

REVIEW

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# Global hotspots and trends of nutritional supplements in sport and exercise from 2000 to 2024: a bibliometric analysis

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## Abstract

**Background** Nutritional supplements for sports and exercise (NSSE) can facilitate the exogenous replenishment of the body. This study provides the first extensive overview of NSSE research through bibliometric and visual analyses.

**Methods** We searched the Web of Science Core Collection database for literature related to “NSSE” from 1st January 2000 to 8th March 2024. A total of 1744 articles were included. CiteSpace, VOSviewer, and Bibliometrix R package software were used to analyze the data.

**Results** Research in the NSSE can be divided into steady growth, exponential growth, fluctuating stage, and surge stages. The United States is the most active country in this field. In recent years, the leading countries have been Croatia, Colombia, Slovenia, Chile, Egypt, China, and Thailand. The Australian Institute of Sports is the top research institution in terms of number of publications. Burke, LM from Australia published the most articles. Research in this area has primarily been published in *Nutrients* in Switzerland. The study population mainly consisted of men, and postmenopausal women were the main focus of the female group. Coronary heart and cardiovascular diseases continue to dominate research.

**Conclusion** Research on the NSSE is developing rapidly, with an annual growth trend. Insulin resistance, sports nutrition, inflammation, alpha-linolenic acid, limb strength performance, female sex, and gut microbiota are the focus of the current research and trends for future research. Future research should focus on improving the scientific training system for athletes and quality of training and life for the general public.

**Keywords** Nutritional supplements, Dietary supplements, Sport, Exercise, Bibliometric analysis

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## Introduction

Nutritional supplements for sports and exercise (NSSE) refer to products containing carbohydrates, proteins, fats, minerals, vitamins, herbs, enzymes, metabolic intermediates (amino acids), or extracts of various plants/foods [1]. As a supplement to the normal diet, these supplements are concentrated sources of nutrients (or other substances) that possess nutritional or physiological effects [2]. Their products can be capsules, tablets, pills, granules, chewable tablets, or gummies [3] intended to supplement dietary deficiencies in nutrients or substances that have a specific physiological effect [4].

Sports and exercise have become indispensable components of individuals' lives in contemporary society [5]. As there is an increase in health awareness, the application of NSSE has become more common to aid sports performance and promote physical rehabilitation [6] while playing a crucial role in enhancing sports performance and supporting exercise schedules [7]. Based on their composition, NSSE can be divided into the carbohydrate category: meeting the deficit in daily carbohydrate intake in high-weight athletes and supporting the immune system by providing a fuel substrate [8–10]. Protein: to assist in the daily dietary protein intake of people with lactose intolerance [11–13]. Fats: A high-fat diet maintains circulating testosterone concentrations, which are important for athletes to maintain their energy balance and replenish intramuscular triacylglycerol stores [14–17]. Vitamins: Vitamins are essential organic compounds used to regulate metabolic processes, energy synthesis, and neurological processes and to prevent cellular damage; they are classified as fat-soluble (vitamins A, D, E, and K) and water-soluble (vitamins B and C) [18–20]. Minerals: Minerals, mainly calcium, sodium chloride, and sodium phosphate, are inorganic elements essential to the body's metabolic processes, important components of enzymes and hormones, and regulators of metabolism and neural control, mainly including calcium, sodium chloride, and sodium phosphate [21–23]. Meanwhile, NSSE can also be classified according to their effects: supplements that directly improve sports performance, including caffeine [24, 25], creatine [26, 27], nitrates [28, 29], sodium bicarbonate [30, 31], and  $\beta$ -alanine [32, 33]; and supplements that indirectly improve sports performance, including zinc [34], iron [35], and probiotics [36], quercetin [37], echinacea [38] and omega-3 unsaturated fatty acids [39]. For athletes and workout enthusiasts, selecting the appropriate NSSE can improve their sports performance, promote recovery, and even delay fatigue [40]. The use of NSSE by athletes, fitness enthusiasts, and individuals engaged in sports activities has increased significantly over the past few decades [41]. As the market for NSSE continues to expand and the variety of products continues to grow [42], there is an increased interest in selecting

the proper product and its mechanism of action in sports [43]. It is essential to understand global research hotspots and trends in the field of NSSE for future research guidance and industry regulation.

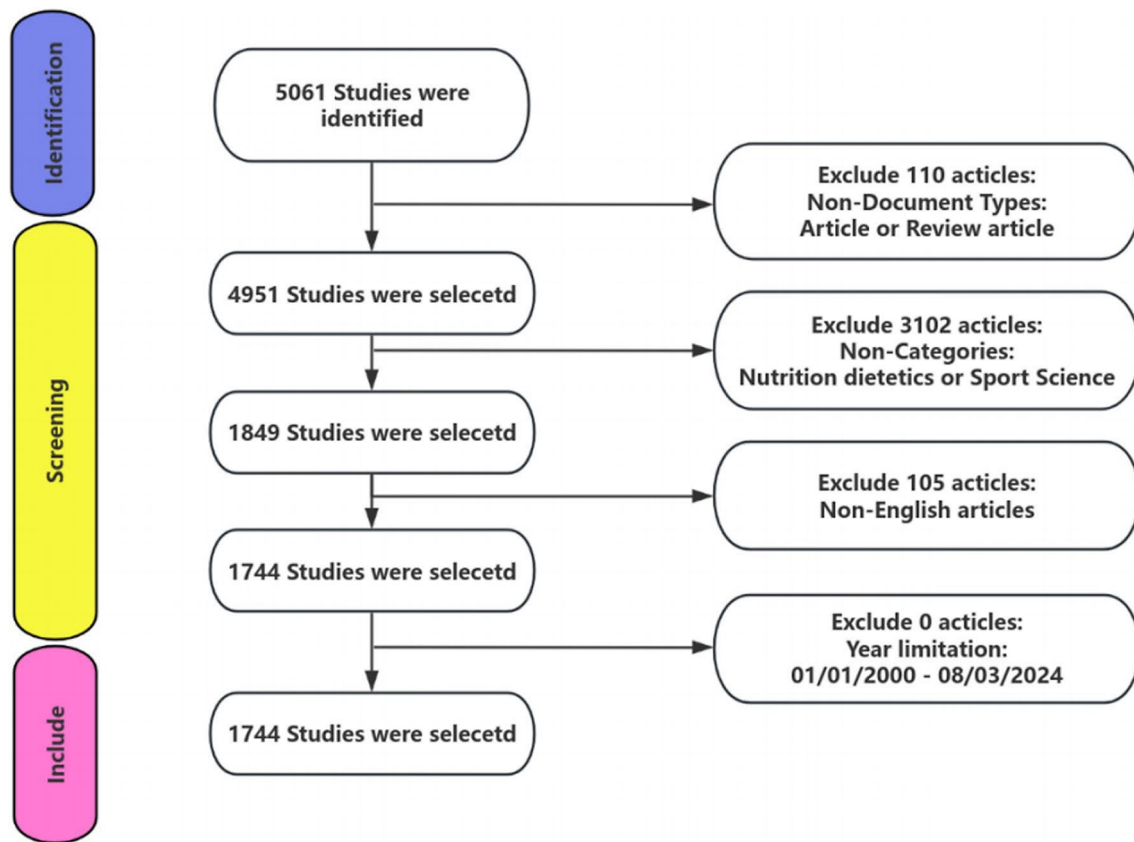
Bibliometrics is the interdisciplinary science of quantitative analysis of all knowledge carriers through mathematical and statistical methods [44], which analyses patterns in the scientific literature to understand the emerging trends and knowledge structures in the field of study [45, 46], and it is a common method for identifying developments in a particular field [47]. We searched for relevant studies on NSSE from 2000 to 2024. By analyzing the geographical distribution of article outputs, trends in key research themes, citation networks, and patterns of collaboration between researchers and institutions, we aimed to systematically analyze hotspots and trends in sports nutritional supplement research and thus reveal the global development dynamics of this field of research, identify future research directions, and promote collaboration between researchers and institutions to further advance NSSE research progress.

