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Original Article

Exploring the therapeutic potential of functional foods for diabetes: A bibliometric analysis and scientific mapping

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Abstract

The incidence of diabetes is increasingly becoming a global health burden. Meanwhile, in recent years, functional foods have been intensively investigated for diabetes management. These foods provide health benefits due to their bioactive compounds that enhance the metabolism and lower the risk of chronic diseases, such as diabetes. The aim of this study was to explore the keywords, countries/territories, publication numbers, institutions, authors, and journals associated with functional foods for the management of diabetes using a comprehensive bibliometric analysis method. Scopus database was used to compile the information, followed by VOSviewer for comprehensive bibliometric data analysis. A total of 1,226 Scopus articles that met the inclusion criteria were analyzed. The results showed that the greatest expansion in research occurred in 2012, and China was identified as the most productive nation in this field. In addition, Food and Function was found as the most recognized journal in this area, and Singh, R.B. as well as Zengin, G. made the greatest contribution. The bibliometric data also illustrated several mechanisms of functional foods for diabetes management, including antioxidant activity, effect on the gastrointestinal microbiomes, and inhibitor α-amylase. These results underscore the immense potential of functional foods in the diabetes management and provide guidance for future research on this subject.

Keywords: Bibliometric analysis, diabetes mellitus, functional foods, treatment, scientific mapping

Introduction

Diabetes is a chronic metabolic disorder characterized by hyperglycemia due to defects in insulin secretion, action, or both [1]. According to the World Health Organization, approximately 422 million adults worldwide are living with diabetes [2]. The management of diabetes involves lifestyle modifications, including dietary changes, physical activity, and medications [3]. One major dietary method that has gained significant attention in recent years is the use of functional foods that have been scientifically showed to possess health benefits beyond basic nutrition [4,5]. These foods contain bioactive compounds that could improve metabolic health and reduce the risk of chronic diseases such as diabetes [6]. The use of functional foods in the management of

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diabetes is gaining popularity due to their potential to improve glycemic control, reduce the risk of complications, and improve overall health outcomes [3].

Despite the various potential benefits, there are still gaps in the evidence regarding their effectiveness and safety [7]. Further research is needed to determine the optimal types and amounts for diabetes management. Additionally, there is a need to consider individual factors such as age, gender, and comorbidities [8]. Functional foods have potential to be a valuable addition to the management of diabetes, but further investigation is needed to fully understand their role. Further in-depth analysis is needed to discover the development of research related to the application of functional foods for diabetes. Bibliometric analysis is considered capable of providing an overview and mapping associated with the future sustainability of this topic [10,11].

Bibliometric analysis often employs statistical and mathematical methods to quantitatively and qualitatively analyze all knowledge sources, such as journal articles. It is a crucial and well-established methods for identifying active research and potential collaborators, sorting popular topics, describing dynamic trends, and determining future boundaries [9]. This method can also be used to assess the impact and productivity of research in the field of functional foods for diabetes. It may help in identifying the most influential authors, institutions, countries, and journals, as well as the most cited papers and research themes. This information is crucial for determining the current state of research, identifying gaps and opportunities, as well as inform future directions. Furthermore, bibliometric analysis is used to track trends over time, which may help researchers stay up-to-date with the latest developments in the field.

The aim of this study was to provide context and literature regarding the various investigations on functional foods for diabetes. The aspects covered included keywords or co-occurrence, countries/territories, publication numbers, institutions, authors, and journals. A bibliometric and visual analysis was conducted to develop a comprehensive knowledge map of functional foods for diabetes. In addition, the findings were utilized in identifying potential fields for further investigations.

Methods

Data resource strategy

The bibliometric data were collected from the Scopus database as of March, 25, 2023. Scopus is one of the largest databases of curated abstracts and citations [10], leading to its used as a bibliometric data source [12]. The topic-specific inquiry used the title, abstract, or keywords: "functional food" AND "diabetes mellitus". A total of 1226 papers from 1998 to 2022 were acquired and incorporated into the final data analysis. Since the present study involved neither human participants nor animal models, ethical approval was not needed.

