo might be cutting-edge, and the research findings might be widely recognized among professionals.

The 10 institutions with more than or equal to 22 publications were used to construct the co-authorship network (Figure 3A). In this visual network, the Universidade de São Paulo and Universidade Federal de Minas Gerais had larger sizes of nodes, representing more publications. The Universidade de São Paulo was at the central position in this field, and the other institutions had close cooperations with them. However, the Universidade de São Paulo had the strongest cooperation with the Universidade Federal de Minas Gerais, showing the thickest link between them in the map. Academic cooperation is imperative for scientific success to improve the number and quality of publications. It is noteworthy that addressing many fundamental problems in modern science requires international collaboration [33]. Therefore, future researchers in this field should build a partnership with the top 10 institutions, specifically the Universidade de São Paulo and Universidade Federal de Minas Gerais.

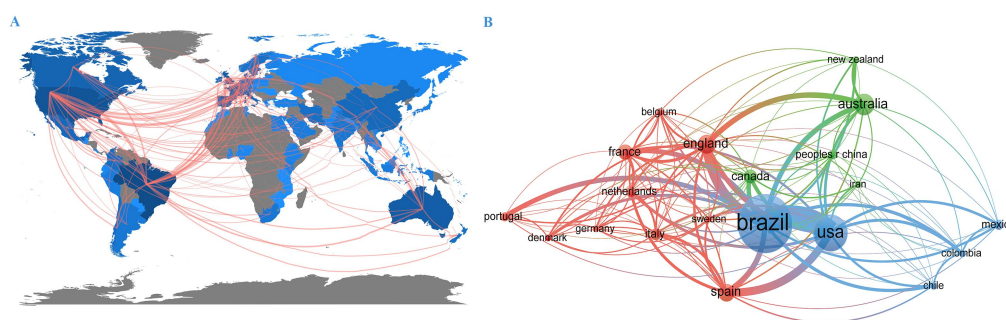


Figure 2. The regional distribution (A) and the network map of countries (B, $T = 15$, $N = 20$) in the field of UPFs.

Table 1 The top 10 countries/regions and institutions in the field of UPFs.

Rank	Country/Region	Count	Organization	Count
1	Brazil (South America)	473	Universidade de São Paulo (Brazil)	206
2	USA (North America)	230	Universidade Federal de Minas Gerais (Brazil)	79
3	Australia (Oceania)	102	Deakin University (Australia)	45
4	England (Europe)	85	Universidade do Estado do Rio de Janeiro (Brazil)	39
5	Spain (Europe)	75	Harvard T.H. Chan School of Public Health (USA)	34
6	France (Europe)	59	Universidade Federal de São Paulo (Brazil)	32
7	Canada (North America)	53	Universidade Federal do Rio de Janeiro (Brazil)	25
8	Italy (Europe)	40	Universidade Federal de Santa Catarina (Brazil)	25
9	Netherlands (Europe)	34	Universidade Federal de Pelotas (Brazil)	24
10	Mexico (North America)	31	Université de Montréal (Canada)	22

Analysis of authors

Based on the WoSCC analysis results, the same author names were merged. Half of the top 10 authors published greater than or equal to 30 publications (Table 2) and were ranked by the number of publications. Monteiro CA published the most papers ($n = 73$) and ranked first, followed by Levy RB ($n = 71$), Louzada MLD ($n = 38$), and Steele EM ($n = 35$). All authors were affiliated with the Universidade de São Paulo in Brazil, with six affiliated with the Center for Epidemiological Research in Nutrition and Health, which further demonstrated the previous point that highly-cited authors tend to gather in the same research section [14]. However, the adverse influences of UPFs should be solved by multidisciplinary professionals [34]. Therefore, the future research team should include public health professionals, health policy makers, and medical experts to explore the acceptable and feasible design of health programs to achieve a safe, healthy, and sustainable food system [35].

The 10 authors with publication numbers greater than or equal to

20 were used to construct the co-authorship map (Figure 3B). The node sizes of Monteiro CA and Levy RB were larger due to more publications. Monteiro CA had the strongest cooperation with Levy RB, showing the thickest link between them on the map. Additionally, Louzada MLD and Steele EM had close cooperation with Monteiro CA, Louzada MLD and Rauber F had close cooperation with Levy RB. Therefore, future scholars could develop cooperative relationships with these productive authors.

Notably, Monteiro CA is a distinguished scholar in this field who proposed NOVA food classification that group foods according to the extent and purpose of the industrial processing applied to them [24]. He broke the previous classification of food into only two categories, unprocessed and processed, which might not be useful for relevant surveys, as almost all foods are being processed in some way in high- and low-income countries [24]. Moreover, Monteiro provided a clear and simple guideline for identifying UPFs, benefiting decision-makers, scientific communities, and others [36].

Table 2 The top 10 authors, highly-cited paper, and co-cited references in the field of UPFs.