## Data collection and research methods

### Data Collection

The Wos database is mostly considered as one of the standardized, consistent, and comprehensive, available sources of scientific literature with the highest quality indexing [48]. Notably, over the last few decades, Wos has been extensively used in various scientometric studies in medicine and other fields [49]. Although PubMed plays a significant role in the field of biomedicine and life sciences, it has limitations in terms of scope and speed [50]. Therefore, this paper does not consider any other literature databases except Web of Science Core Collection (WOSCC).

Relevant literature data used in this paper are obtained from the WOSCC database under the theme (TS)=(“Dietary Supplements” OR “Nutraceuticals” OR “Health Supplements” OR “Dietary Additives” OR “Nutrient Supplements” OR “Food Supplements” OR “Dietary Enhancements” OR “Nutrient Additives” OR “Nutritional Enhancements”) AND (TS)=(“Physical activity” OR “Athletics” OR “Fitness training” OR “Sports and physical activity” OR “Exercise and sports” OR “Athletic pursuits” OR “Training and athletics” OR “Exercise and fitness” OR “Sports and training”) is the search formula; a total of 5061 documents were retrieved with the manual selection criteria: document types=article or review article; WOSCC category: “Nutrition dietetics” or “Sport Science”; language=English; timeline=01/01/2000–08/03/2024 and 1744 studies were finally included (Fig. 1). The retrieved literature is exported in plain text format with full records and cited references, named “download-01,” and saved to the “input” folder, then



**Fig. 1** Flow diagram of the publications screening process

imported into the three analyzing software copied and pasted the transformed data files in the “output” folder into the “data” folder for data analysis.

### Research methods

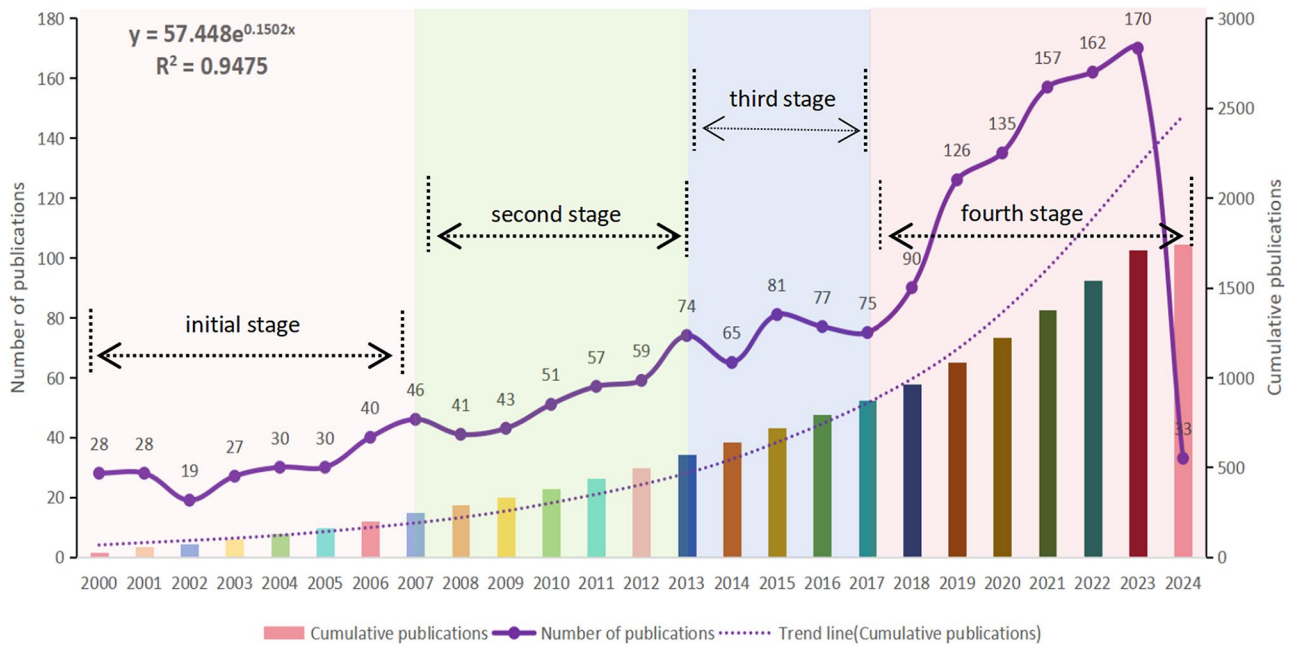
The CiteSpace 6.2. The R4 (64-bit) (CiteSpace: visualizing patterns and trends in the scientific literature (drexel.edu)) software tool [51] enables the evolution of a field of knowledge to be presented on a citation network map [52], and citation nodes and other data to be automatically identified, making it easier for analysts to conduct quantitative and qualitative research on scientific subject areas [53]. This paper employs its distinctive functionalities of keyword clustering graph analysis and prominence map analysis to visually present the research dynamics among nations and the clustered distribution of keywords.

VOSviewer1.6.19 (VOSviewer-Visualizing scientific landscapes) software can be used to construct and view bibliometric maps [51]. This software enables scientific knowledge mapping mainly through the construction of relationships and visual analysis of literature knowledge units and shows the structure, evolution, and cooperation of knowledge domains [54]. This paper utilizes its multi-faceted color-coded clustering visualization capabilities

to conduct an in-depth analysis of countries, institutions, authors, and journals, thereby uncovering the intrinsic relationships and structural characteristics within various domains.

The Bibliometrix R package (<http://www.bibliometrix.org>) is an open-source tool for comprehensive scientific mapping analyses of scientific literature [55]. It has powerful bibliometric algorithms and data analysis capabilities in addition to the visualization capabilities of tools such as CiteSpace and VOSviewer [56]. This paper harnesses its capabilities for data processing within the R environment to produce a world map-style analysis of national collaboration networks and thematic evolution trends. Through diverse dimensional presentations, it further uncovers the profound patterns of change within this field over time.

In summary, each of the three software packages possesses unique strengths in the context of writing articles in bibliometrics. To ensure that the images can more clearly and accurately depict the original data, the selection of research methods in this paper is based on the characteristics of the software and the presentation features of the data results.



**Fig. 2** Yearly publications on NSSE from 2000 to 2024

**Results**

**Analysis of publication**

Literature publication volume reflects the activity and importance of research in a certain field [57]; a higher volume of publications represents high attention and research enthusiasm in this field [58]. In the WOSCC, by analyzing a total of 1744 studies published by researchers in this field from 2000 to 2024, it can be seen that there are four stages in Fig. 2: steady growth during the first stage (2000–2007); six-year exponential growth during the second stage (2007–2013); four years of fluctuation in the third stage (2013–2017); and a surge in the number of articles in the fourth stage (2017–2024) when it reached 170 articles. The Price curve reveals the law of growth of scientific literature. This curve is derived from a smoothing method in which the number of publications is depicted point-by-point in a coordinate system for each of the different eras, using the number of publications as the vertical axis and year as the horizontal axis, which demonstrates the trend of the total number of studies over time [59]. The  $R^2$  value indicates the degree of fit of the model, and  $y$  value provides the annual growth rate [60];  $y=47.448e^{0.1502x}$  and  $R^2=0.9475$  indicate that the annual growth rate of research in this field is 16.26% and that the model can explain the variations in the data effectively.