Data analysis

The total publication records were exported to VOSviewer version 1.6.18 for additional bibliometric analysis and visualization. In this study, the VOSviewer was used to visually analyze co-occurrence patterns, with circles representing the breakdown of countries and author keywords. The distance between two circles indicated the strength of the relationship between terms, with greater distance suggesting a weaker relationship. Various colors in the visualization represented different term clusters, while the size of the circles correlated positively with the frequency of terms. Additionally, the line thickness corresponded to the strength of the relationship between terms. The higher the diameter of the circle, the greater the frequency of the terms [13]. Data were extracted from the Scopus database using the analyzed results menu to gain insights into research growth patterns, identify the most prolific authors, determine the nation with the most publications and types, as well as examine the most cited journals. Visualization and analysis of research trends from article data were downloaded in CSV format using VOSviewer, which was used to create a keyword map based on a shared network. The flow of the data search strategy as well as its analysis are presented in **Figure 1**.

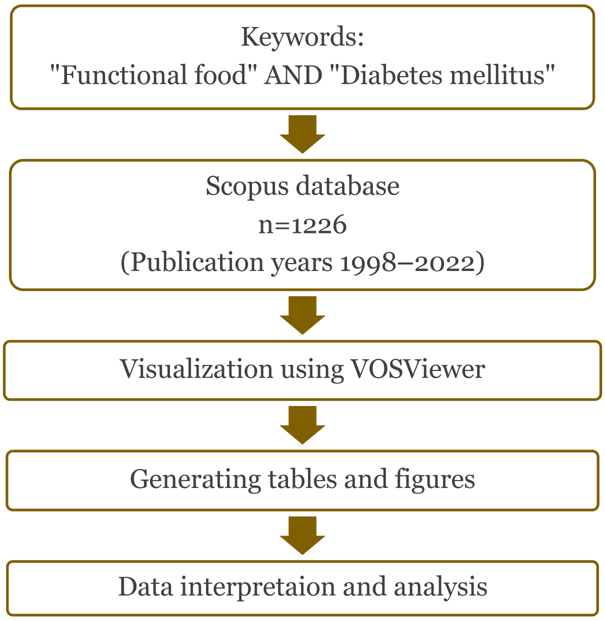

Figure 1. Flow diagram of method (search strategy and data processing).

Results

Analysis of global publication trends

The growth in scientific publications in the field of functional foods and diabetes experienced a worldwide increase from 1998 to 2022 as depicted in **Figure 2**. There was an upward trend in the number of publications annually, with the largest increase occurring in 2011–2012 (89.28%), 2014–2015 (65.21%), and 2020–2021 (37.09%). This suggested a growing global interest in functional foods research for health, particularly in relation to diabetes management.

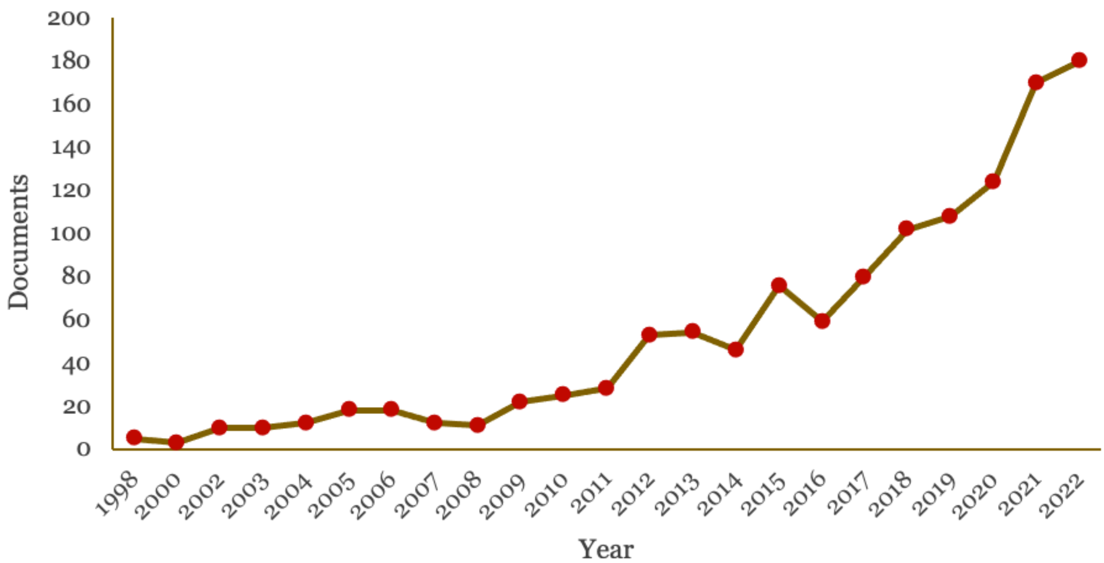

Figure 2. Research trends in the field of functional foods and diabetes based on the number of publications each year.