Rank	Author	Count	Highly-cited Paper	Count	Co-cited Reference	Count
1	Monteiro CA	73	Moodie R, 2013, lancet, v381, p670	941	Monteiro CA, 2018, public health nutr, v21, p5	339
2	Levy RB	71	Monteiro CA, 2019, public health nutr, v22, p936	641	Monteiro CA, 2019, public health nutr, v22, p936	336
3	Louzada MLD	38	Hall KD, 2019, cell metab, v30, p67	569	Monteiro CA, 2013, obes rev, v14, p21	263
4	Steele EM	35	Monteiro CA, 2011, public health nutr, v14, p5	524	Monteiro CA, 2016, world nutr, v7, p28	236
5	Rauber F	30	Popkin BM, 2020, lancet, v395, p65	441	Louzada MLD, 2015, rev saude publ, v49	233
6	Canella DS	26	Fiolet T, 2018, bmj-brit med j, v360	413	Fiolet T, 2018, bmj-brit med j, v360	206
7	Claro RM	25	Steele EM, 2016, bmj open, v6	382	Moubarac JC, 2017, appetite, v108, p512	203
8	Martins AP	23	Monteiro CA, 2010, cad saude publica, v26, p2039	376	Steele EM, 2016, bmj open, v6	199
9	Moubarac JC	23	Louzada MLD, 2015, rev saude publica, v49	364	Louzada MLD, 2015, prev med, v81, p9	187
10	Khandpur N	21	Louzada MLD, 2015, prev med, v81, p9	340	Hall KD, 2019, cell metab, v30, p67	186
					Mendonca RD, 2016, am j clin nutr, v104, p1433	186

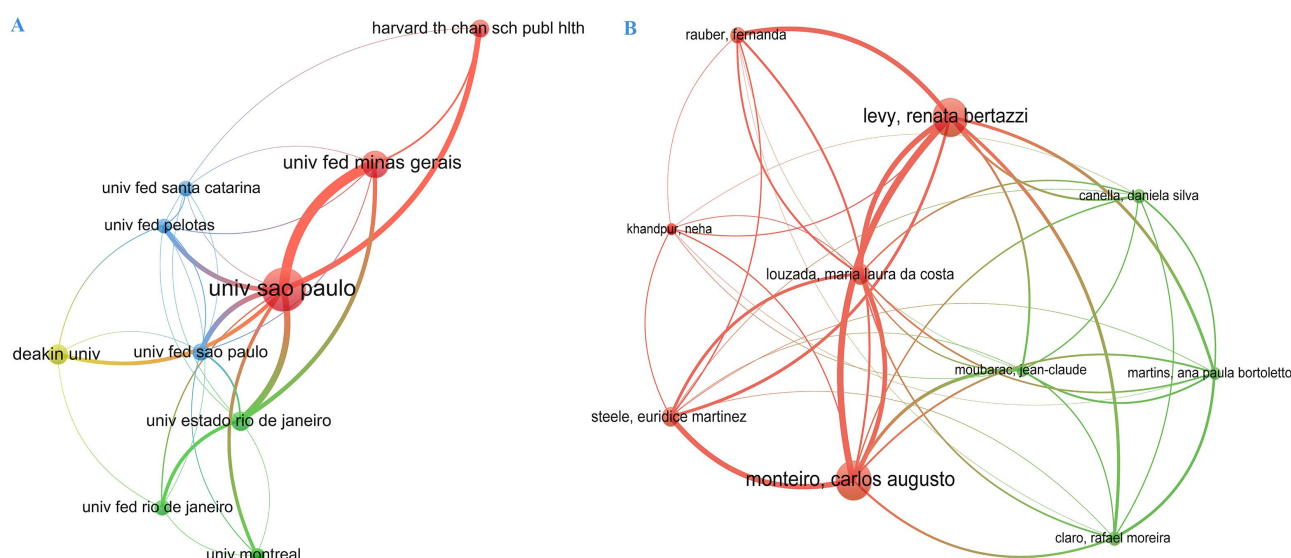


Figure 3. The network map of institutions (A, T = 22, N = 10) and authors (B, T = 20, N = 10) in the field of UPFs.

Analysis of journals

Academic journal is a vehicle for storing human and understanding of the current state of the world and its future direction [37]. Academic journals usually have their own different specific topics, from which multidisciplinary scholars inherit, communicate, and generalize scientific achievements [37]. According to the number of publications, the top 10 journals in the field of UPFs published 449 papers, accounting for 44.11% of the total publication (Table 3). As a peer-reviewed journal devoted to human nutrition research, *Nutrients* published the most papers ($n = 126$, 12.38%, $IF_{2021} = 6.706$), followed by *Public Health Nutrition* ($n = 105$, 10.31%, $IF_{2021} = 4.539$), *Frontiers in Nutrition* ($n = 40$, 3.93%, $IF_{2021} = 6.59$), and *British Journal of Nutrition* ($n = 30$, 2.95%, $IF_{2021} = 4.125$) (Table 3). Overall, the top 10 journals that published UPF research were mostly relevant to nutrition/dietary and public health. However, two (*Nutrients* and *International Journal of Environmental Research and Public Health*) of the top 10 journals belonged to a recent mega-journal list published. They defined mega-journals as open-access journals that charge article publication fees and have a fast turnaround, with 2000 full papers published per year [38]. Moreover, the authors expressed a specific concern that these mega-journals perpetuate and exacerbate an already dysfunctional scientific assessment and publication system [38]. Furthermore, researchers suffering from academic competition pressure tend to prefer submitting their scientific achievements to mega-journals, contributing to the occurrence of questionable publishing, as scientific deadlocks and financial losses can occur after the publication of a questionable paper [39].

Scientific communities usually rank academic journals quantitatively by assigning their IFs, which represent their influence, prestige, and novelty to some extent [37]. Although IF has been recently criticized because of some serious limitations, it still maintains strengths in science assessment and library collection management [40]. Of the 10 top journals that published UPF research, six (60.00%) had an IF_{2021} of ≥ 4 , and the journals with the highest IFs were *Nutrients* and *Frontiers in Nutrition*, with the IFs of 6.706 and 6.59, respectively. However, some journal editors game the system to manipulate the IF of their journals, which in many cases distort the scientific process [41].