**Analysis of countries**

The number of national publications reflects the degree of research activity and contributions of different countries in a certain field. By comparing the number of

**Table 1** Top 10 productive countries based on publications

Rank	Country	Publications
1	United States	575
2	England	194
3	Australia	190
4	Canada	156
5	Spain	153
6	Brazil	124
7	Italy	97
8	Germany	74
9	Peoples R China	70
10	Netherlands	60

studies published in different countries, the research level and importance of each country in this field can be determined [61]. Table 1 shows that the United States was the most active in the field of sports nutrition supplement research, and its study output was at the top of the list, with 575 studies, accounting for 32.9% of the total. The England ranked second with 194 studies, Australia had the third highest number of publications with 190 studies, followed by Canada and Spain with 156 and 153 studies, respectively. These five countries published more than 150 articles. The country-region distribution map can also show academic research cooperation between various country-regions [62], as shown in Fig. 3, where the United States is closely connected with the England, Australia, Canada, China, France, and Spain. The strength and density of connections among European, North American, and Australian countries were particularly prominent. Brazil contributed the most to South American countries, whereas China contributed

Country Collaboration Map

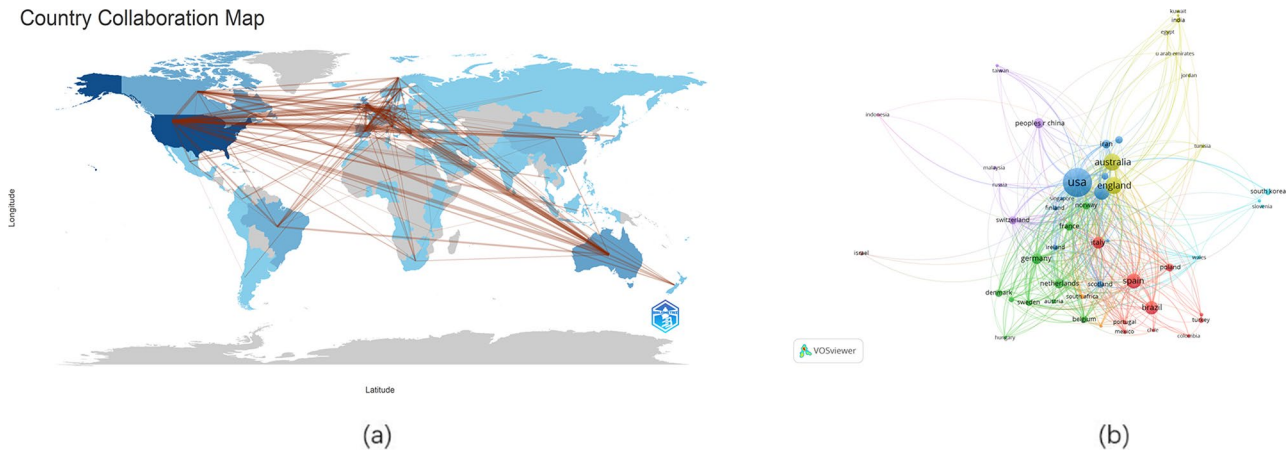


Fig. 3 The collaboration network of countries. (a) was produced by Bibliometrix R package, and (b) was produced by VOSviewer

### Top 25 Countries with the Strongest Citation Bursts

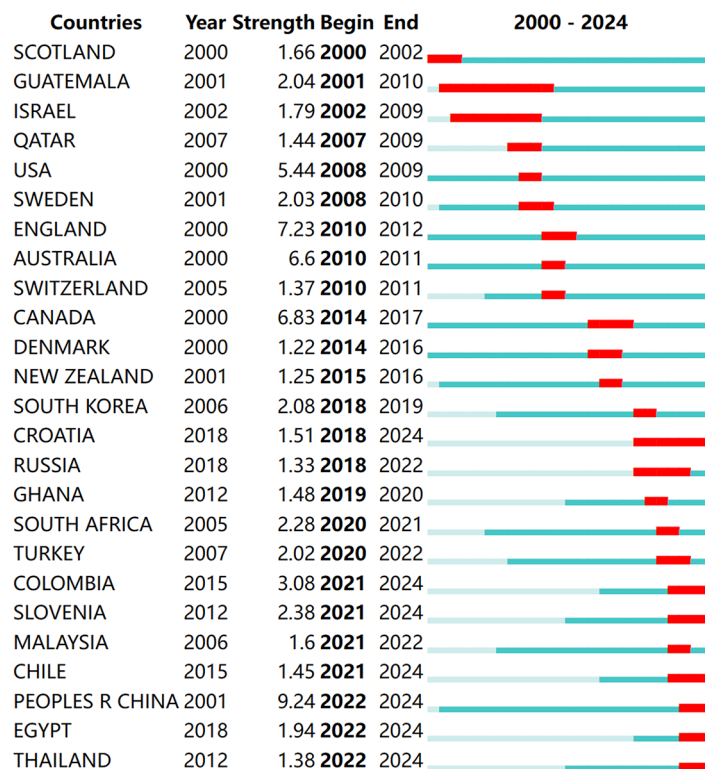


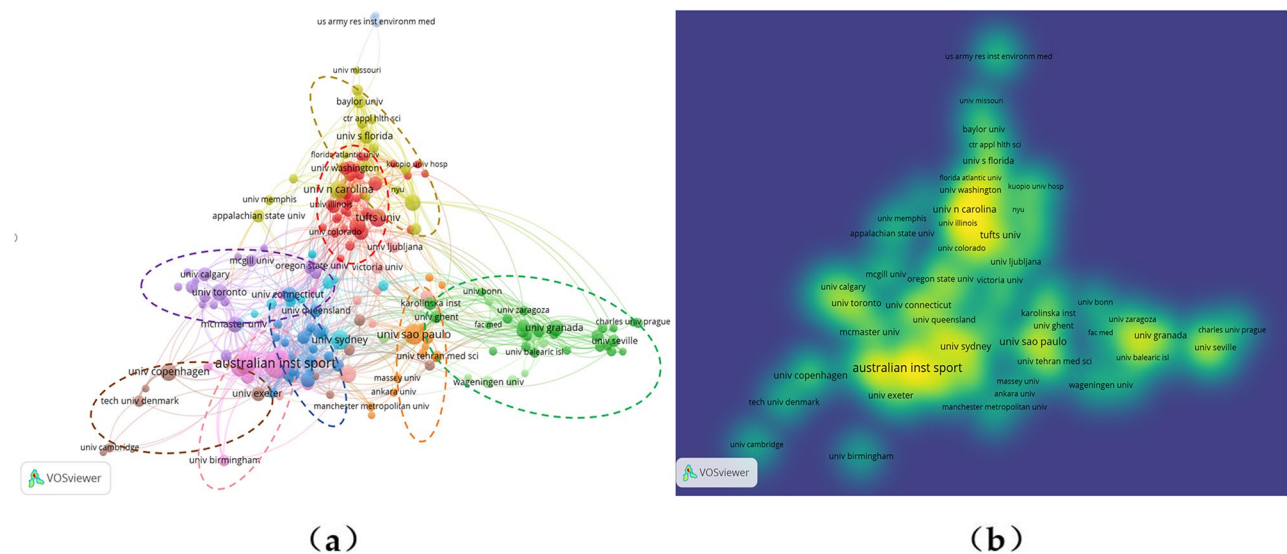
Fig. 4 The top 25 countries with the strongest citation bursts produced by CiteSpace

significantly to Asian countries. The top 25 countries with the strongest citation frequencies (Fig. 4) can be seen as citations in terms of years, which are highlighted in countries worldwide. Each blue or red short line represents a year, and the red line represents a burst detected year [63]; Scotland, the United States, England, Australia, Denmark, Canada, and China had the longest history of research in this area. Strength represents the strength of the burst; the larger the value of the burst, the higher

the credibility of the burst in a certain period. The red bar indicates that the keyword was cited more frequently, whereas the green bar indicates that the keyword was cited less frequently [64]. During this period, the England ranked second with a burst value of 7.23, whereas China ranked first with a burst value of 9.24. In recent years, the main research countries have been Croatia, Colombia, Slovenia, Chile, Egypt, China, and Thailand, showing that European countries are still interested in this

**Table 2** Top 10 institutions of publications

Rank	Frequency	Centrality	Institution	Country
1	58	0.26	Australian Institute of Sport	Australia
2	30	0.05	University of Oxford	United States
3	28	0.05	State University System of Florida	United States
4	27	0.22	Harvard University	United States
5	26	0.15	University of North Carolina	United States
6	25	0.16	University of California System	United States
7	17	0.04	University of Sydney	Australia
8	17	0.10	Texas A&M University System	United States
9	16	0.02	Universidade de Sao Paulo	Brazil
10	15	0.02	Australian Catholic University	Australia

**Fig. 5** The collaboration network of institutions. (a) and (b) were produced by VOSviewer

field, followed by South American and Southeast Asian countries.