Analysis of the core journal of functional foods for diabetes

The top ten peer-reviewed journals that published the most articles in the field of functional foods and diabetes over the past 24 years was presented in **Figure 3.** The top three were Food and Function (H index 89 and S.J.R 2021 1.01), Nutrients (H index 143 and S.J.R 2021 1.29), and International Journal of Biological Macromolecules (H index 144 and S.J.R 2021 1.1). This evidence supported the position of these journals as leading scientific publications worldwide.

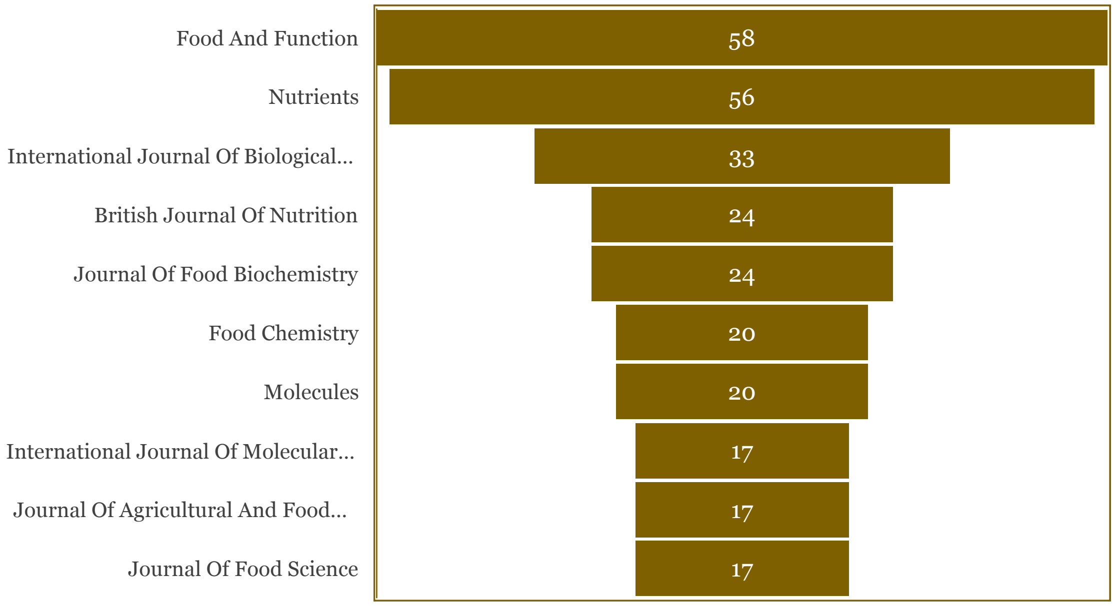

Figure 3. Top ten journals with the most publications in the functional foods and diabetes.

The most productive authors in the publication of functional foods and diabetes

The top ten contributors of articles published in Scopus journals regarding functional foods for the management of diabetes are presented in **Figure 4**. Singh, R.B., and Zengin, G., have published approximately ten works each, making these authors the most prolific on the list. Bahadori, M.B, Liu, B and Oboh, G, authored eight publications each, followed by Chen, H., Dinparast, L., Pella, D., and Zhang, J. with seven papers, while Bahadori, S. had six additional articles. All of the authors have contributed a large number of works to functional foods and diabetes. Moreover, the ten most valuable publications by citation weight are summarized in **Table 1.**