As shown in Figure 4A, 11 journals with a publication number greater than or equal to 20 were used to construct the network map of academic journals, demonstrating the number of publications and citation relationships. Dual-map overlays can display the distribution relationship between citing and cited journals, facilitating the analysis of the literature at a disciplinary level [42]. As shown in Figure 4B, the labels represented the disciplines covered by the journal, and the lines on the map started from the left (citing journals) and ended on the right (cited journals), representing the citation links [42]. The thickness of a line is proportional to the z-score-scaled frequency of

citation [43]. Four main citation paths were identified, including three green paths and one blue path. The green paths indicated that the UPF papers, published in the Environmental/Toxicology/Nutrition journals, Molecular/Biology/Genetics journals, and the Health/Nursing/Medicine journals were usually cited in the UPF studies, published in the Medicine/Medical/Clinical journals. The blue path represented UPF literatures, published in the Health/Nursing/Medicine journals, were typically cited in the studies, published in the Psychology/Education/Health journals.

Analysis of references

References of scientific papers can be considered as the cumulative knowledge storage of the authors and are mainly cited to support the viewpoints, methodology, or conclusions of those papers [44]. In scientometric analyses, the number of citations is often used to evaluate the quality of a paper, the influence of a researcher, and the scientific capacity of a research institution [44].

According to the number of citations, the top 10 highly-cited papers were obtained from WoSCC and are reported in Table 2. In 2013, the article entitled “Profits and pandemics: prevention of harmful effects of tobacco, alcohol, and ultra-processed food and drink industries” published by Moodie et al. [45] in *Lancet*, was the highest-cited paper, with 941 citations in the literature. This paper proposed some approaches for unhealthy industries to prevent and control non-communicable diseases and concluded that public regulation and market prevention can prevent the adverse impact caused by these industries [45]. In additional, Monteiro et al. [46] published the fourth most highly-cited paper ($n = 524$) entitled “Increasing consumption of ultra-processed foods and likely impact on human health: evidence from Brazil” in *Public Health Nutrition*. The authors surveyed the underlying impact of UPFs on dietary quality among Brazilian households and found that UPFs have a high energy density and a poor nutritional profile [46]. Consequently, they suggested that authorities should consider implementing any possible measures to halt the increasing trend of UPFs contributing to the overall diet [46]. The fifth most highly-cited review was published in the *Lancet* by Popkin et al. [47], with 441 citations, which focused on the dynamics of the double burden of malnutrition in low- and middle-income countries and its variation in terms of socioeconomic levels. They indicated that the increased burden of malnutrition is largely due to rapid changes in the food systems, especially the availability of cheap UPFs in low- and middle-income countries [47]. In 2010, *Cadernos de Saude Publica* published the eighth most highly-cited article ($n = 376$), and Monteiro et al. [24] introduced a new food classification classifying foods into three main groups based on the extent and purpose of industrial processing, and discussed the impact of UPFs on dietary quality, eating structure, and health status. They found that UPFs have adverse effects on the above aspects; thus, relevant policies must be introduced to reduce UPF consumption [24].

Table 3. The top 10 journals of UPF research.

Rank	Journal	Country/Region	Publisher	Count	IF_{2021}
1	Nutrients	Switzerland	MDPI	126	6.706
2	Public Health Nutrition	England	Cambridge University Press	105	4.539
3	Frontiers in Nutrition	Switzerland	Frontiers Media SA	40	6.59
4	British Journal of Nutrition	England	Cambridge University Press	30	4.125
5	Ciencia & Saude Coletiva	Brazil	ABRASCO	29	1.917
6	Revista de Nutricao-Brazilian Journal of Nutrition	Brazil	Pontifical Catholic University of Campinas	26	1.141
7	Revista de Saude Publica	Brazil	Faculdade de Saúde Pública da Universidade de São Paulo	25	2.772
8	Cadernos de Saude Publica	Brazil	ENSP	24	3.371
9	Appetite	Netherlands	Elsevier	22	5.016
10	International Journal of Environmental Research and Public Health	Switzerland	MDPI	22	4.614