#### Analysis of institutions

Institutional analysis not only assesses and compares the research output and impact of different research institutions but also understands the development trend and forefront of the research field [65]. Table 2 shows that 6 of the top 10 institutions in terms of publications are from the United States and three are from Australia, of which the Australian Institute of Sport is ranked first, with 58 publications and a centrality of 0.26. In VOSviewer, keywords of the same color indicate that they belong to the same research topic or cluster, as identified by co-occurrence network analysis [66]. Figure 5 illustrates the collaboration network of institutions in the NSSE field. It can be seen that institution collaborations can be divided into the following eight clusters: (1) The brown cluster is dominated by the University of Copenhagen from Denmark and the University of Exeter from England. (2) The purple cluster is dominated by the University of Toronto

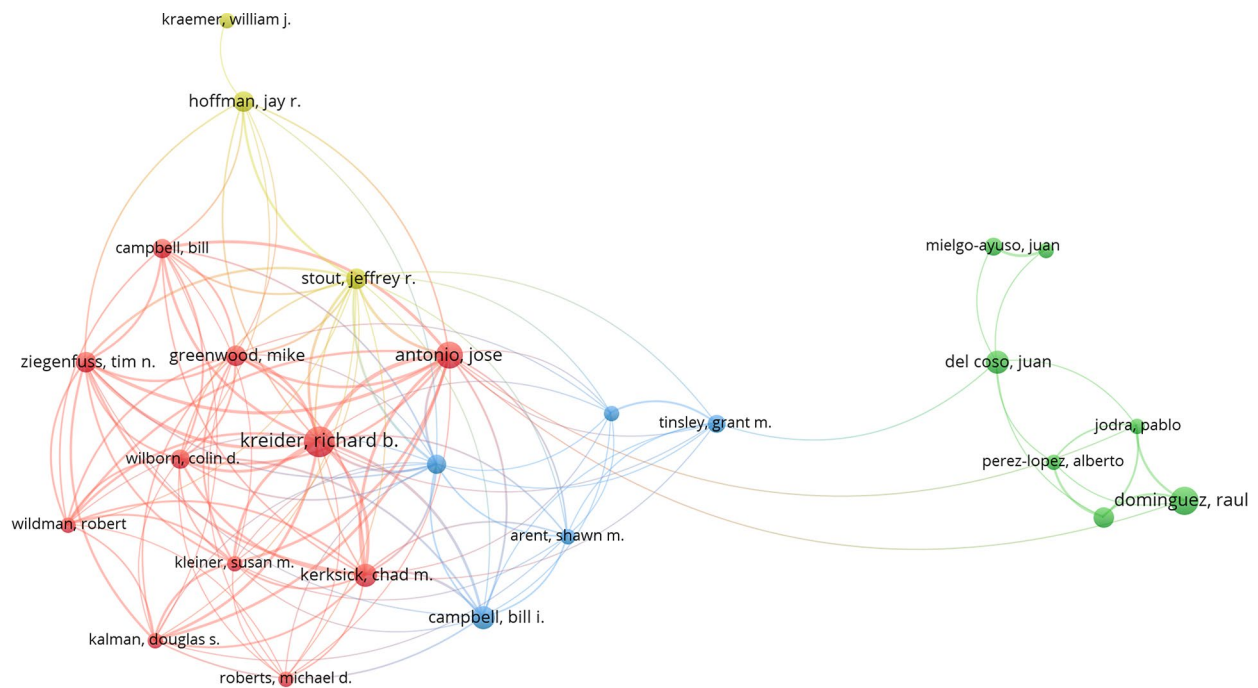
from Canada and University of Calgary. (3) The pink cluster was dominated by the Australian Institute of Sports, Australia, and University of Birmingham, England. (4) The blue cluster is dominated by the University of Sydney and University of Queensland, Australia. (5) The red cluster was dominated by the University of Colorado and Tufts University in the United States. (6) The yellow cluster is dominated by the University of North Carolina and State University System of Florida in the United States. (7) The orange cluster is dominated by the Universidade de Sao Paulo in Brazil and Tehran University of Medical Sciences in Iran. (8) The green cluster is dominated by Universidad de Granada in Spain and Wageningen University in the Netherlands. These institutions collectively contributed to the rapid development of this field.

#### Analysis of authors

The analysis of the authors facilitated the identification of leading experts and major contributors to the field and allowed for a deeper understanding of the social structure and dynamic development of research in the field

**Table 3** Top 10 authors of publications

Rank	Citations	Author	Country	Institution
1	53	Burke, LM	Australia	Australian Catholic University
2	31	Castell, LM	England	University of Oxford
3	29	Stear, SJ	England	Performance Influencers Ltd
4	19	Kreider; RB	United States	Texas A&M International University
5	15	Dominguez, R	Spain	University of Alcalá
6	14	Antonio, J	United States	Nova Southeastern University
7	14	Lieberman; HR	United States	US Army Res Inst Environment Med
8	12	Peeling, P	Australia	Western Australian Inst Sport
9	11	Kerksick, CM	United States	Lindenwood University
10	11	Maughan, RJ	Scotland	University of St Andrews

**Fig. 6** The collaboration network of authors. Produced by VOSviewer

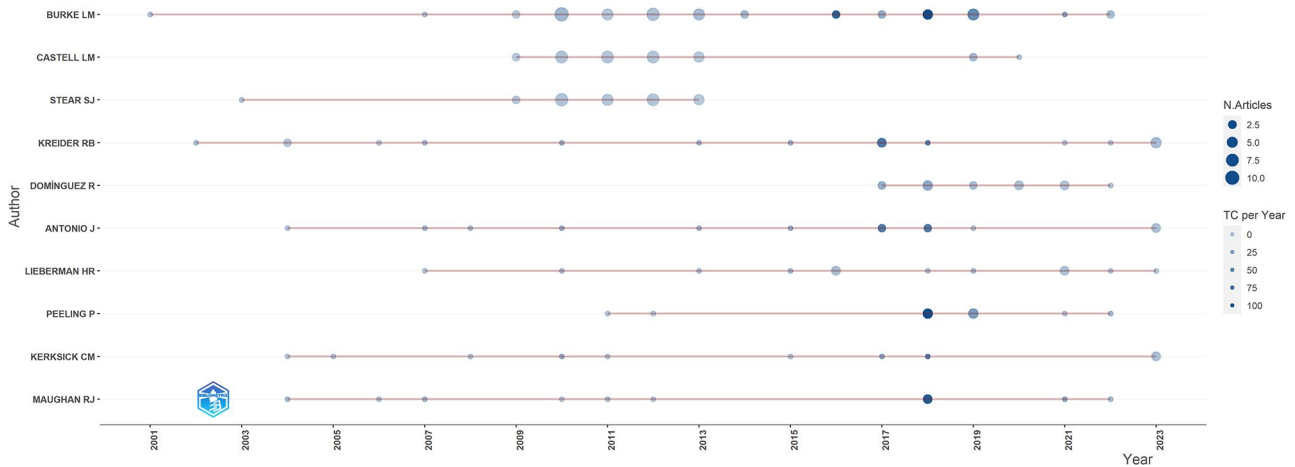
[67]. Table 3 illustrates that among the top 10 authors in terms of global publications, there are four authors from the United States. Among them, Burke, LM from Australia had the most publications, and he made an important contribution to the field of sports nutritional supplementation.