In the field of scientometrics, the co-cited references are defined as the references cited together by other publications, and the topics focused by them can be viewed as knowledge bases in the particular field. The top 10 co-cited references with 11 publications (same co-citations of two papers) are presented in Table 2. Of those, six were also the highly-cited papers, and all of these highly co-cited papers were discussed in detail below. Monteiro et al. [48] published a study, entitled “The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing” in the *Public Health Nutrition*, which was the most co-cited paper ($n = 339$) and ranked first. The authors investigated the influence of UPFs on successfully achieving the United Nations Sustainable Development Goals [48]. Moreover, they argued that the increase in UPF production and consumption is causing a crisis in the world and should be addressed as part of the United Nations Sustainable Development Goals and its function in the Nutrition Decade [48]. In 2019, Monteiro et al. [36] published the second most co-cited article ($n = 336$) entitled “Ultra-processed foods: what they are and how to identify them”, which also the second most highly-cited paper with 641 citations. They provided guidance designed to clearly and simply identify UPFs to formulate policies for decision makers and public health professionals [36]. The third most co-cited review ($n = 336$) was published by Monteiro et al. [49], which revealed that UPFs dominate the food supplies of high-income countries, with a rapid increase in consumption in middle-income countries. Moreover, they proposed that transnational food manufacturing, retailing, and fast-food service corporations were the main driving forces shaping the global food system [49]. *World Nutrition* published the fourth most co-cited study ($n = 236$) entitled “NOVA. The star shines bright” by Monteiro et al. [50] in 2016. They introduced the NOVA classification system, which categorizes foods according to the extent and purpose of food processing, rather than nutrients [50]. In 2015, Louzada et al. [51], who published the fifth most co-cited article ($n = 233$) in *Revista de Saude Publica*, discussed the association between UPFs and diet quality, and replacing a traditional diet based on natural or minimally processed foods with UPFs has been observed to be detrimental to health in Brazil [51]. In addition, this article was ranked the ninth most highly-cited paper with a citation of 364 times [51]. Similar results were observed in the seventh most co-cited article, “Consumption of ultra-processed foods predicts diet quality in Canada” ($n = 203$) published in *Appetite* by Moubarac et al. [52]. The sixth most co-cited and highly-cited article was published in 2018 by Fiolet et al. [53]. This large prospective cohort study showed that a 10% increased dietary UPF was associated with a significant increase of more than 10% in overall and breast cancer risk [53], with 206 co-citations and 413 citations, respectively. In 2016, the eighth most co-cited article ($n = 199$) was published by Steele et al. [54] in *BMJ Open*, which was also the seventh most highly-cited article with 382 citations. They investigated the contribution of UPFs to the intake of added sugar in the USA and concluded that UPF accounts for 57.9% of energy intake, and 89.7% of energy intake comes from added sugars [54]. Louzada et al. [55] published the ninth most co-cited ($n = 187$) and tenth most highly cited article ($n = 340$) in *Preventive Medicine*. This cross-sectional study surveyed the effect of UPFs on obesity indicators and found that the highest UPF consumption was positively associated with higher body mass index, excess weight, etc [55]. A cohort study and randomized controlled trial both were the tenth most co-cited papers due to the same number of citations ($n=186$). The cohort study was published in *American Journal of Clinical Nutrition* by Mendonca et al. [56] in 2016, investigating the association between UPF consumption and the incidence of overweight/obesity in adults. They revealed that increased UPF consumption has a significant effect on the risk of overweight/obesity [56]. Hall et al. [57] conducted a randomized controlled trial to survey the effect of UPFs on energy intake and weight gain among adults with stable weights, which was the third most highly-cited paper ($n = 569$) published in *Cell Metabolism*. They suggested that UPFs should be limited to prevent and treat obesity based on the high correlation between UPF consumption and above unhealthy outcomes [57]. Generally, the top 10 co-cited references

were focused on the NOVA system, the definition of UPFs, the prevalence of UPFs, and the impact of UPFs on dietary quality and health status, and they can be viewed as the main research base.

Seventeen references with co-citations greater than or equal to 145 were used to construct the network map of co-citations (Figure 4C). The node size of “Monteiro CA, 2019, Public Health Nutrition, V22, P936” and “Monteiro CA, 2018, Public Health Nutrition, V21, P5” were larger due to more co-citations, demonstrating the most active co-cited relationships, with the thickest link between them in the map. The paper published by Monteiro et al. [48] in 2018 suggested that given the multiple threats (e.g., food supply, food security, human health), 2016-2025 is designated by the United Nations as the Decade of Nutrition, so it is necessary to identify the nutritional value of foods and whether these can contribute to sustainable development. In 2019, Monteiro et al. [36] provided a clear and understandable guide to the growing interest in UPFs among people from all walks of life to help them identify UPFs. Therefore, the researcher may tend to cite them simultaneously, because of a relatively stronger relevance between them.

Accurate citation is essential to ensure the reliability, accuracy and credibility of academic papers in scientific fields [58]. Miscitation may affect the accuracy of co-citation analysis in the field of scientometrics. Recently, the issue of miscitation has emerged as a significant concern in multiple fields [58-60]. For example, Cobb et al. [58] investigated the accuracy of 3347 citations in 89 articles from eight top psychology journals and found that approximately one of 10 citations completely miscited the previous research. Lazonder et al. [60] randomly selected 500 educational research articles published between 2016 and 2020 and estimated that the miscited rate of educational research articles was 15%, indicating that on average, one of every six to seven citations contained an error [60]. Therefore, the authors of scientific articles should undertake the principal burden of ensuring the accuracy of citations [59]. They should recognize the importance of citation accuracy, select primary sources for citation, read the full texts rather than just abstracts to understand before citing, clearly and accurately state findings of a previous publication in their papers, and cross-check to ensure correctness [58, 59]. Lastly, the journal editors and reviewers should further review and check each citation for accuracy during the manuscript reviewing and quality examination process [59].

Analysis of research topics

Author's keywords in the scientific literature are terms selected and created by authors, who apply keywords to represent their research topics [61]. The co-occurrence analysis of author's keywords can be conducted in a scientometric study to elucidate the scientific knowledge structure and research hotspots in different disciplines [61].

In this study, after relabeling the synonymic words using the thesaurus file, 76 keywords meeting the threshold of a minimum of 10 occurrences were used to conduct the time-based overlay map of co-occurrence analysis of author's keywords using VOSviewer (Figure 5A, Table 4). As shown in Figure 5A, the size of nodes corresponded to the number of occurrences, and different colors represented the average year of the keyword appearance (from blue to red). Thus, the labels of orange and red nodes were identified as recent research hotspots in this study, including “COVID-19”, “diabetes mellitus”, “food addiction”, “commercial determinants of health”, “mediterranean diet”, “pregnancy”, “inflammation”, and “systematic review”.

The cluster map of co-cited references was constructed using Citespace to validate and supply the results identified by VOSviewer (Figure 5B), and its timeline visualization is shown in Figure 6A. A total of 13 clusters were named using the terms extracted from the keywords of citing papers based on the log-likelihood rate (LLR) method. Notably, the cluster results were significant and highly credible according to the values of modularity ($Q = 0.58$) and weighted mean silhouette ($S = 0.84$). As shown in Figure 6A, seven clusters, including “#1 NOVA food classification”, “#2 type 2

For “systematic review”, a systematic review is an important method of evidence synthesis, specifically using explicit and predesigned scientific tools to identify, select, evaluate, and summarize the results of similar but separate studies of a specific topic [62]. The results of systematic reviews typically play a vital role in informing clinical practice guidelines and health policies for clinical doctors and public health professionals. Six references showed stronger burstiness between 2022 and 2023 (Figure 6B), with four published in 2020 or 2021 belonging to the document type of systematic review [26, 63–65]. Thus, indicating that the application of the systematic review method to study the association between UPFs and multiple health outcomes has gained considerable attention by scholars in this field. For instance, a paper entitled “Consumption of ultra-processed foods and health outcomes: a systematic review of epidemiological studies” by Chen et al. [63] was published in *Nutrition Journal*, and the results suggested that high UPF consumption was positively associated with a variety of unhealthy outcomes (e.g.,

With regard to “NOVA food classification”, the NOVA system is the most authoritative and widely used food classification system at present, categorizing foods into four groups based on the nature, extent and purpose of processing, unprocessed or minimally processed foods (Group 1), processed culinary ingredients (Group 2), processed foods (Group 3), and UPFs (Group 4) [66]. Although, several food classification systems have been developed to distinguish the different industrial processing levels of foods, inconsistencies may exist between them [67]. For instance, Valenzuela et al. conducted a study in 2022 to assess the quantitative and qualitative differences between NOVA, Nutri-Score, and Chilean Front-of-package food warning label and found that NOVA has concrete differences compared to other classification systems in terms of distribution of product categories [67]. Moreover, Dickie et al. [66] pointed out that although the adverse outcomes of UPFs are of significant concern, the policy makers rarely incorporate this concept of NOVA system into the nutrition classification scheme. Thus, they explored a model nutrition classification scheme combining the processing level and nutrient criteria, which could be effective for food classification and policy formulation.

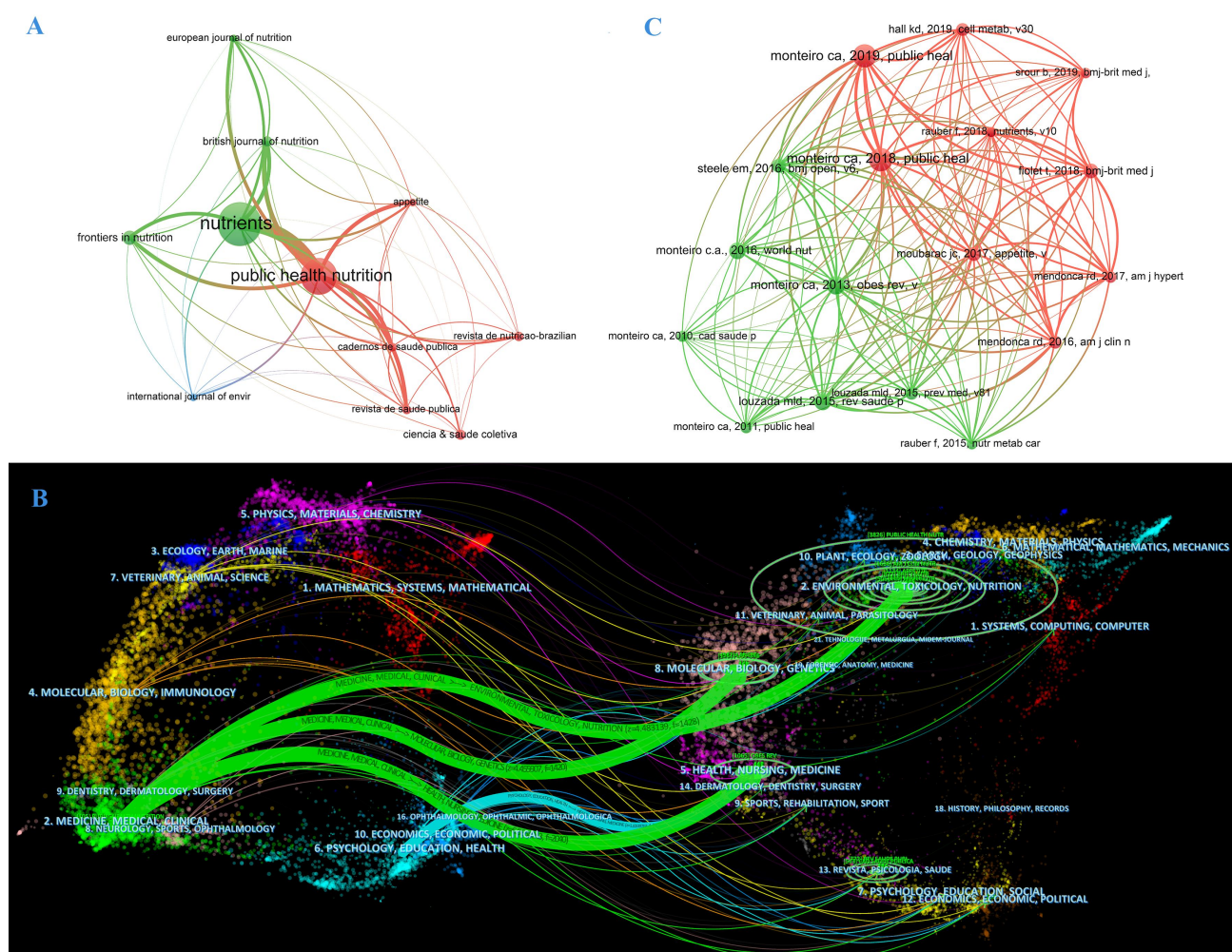


Figure 4. The network map of academic journals (A, T = 20, N = 11), dual-map overlay of journals (B) related to UPF research and co-cited references (C, T = 145, N = 17).