Figure 6 illustrates the collaborative network of authors in the NSSE field. The author's collaborations can be divided into the following four clusters. The red cluster is the Kreider, RB. team from the United States, whose research fields are sports sciences and nutrition and dietetics. Figure 7 reveals that there are four authors with a long research timeline in the field: Burke, LM; Kreider;

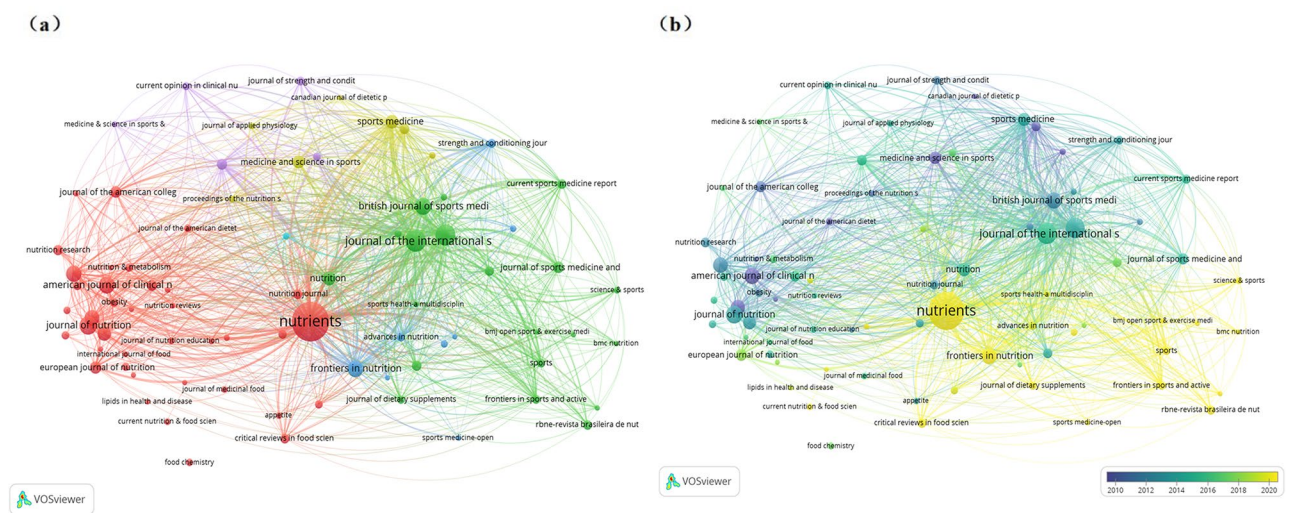
RB; Antonio, J; and Kerksick, CM. These authors collectively contributed to the rapid growth of this field.

#### Analysis of journals

Journal analysis is a crucial method for identifying and evaluating high-impact scientific research and is also an important tool for guiding research management and decision-making [68]. Figure 8 depicts the top 10 journals in terms of the number of publications, among which *Nutrients* from Switzerland ranked first with 262 publications, which had an IF of 5.9, and a quartile of Q1. Four of the top 10 institutions were from the USA, four journals were from England, and two journals were from Switzerland. In terms of IF, the highest-ranked journal



**Fig. 7** The author’s achievements in the field of NSSE over time. Produced by Bibliometrix R package



**Fig. 8** The collaboration network of journals. (a) and (b) were produced by VOSviewer

was the British Journal of Sports Medicine from England at 18.6.

**Analysis of high cited articles**

The number of citations reflects the influence and importance of a publication in the academic field, and highly cited literature is generally considered research of high academic value [69]. The top 10 cited publications as presented in Fig. 9 were categorized as follows: 7 of the Category Zone were Q1, 8 of the 10 were from the USA, and 2 were from England. The article “Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition,” published in the Journal of The Academy of Nutrition and Dietetics in 2016 by Thomas was cited 760 times and ranked first.

**Analysis of keywords**

**Analysis of keyword timeline**

The analysis keyword timeline provides a good understanding of the core content information of a topic for each period and assists in exploring the development of the research topic over time [70]. The top 25 keywords with the strongest citation bursts in the field of sports nutritional supplements are shown in Fig. 10(a), a timeline view map of high-frequency keyword co-occurrence is shown in Fig. 10(b), and thematic evolution and development trend of the NSSE are shown in Fig. 10(c). A combination of the three can clearly and accurately show the changing trends of focus in the field. The study population transitioned from children in 2000 to adolescents in 2011, with men as the primary sex and women being the main focus of researchers around 2016. Postmenopausal women were the main focus of the female population during this period.



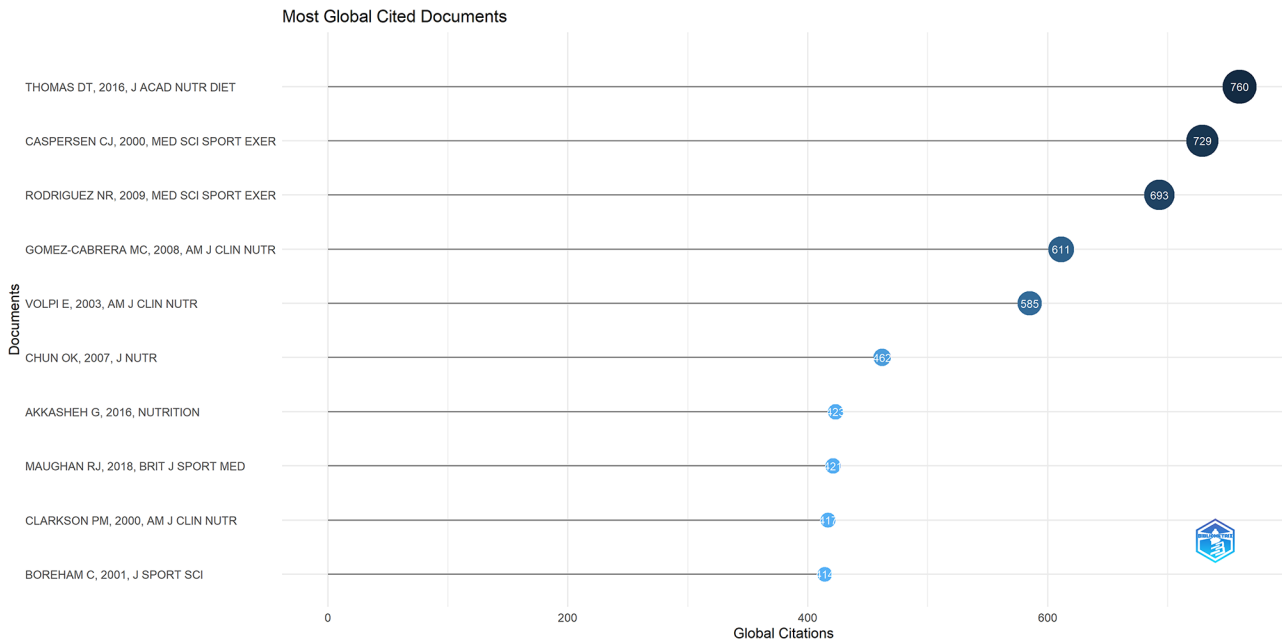


Fig. 9 The collaboration network of high-cited publications. Produced by Bibliometrix R package

### Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2000 - 2024
coronary heart disease	2001	9.05	2001	2013	[Timeline bar]
bone mineral density	2001	6.94	2001	2009	[Timeline bar]
men	2002	7.67	2002	2011	[Timeline bar]
vitamin	2002	6.62	2002	2015	[Timeline bar]
body composition	2000	7.04	2003	2006	[Timeline bar]
united states	2004	11.36	2004	2011	[Timeline bar]
vitamin e	2004	6.07	2004	2014	[Timeline bar]
humans	2007	5.51	2007	2012	[Timeline bar]
cancer	2008	5.56	2008	2014	[Timeline bar]
adolescents	2011	6.16	2011	2016	[Timeline bar]
cardiovascular disease	2001	7.34	2013	2017	[Timeline bar]
vitamin d	2008	6.09	2014	2017	[Timeline bar]
dietary supplement	2015	7.91	2015	2017	[Timeline bar]
dietary intake	2001	6.9	2015	2017	[Timeline bar]
children	2000	5.82	2015	2016	[Timeline bar]
weight loss	2006	6.01	2016	2020	[Timeline bar]
dietary nitrate supplementation	2017	7.53	2017	2019	[Timeline bar]
ergogenic aids	2000	5.66	2018	2020	[Timeline bar]
metaanalysis	2018	5.47	2018	2020	[Timeline bar]
prevalence	2015	7.98	2020	2021	[Timeline bar]
nitric oxide	2017	7.16	2020	2022	[Timeline bar]
insulin resistance	2011	6.59	2021	2024	[Timeline bar]
sports nutrition	2016	6.87	2022	2024	[Timeline bar]
inflammation	2022	6.83	2022	2024	[Timeline bar]
gut microbiota	2022	6.34	2022	2024	[Timeline bar]

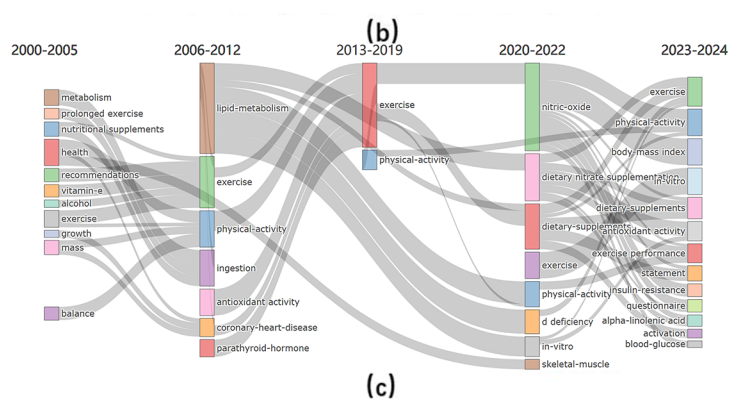
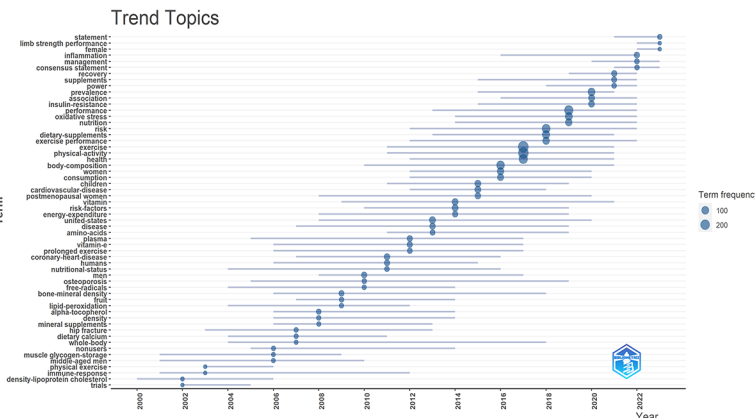


Fig. 10 (a) The top 25 keywords with the strongest citation bursts. (b) The timeline view map of high-frequency keyword co-occurrence. (c) Thematic evolution of the NSSE research (2000–2024). (a) was produced by CiteSpace, and both 10 (b) and (c) were produced by Bibliometrix R package

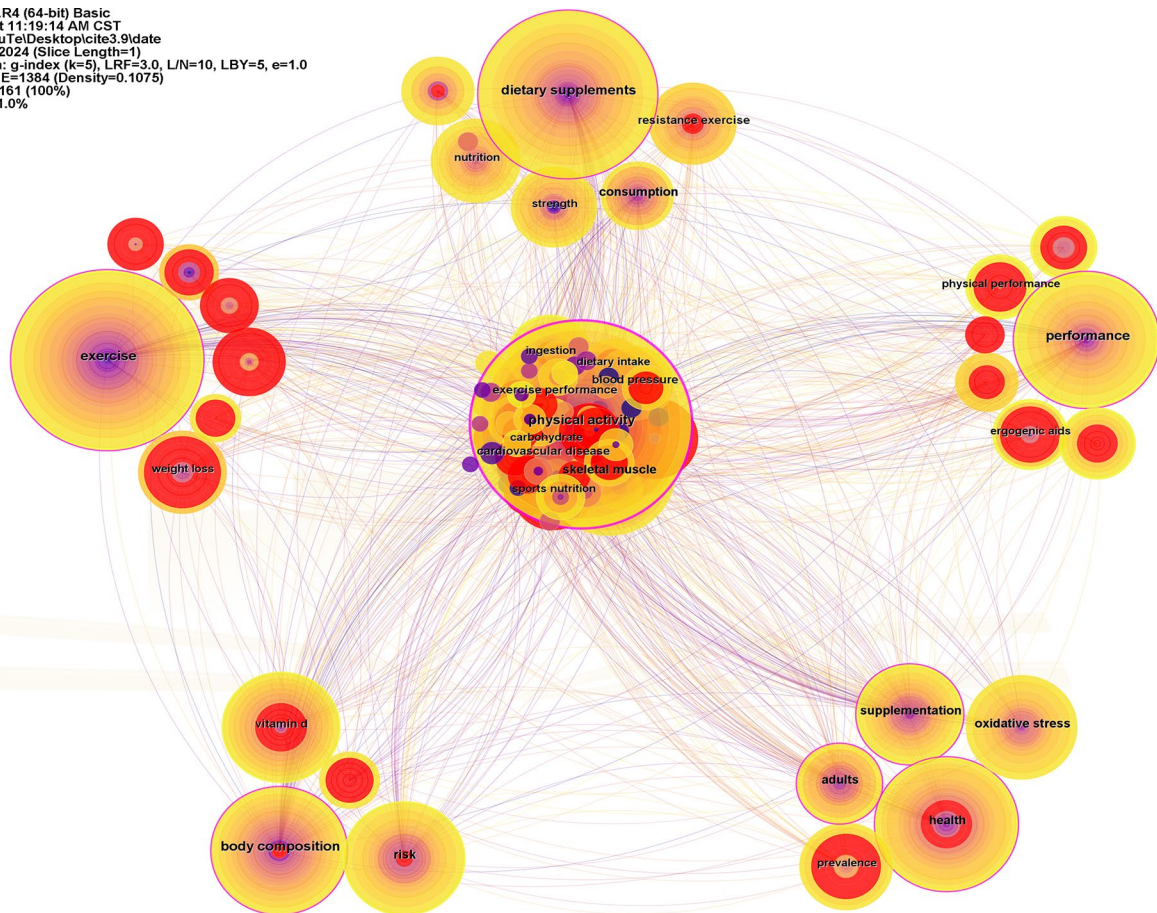
Bone density and osteoporosis were hotspots of research in 2010. Lipid metabolism saw a surge in research in 2006, and nitric oxide witnessed a surge in research in 2020. Research on vitamin D surged in 2002, and vitamins E and D have been the focus of research. Thus, the overall research has become progressively more specific and refined. The research approach of the meta-analysis was gradually published in 2018, which echoes the graph of the number of publications, indicating that at this time, the number of publications in this field of research had accumulated, authors involved in the research had reached a certain level, and period of academic contention and collision began. Among the keywords, the United States was the keyword with the greatest strength, with a value of 11.36, which proved that it was the leading country in this field of research from 2004 to 2011, with absolute influence and value contributions. Coronary heart and cardiovascular diseases continue to dominate the research. Insulin resistance, sports nutrition, inflammation, alpha-linolenic acid, limb strength performance, female sex, and gut microbiota are

the focus of current and future studies. Insulin resistance, sports nutrition, inflammation, alpha-linolenic acid, limb strength performance, female sex, and gut microbiota are the main focus of the current stage of research and future studies.