As for “COVID-19”, COVID-19 started in December 2019, and so far, there are over 766 million confirmed cases and 6.9 million death reports worldwide (as of 17 May 2023) [68]. The declaration of the COVID-19 pandemic on 11 March 2020 significantly affected the food consumption structure and behavior of the population [69–71]. For example, Coletro et al. [69] explored the association between the health risk behaviors (e.g., sedentary behavior, high UPF consumption) caused by COVID-19 and the risk of anxiety or depression in adults. They found that cheap, convenient, palatable, non-perishable, and easily accessible UPFs adopt to the need of this health crisis, leading to a significant increase in their consumption during this period [69]. This increase was further shown to be associated with the prevalence of mental disorders in their study [69]. In addition, Zhou et al. [71] evaluated the association between UPF consumption and the risk of COVID-19 infection, concluding that higher UPF consumption is significantly associated with an increased risk of COVID-19.

In terms of “diabetes”, more than 500 million people are living with diabetes worldwide in 2021, with approximately 10.5% of prevalence in 20–79-year-olds [72]. Diabetes has become a global health problem, causing life-threatening, disabling, and costly complications and shortened life expectancy [72]. For example, Sen et al. [73] investigated whether UPF intake and depression were the risk factors for developing type 2 diabetes mellitus and found that high UPF consumption combined with serious depression were associated with the highest risk for type 2 diabetes mellitus. A study published by Li et al. [74] in *Nutrients* evaluated the association between UPF consumption and diabetes in China. They concluded that an average daily intake of more than 50 g of UPFs was associated with 40% increased diabetes risk compared to no consumption [74]. Therefore, early controlling the consumption of UPFs might be essential for diabetes mellitus prevention.

For “pregnancy”, it adequately shows the responses of researchers to the effect of UPFs on special populations. Maternal nutrition has a critical impact on the short and long-term health of both mothers and children, while present evidence shows that UPFs with potential adverse effects account for nearly half of the energy among women [75]. Therefore, studies on the association between UPF consumption and pregnancy outcomes could help public health practitioners make sensible policies. For instance, a cross-sectional study published by Paula et al. [76] in 2023 assessed the association between UPF consumption and dietary nutrient intake in pregnant women and found that high intake of UPFs has a negative impact on nutrition value and contributes to lower nutrient intake in pregnant women. Furthermore, they suggested that a decreased UPF consumption might improve the adherence of pregnant women to the dietary guideline, and is beneficial to maternal and neonatal health [76]. Oliveira et al. [77] carried out a systematic review to determine whether UPF consumption by women and children was positively associated with health outcomes [77]. They found that highest UPF consumption has a negative impact on nutrition and disease development indicators in pregnant and lactating women and children [77].

With regard to “food addiction”, it is an abnormal, recurring pattern of excessive food consumption with negative consequences, while evidence-based treatments for food addiction have not been developed yet [4, 78]. Laurent et al. [79] discussed the challenges of UPFs to dietary adherence and verified the related evidence to reduce the consumption of UPFs. They summarized that compared to minimally processed foods, UPF consumption has a greater addictive-like response and abuse liability [79]. A paper entitled “Preliminary Evidence that Tolerance and Withdrawal Occur in Response to Ultra-processed Foods” was published by Parnarouskis et al. [80] in *Current Addiction Reports* pointed out that although UPF nature contributes to addiction, researchers pay little attention to the core symptoms (i.e., tolerance and withdrawal). Based on preliminary evidence, they found that tolerance and withdrawal might occur in response to UPFs [80]. Therefore, future researchers can take on a whole food low-carbohydrate approach along with providing psychosocial support to treat food addiction related to UPFs [81].

As for “warning labels”, it is designed to help consumers correctly identify the food products with high nutrients, thereby discouraging them from wanting to intake “high in” products [82]. For example, Miller et al. [83] investigated the understanding and viewpoint of young adults on nutrient warning labels and found that the labels detecting the amount of sugar in a beverage using teaspoons are most likely to influence consumer attitudes compared to a general textual warning of “high in sugar”. Notably, UPF manufacturers and non-health sector staff stated that taxes and regulations on UPFs might decrease the employment rate and wages of workers [84]. In contrast, Diaz et al. [84] showed no impact on employment and wages due to industry substitution and other actions. Therefore, warning label is a promising strategy that more countries need engage in, and they should use pictogram label to achieve a better warning effect.

For “plant-based diet”, a plant-based diet is a sustainable dietary pattern consisting of all non-animal components, gaining interest due to its benefits to the environment and human health [85, 86]. However, it is important to note that some plant-based foods can be highly processed [85, 86]. For example, Macdiarmid [87] published a paper entitled “The food system and climate change: are plant-based diets becoming unhealthy and less environmentally sustainable?” in *Proceedings of The Nutrition Society* in 2021. The paper found that the plant-based diet has a chain reaction to climate changes and human health, contributing to the health and the environmental benefits brought by changes in any plant-based diet [87]. A randomized controlled trial was carried out by Toribio-Mateas et al. [88] to assess the changes in gut microbiota in a group of 20 participants who replaced several meat-containing meals per week with plant-based meat alternatives products. They concluded that the occasional replacement of animal meat with plant-based meat alternatives could promote positive changes in the consumer's gut microbiome.

In terms of “commercial determinants of health”, these are the products and practices of some business practitioners, particularly large multinational corporations, which contribute to avoidable unhealthy outcomes, planetary damage, and social and health inequities [89]. For instance, UPF corporations adopt various marketing strategies to develop a nice nutrition profile of their products and formulate a broader food system to influence the understanding of the UPF concept among scientists and the public [90]. Notably, they fund nutritional studies that lead researchers to conclusions that are more favorable to their products. Through these scientific studies and marketing activities, they guide the public to focus on the nutrients of UPFs and reduce the levels of nutrients to mislead the public into thinking UPFs are “healthy foods” [90]. Therefore, researchers can develop a monitoring mechanism for open agendas and real-time reporting of political activities to obtain usable and reproducible data [90, 91]. Additionally, journal publishers and decision-making committees should disclose conflicts of interest, such as public health actors refusing fundings from industries, nonprofessional associations, etc., as much as possible to reduce bias in performing dietary studies and guidelines. Furthermore, government sectors should ban policies and regulations that focus only on single and isolated nutrients and individual products and practices, shift regulatory focus on the entire UPF category, and regulate the entire product portfolio of these companies [90, 91].

Interestingly, at the time we nearly completed the manuscript, the *Lancet* published a series of three reviews discussing this issue [89, 92, 93], validating this hotspot identified in this study further. The first paper proposed that four industrial sectors (i.e., tobacco, UPF, fossil fuel, and alcohol) are currently responsible for more than one-third of global deaths and how commercial actors are increasingly causing harm and externalizing the costs [89]. They call on the government to take action to improve the current pathological situation where the increase in power and wealth of the business sectors has led to the policy addressing the healthcare sector failing to implement [89]. Lacy-Nichols et al. [93] published the second study entitled “Conceptualising commercial entities in public health: beyond unhealthy commodities and transnational corporations”, and they proposed that the governance of business interests in public health is

achieved by developing a distinct framework to distinguish between business entities and their promotional and harmful effect on health, rather than focusing narrowly on unhealthy commodities, such as tobacco, alcohol, and UPFs [93]. The third publication provided a future direction for commercial determinants of health in achieving health for all and the equal enjoyment of the right to health [92]. To be specific, Friel et al. [92] suggested that progressive business entities must take the initiative to advance regenerative business models and do the right thing under the regulations of the government, health professionals, and other civil society groups.

Strengths and limitations

This study has several strengths. Firstly, this is the first study to use the scientometric method to systematically analyze global UPF research, which can provide useful references for researchers in the field of UPFs. Secondly, three (CiteSpace, VOSviewer, and R-bibliometrix) widely used scientometric software tools were employed to conduct data analysis at the same time, and they were designed by well-known information scientists. For example, the

results of CiteSpace and VOSviewer complemented and validated each other, further ensuring the accuracy of research hotspots. Thirdly, the data (e.g., keywords) were cleaned, and the overall quality of the analysis was solid due to the reliability of the distributivity and homogeneity of clusters. Lastly, the objective was to conduct a high-quality scientometric analysis to identify the research trends in the field of UPFs, and the SCIE and SSCI publications from WoSCC might be the appropriate choice.

Like other scientometric research, this study has several limitations. Firstly, except for the WoSCC database, other large medical databases, such as PubMed, were not searched, as fusing the data from multiple different databases is extremely difficult for analysis. Secondly, all information was extracted by software tools, unlike systematic reviews or umbrella reviews, where data are manually extracted and cross-checked by two or more independent researchers [94]. Thus, data used to support this study results may have bias. Thirdly, only the publications that mentioned UPF(s) in their titles, abstracts, or author's keywords were included, while studies that thematically address UPFs but do not label them as such were not covered.

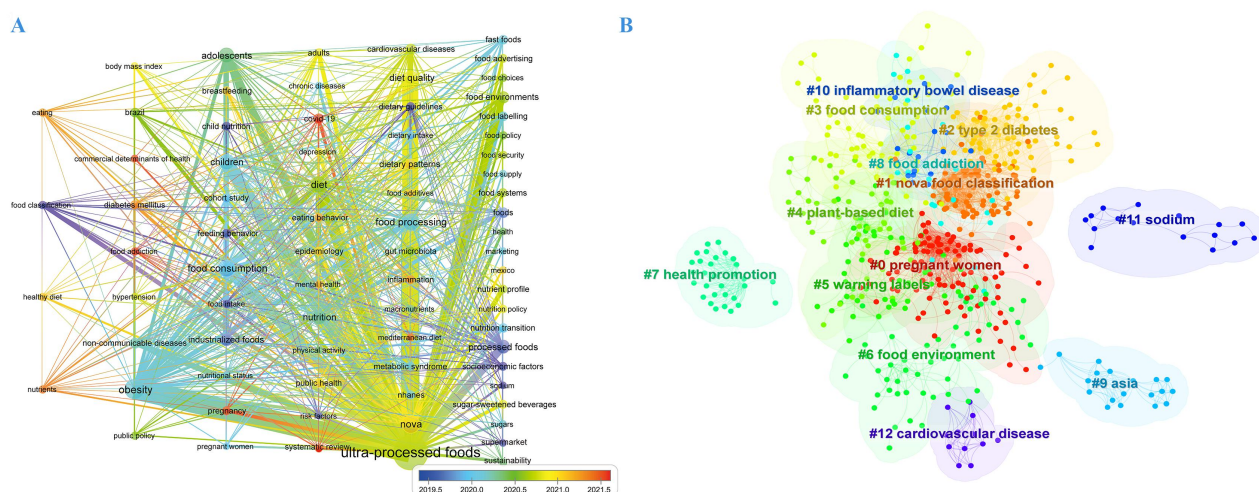


Figure 5. Time-based overlay map of author's keywords (A, $T = 10$, $N = 76$) and the cluster map of document co-citation (B, g -index: $k = 20$, $LRF = 3$, $LBV = -1$, $e = 1$).