**Analysis of collaboration, clustering, and high co-occurrence keywords**

High-frequency keywords are often used to identify popular issues in the research field [71]. Figure 11 shows the co-occurrence of high-frequency keywords in the NSSE field, with 161 nodes, 1,384 links, and a network density of 0.1075. Combined with Table 4, it can be seen that: physical activity tops the list with a co-occurrence frequency of 376 and centrality of 0.23. Exercise, dietary supplements, performance, health, body composition, skeletal muscle, risk, oxidative stress, and supplementation were high-frequency co-occurring keywords. Figure 12 depicts the clustering network of words with 161 nodes, 1384 connectors, and a network density of 0.1075. These five clusters are #0 sports nutrition (dietary

CiteSpace, v. 6.2.R4 (64-bit) Basic  
 March 10, 2024 at 11:19:14 AM CST  
 WoS: C:\Users\FuTel\Desktop\cite3.9\data  
 Timespan: 2000-2024 (Slice Length=1)  
 Selection Criteria: g-index (k=5), LRF=3.0, L/N=10, LBY=5, e=1.0  
 Network: N=161, E=1384 (Density=0.1075)  
 Largest 30 CCs: 161 (100%)  
 Nodes Labeled: 1.0%  
 Pruning: None



**Fig. 11** The collaboration network of keywords was produced by CiteSpace

**Table 4** Top 10 in terms of high co-occurrence keywords

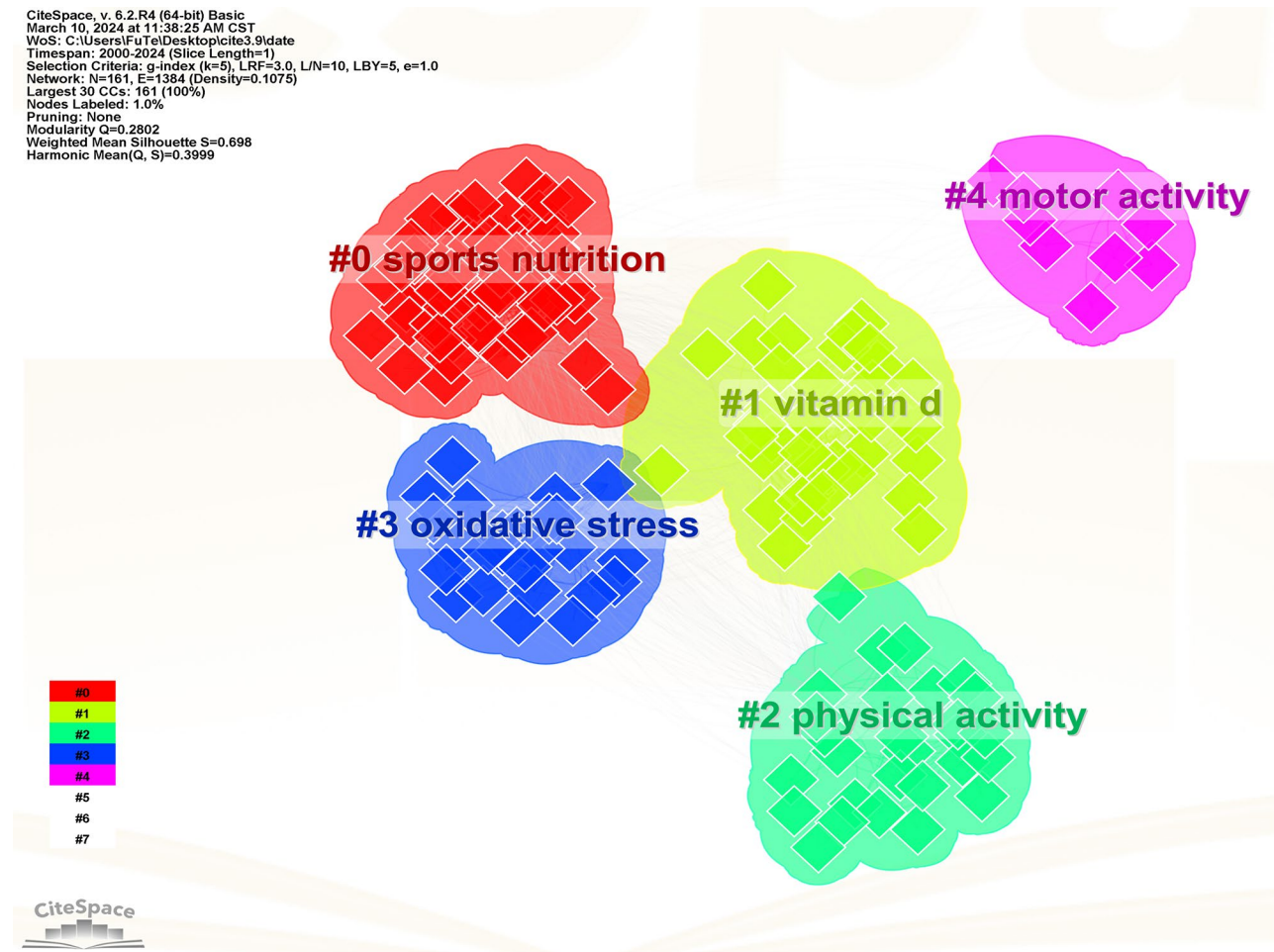
Rank	Frequency	Centrality	Keywords
1	376	0.23	Physical activity
2	296	0.17	Exercise
3	258	0.13	Dietary supplements
4	170	0.16	Performance
5	167	0.12	Health
6	154	0.15	Body composition
7	140	0.09	Skeletal muscle
8	124	0.05	Risk
9	107	0.05	Oxidative stress
10	105	0.11	Supplementation

supplements, exercise performance), #1 vitamin D (cross-sectional study, vitamin supplements), #2 physical activity (body composition, ascorbic acid), #3 oxidative stress (functional food, body mass index), and #4 motor activity (dietary intake and eating behavior).

**Discussion**

In the era of competitive sports, an increasing number of people take NSSE [72], and between 40 and 60% of young Americans take NSSE to improve physical performance [20]. In sports, it is used by athletes at all levels [73], especially elite athletes, where the use of herbal supplements may be high [74, 75]. The high base variety and frequency of use of NSSE is an ongoing challenge for practitioners and athletes who need to maintain the validity of claims and scientific evidence [76]. Compared with professional athletes, the mass population seems to use NSSE mainly for health-related reasons, with little interest in enhancing sports performance [77, 78]. Through bibliometric analyses, this study systematically compiled the changing trends in sports nutrition supplement research hotspots from 2000 to 2024, providing valuable references and insights for researchers and practitioners in related fields.

The overall development of research publications in the field of NSSE is favorable and is currently in the stage of a surge in the amount of literature. From a global perspective, North American countries, European countries, and



**Fig. 12** The clustering network of keywords was produced by CiteSpace

Australia have close cooperation, Brazil contributes significantly to South American countries, and China produces a substantial amount of output in Asian countries. European countries, as the first countries to step into this field, are now at a stage where research attention is not decreasing, followed by South American and Southeast Asian countries as the new research mainstay.