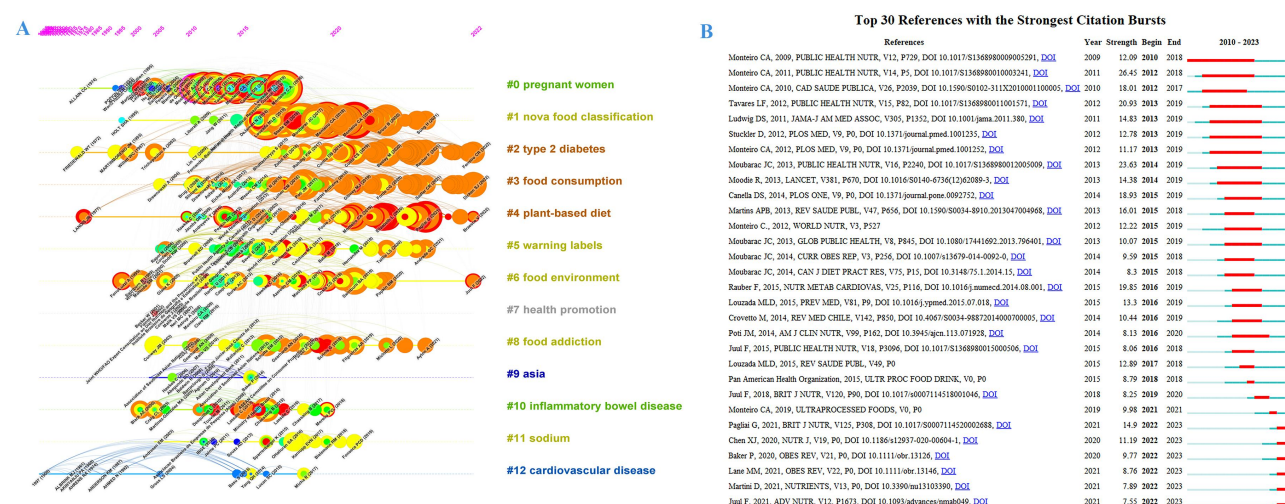


Figure 6. Timeline visualization of cluster map of document co-citation (A) and the top 30 references with the strongest citation burstness (B, $MD = 1$).

Table 4. The top 76 highly-occurrence author's keywords in papers related to UPF.

Rank	Keyword	Occurrences	Rank	Keyword	Occurrences
1	Ultra-processed foods	457	39	Gut microbiota	15
2	Obesity	121	40	Pregnancy	15
3	NOVA	93	41	Socioeconomic factors	15
4	Food consumption	82	42	Sugar-sweetened beverages	15
5	Food processing	82	43	Dietary intake	14
6	Diet	71	44	Food classification	14
7	Children	64	45	Food intake	14
8	Adolescents	57	46	Nutrition policy	14
9	Nutrition	56	47	Public policy	14
10	Diet quality	48	48	Sustainability	14
11	Processed foods	48	49	Depression	13
12	Industrialized foods	38	50	Food security	13
13	Food environments	34	51	Healthy diet	13
14	Dietary patterns	29	52	Mental health	13
15	Cardiovascular diseases	27	53	Nutrients	13
16	Non-communicable diseases	27	54	Eating	12
17	Foods	26	55	Food addiction	12
18	COVID-19	22	56	Food additives	12
19	Adults	19	57	Food choices	12
20	Epidemiology	19	58	Food policy	12
21	Food labelling	19	59	Food supply	11
22	Public health	19	60	Hypertension	11
23	Brazil	18	61	Nutritional status	11
24	Cohort study	18	62	Physical activity	11
25	Fast foods	18	63	Pregnant women	11
26	Nutrition transition	18	64	Risk factors	11
27	Feeding behavior	17	65	Sugars	11
28	Food systems	17	66	Supermarket	11
29	Metabolic syndrome	17	67	Body mass index	10
30	Nutrient profile	17	68	Chronic diseases	10
31	Child nutrition	16	69	Commercial determinants of health	10
32	Eating behavior	16	70	Health	10
33	Inflammation	16	71	Macronutrients	10
34	NHANES	16	72	Marketing	10
35	Breastfeeding	15	73	Mediterranean diet	10
36	Diabetes mellitus	15	74	Mexico	10
37	Dietary guidelines	15	75	Sodium	10
38	Food advertising	15	76	Systematic review	10

Conclusions

In this study, the intellectual landscape and emerging research trends in the field of UPFs were identified using three well-known scientometric software: R-bibliometrix, CiteSpace, and VOSviewer. The results showed that Brazil was a leading country in terms of the largest number of publications, with over half of the top 10 active institutions located in Brazil. The University of São Paulo contributed the most publications, and the 10 most productive authors were affiliated with this institution. Monteiro CA and Levy RB were

high-yield scholars who significantly contributed to the development of this field. The first core journal was *Nutrients*. The NOVA system, the definition of UPFs, the prevalence of UPFs, and the impact of UPFs on dietary quality and health status were identified as the main research bases. “Systematic review”, “NOVA food classification”, “COVID-19”, “diabetes”, “pregnancy”, “food addiction”, “warning labels”, “plant-based diet”, and “commercial determinants of health” were the main research hotspots.

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