Top research organizations worldwide in the field of sports nutrition supplements have conducted in-depth studies in the following thematic directions: (1) The University of Copenhagen, Denmark, focuses on the fact that supplementation with anthocyanin-rich blueberry concentrate improves brain perfusion and activation in brain regions associated with cognitive function in healthy older adults [79]. (2) The University of Toronto, Canada, has shown that caffeine supplementation has been shown to significantly improve sports performance [80]. (3) The Australian Institute of Sport focused on the use of dual-energy X-ray absorptiometry to test the composition of groups of athletes [81]. (4) The University of Sydney, Australia, focused on the association between nitrate supplementation and a modest, although not statistically significant, improvement in constant load time in a fatigue task [82]. (5) The University of Colorado in the United States concluded that ethyl creatine is not as effective as creatine monohydrate in increasing serum and muscle creatine levels or improving body composition, muscle mass, strength, and power [83]. (6) The University of North Carolina in the United States shows that supplementation with 4–6 g of  $\beta$ -alanine per day improved sports performance [84]. (7) Universidade de Sao Paulo, Brazil, showed that sodium bicarbonate supplementation improves muscular endurance and performance in both single- and multi-round sports in male and female athletes [85]. (8) Universidad de Granada, Spain, the main study reported that a single dose of oral ATP was not bioavailable [86].

The top contributing authors and teams conducted in-depth research on the following topics: (1) The Kreider et al. team in the United States focuses on creatine supplementation to enhance post-exercise recovery, injury prevention, thermoregulation, rehabilitation, and concussion or spinal cord neuroprotection in addition to improving sports and exercise [87]. (2) Hoffman et al. in the United States focussed their research on the fact that short-term supplementation with  $\beta$ -alanine increases training volume and reduces subjective fatigue in college football players [88]. (3) The primary finding of Campbell et al. from the United States is that probiotic supplementation promotes a healthy immune response [89]. (4) Domínguez et al. from Spain primarily found that beetroot juice supplementation has a potentiating effect on cardiorespiratory endurance in athletes [90]. (5) Burke of Australia, focused on the role of carbohydrates as a substrate for

muscles and the central nervous system, which is critical for performance during intermittent high-intensity work and prolonged aerobic exercise, and provided strategies for matching dietary cycles with training in athletes [91]. (6) Kreider et al. from the United States focussed on the fact that a daily protein intake of 1.4–2.0 g/kg in sport populations is not only safe, but also improves training adaptations to sport training, recovery, immune function, and lean body mass gain and maintenance [92]. (7) The main study by Antonio et al. in the United States showed that a high-protein diet (3.4 g/kg/d) combined with a heavy resistance training program improved body composition in trained individuals [93]. (8) Kerksick et al. in the United States focused on the fact that carbohydrate intake contributes to glycogen storage, especially when combined with protein intake [94]. These authors have advanced the field through leaps and bounds.

Currently, the most controversial issue in the field is how NSSE should be characterized, in which the attributes of the product are ambiguous between dietary supplements and pharmaceuticals, whether they should be classified as prescription or over-the-counter, how their dosage should be standardized as a baseline, how they should be balanced with the diet after being added to an athlete's training schedule, and how their efficacy should be related to the indicators in promotional campaigns and their effectiveness in practical use. However, a large part of nutritional supplements can provide athletes with dimensions that cannot be reached in traditional training systems. By analyzing high-frequency keywords, it is clear that the focus of the study group shifted from children in 2000 [95] to adolescents in and after 2011 [96]. In terms of sex, men [97] are the most frequently researched, while women [98] became the focus of research in 2016, especially postmenopausal females [99]. Throughout the evolution of research in this field, the concept of nutritional supplements has been introduced in initial studies, with a focus on metabolism, health, and Vitamin E during the same period, indicating that in this stage, researchers have favored exogenous nutritional supplements that are beneficial for physical health and improve sports performance. Lipid metabolism [100] saw a surge in research in 2006, taking up many positions during the same period, along with antioxidant activity, coronary heart disease, and parathyroid hormones. The keyword fruit was a hot topic in 2009, and in common perception, fruit as a natural food is not included in the category of NSSE; however, it can be an important source of nutrients to supplement the body. Research on bone density [101] and osteoporosis [102] peaked in 2010. During this stage, the field has shifted from the theoretical concept of dietary supplements to nutritional supplements for sports, and the overall research has been more focused on the integration of sports and human sciences, which also indicates

that the field is gradually moving towards concreteness and refinement. In 2018, meta-analysis research methods began to appear frequently in the literature, consistent with an increasing trend in the number of publications. This means that the research results in this field have accumulated to a considerable level; the number of participating countries, institutions, and personnel has significantly increased; and the academic research debate has entered an active period. Nitric oxide [103] was in the spotlight in 2020, evolved from the keyword “Exercise” in 2013, along with nitrate and skeletal muscle from lipid metabolism research. Many consensus statements were published in 2022, which showed that experts in the field had agreed on common and specific issues based on current scientific research. This is not only a significant milestone in the field of sports nutrition supplements but also a milestone in the field of sports nutrition supplements. Insulin resistance, sports nutrition, inflammation, alpha-linolenic acid, limb strength performance, female sex, and gut microbiota are current research focuses and future research trends. Future research should continue to focus on its effects on sports performance and physical function to improve the scientific training system for athletes and the popular health maintenance system for the general population and to improve training and quality of life.

In summary, NSSE plays a vital role in athletes’ sports nutrition programs and, if used properly, some supplements can assist athletes in achieving their sports nutrition goals. However, considerable effort and expertise are required to determine which products are appropriate, how to integrate them into an athlete’s sports nutrition program, and how to ensure that any benefits outweigh the possible negative effects. Therefore, when deciding whether to use sports nutritional supplements, athletes and teams should weigh the efficacy against possible risks and controversies. In future research and practice, more scientific evidence and regulatory measures are required to address the current controversies and issues and promote the rational use and development of sports nutrition supplements.

### Limitations

Bibliometric analysis in the field of sports nutritional supplements was conducted with the support of three software packages, CiteSpace, VOSviewer, and Bibliometrix’s R, using visual mapping to reveal the development trends and patterns in the field with more intuitive images and to derive a series of new findings and interpretations. This study searched the literature covering only Web of Science core ensemble database articles, which excluded other sources of literature, such as books and reports, and chose a small coverage of data sources. This study mainly analyzes the number of publications, journals,

authors, institutions, countries, and regions, as well as keywords, aiming to provide a macro-analysis of the field; therefore, some important details are not reflected in the study. In this study, the search period was limited from 01 January 2000 to 08 March 2024, language was limited to English, article type was Article and Review, WOS category was Nutrition Dietetics or Sport Science, and articles published beyond this were not included in the analysis list.

### Conclusions

This study presents the first extensive overview of sports nutritional supplement research through bibliometric and visual analyses and provides useful insights and analyses on future research directions. Research in the field of the NSSE can be divided into four stages: steady growth (2000–2007), exponential growth (2007–2013), fluctuation (2013–2017) and surge (2017–2024). The United States is the most active country in the field of nutritional supplements. European countries are the early batch of countries in this field, whose attention to research is not decreasing at the current stage, followed by South American and Southeast Asian countries as the emerging research mainstay countries. In recent years, Croatia, Colombia, Slovenia, Chile, Egypt, China, and Thailand have become the dominant countries in this field. The Australian Catholic University is the top research organization in the field. Burke LM from Australia had the most publications. Research in this area has been published in *Nutrients* in Switzerland. The study population mainly comprised men, and postmenopausal women were the main focus of the female group. Coronary heart and cardiovascular diseases continue to dominate research in this field. A milestone was achieved when the consensus statement was published in large numbers in 2022, signaling the agreement of experts in the field on common issues as well as some specific issues. Insulin resistance, sports nutrition, inflammation, alpha-linolenic acid, limb strength performance, female sex, and gut microbiota are the focus of the current stage of research and future studies.

### Author contributions

H.L. was responsible for the concept, design, and supervision. C.S., H.Z. and Y.X. collected the data from the database. T.F. and F.L. analyzed the data. T.F. wrote the original draft. H.L. revised the manuscript critically. All authors reviewed the manuscript.

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### Data availability

No datasets were generated or analysed during the current study.

## Declarations

### Institutional review board statement

Not applicable.

### Informed consent statement

Not applicable.

### Competing interests

The authors declare no competing interests.

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