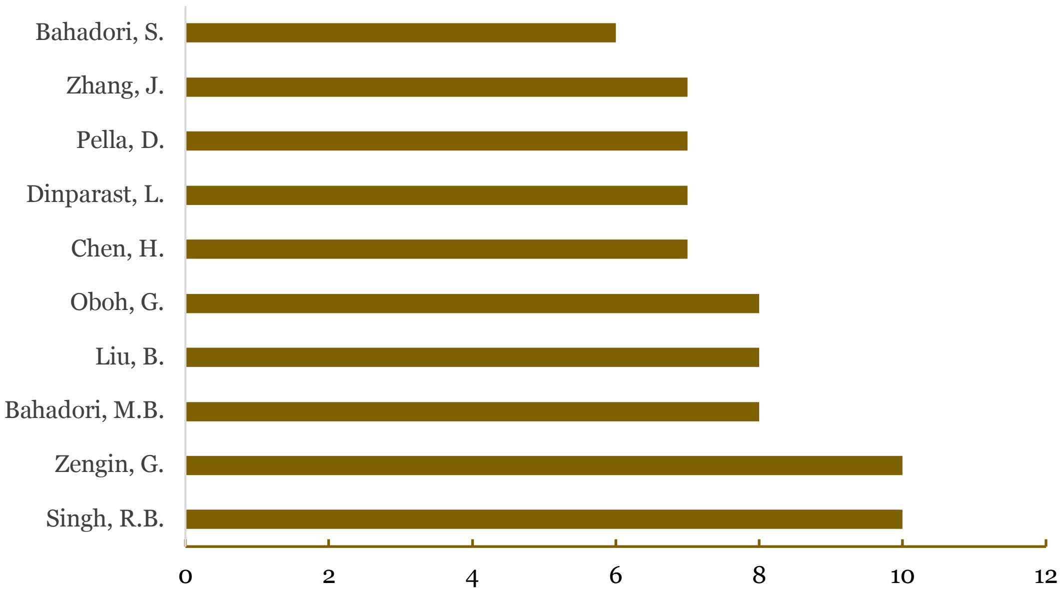

Figure 4. Top ten contributing authors in the area of functional foods and diabetes research worldwide together with the number of their published papers.

Table 1. Top ten most valuable publications by citation weight

Rank	Authors	Title	Year	Journal	Cited by	Reference
1	Piepoli M.F.; Hoes A.W.; Agewall S.; Albus C.; et al	2016 European guidelines on cardiovascular disease prevention in clinical practice	2016	European Heart Journal	4683	[14]
2	Catapano A.L.; Graham I.; De Backer G. et al.	2016 ESC/EAS guidelines for the management of dyslipidaemias	2016	European Heart Journal	2077	[15]
3	Mozaffarian D.	Dietary and policy priorities for cardiovascular disease, diabetes, and obesity	2016	Circulation	1172	[16]
4	Visseren F.L.J.; MacH F.; Smulders Y.M.; Carballo D.; et al.	2021 ESC guidelines on cardiovascular disease prevention in clinical practice	2021	European Heart Journal	1004	[17]
5	FitzGerald R.J.; Murray B.A.; Walsh D.J.	Hypotensive peptides from milk proteins	2004	Journal of Nutrition	601	[18]
6	Tundis R.; Loizzo M.R.; Menichini F.	Natural products as α-amylase and α-glucosidase inhibitors and their hypoglycaemic potential in the treatment of diabetes: An update	2010	Mini-Reviews in Medicinal Chemistry	513	[19]
7	Lordan S.; Ross R.P.; Stanton C.	Marine bioactives as functional foods ingredients: Potential to reduce the incidence of chronic diseases	2011	Marine Drugs	496	[20]
8	Kumar S.; Narwal S.; Kumar V.; Prakash O.	α-glucosidase inhibitors from plants: A natural approach to treat diabetes	2011	Pharmacognosy Reviews	479	[21]
9	Ejtahed H.S.; Mohtadi-Nia J.; Homayouni-Rad A.; Niafar M.; Asghari-Jafarabadi M.; Mofid V	Probiotic yogurt improves antioxidant status in type 2 diabetic patients	2012	Nutrition	452	[22]
10	Wu G.	Functional amino acids in nutrition and health	2013	Amino Acids	439	[23]

Top fifteen countries of authors based on publication number in the field of functional foods and diabetes

The top fifteen countries based on publication number in the field of functional foods and diabetes are presented in **Figure 5**. China published the most articles concerning functional foods and diabetes, with 281 publications (22.92%), followed by the United States with 131 (10.68%), India with 120 (9.78%), and Indonesia in the 12th positions with 38 publications (3.09%).

Type of publication in the field of functional foods and diabetes

Based on the type of publication, majority of publications were journal articles, accounting for 769 documents (62.7%), while 346 (28.2%) were reviews (**Figure 6**). This was followed by conference papers, book chapters, editorials, and brief surveys, at 37 (3.0%), 34 (2.8%), 18 (1.5%), and 8 (0.7%), respectively. Other forms of publication included letters, notes, books, and conference reviews, which accounted for 7 (0.6%), 5 (0.1%), 1 (0.1%), and 1 (0.1%), respectively.

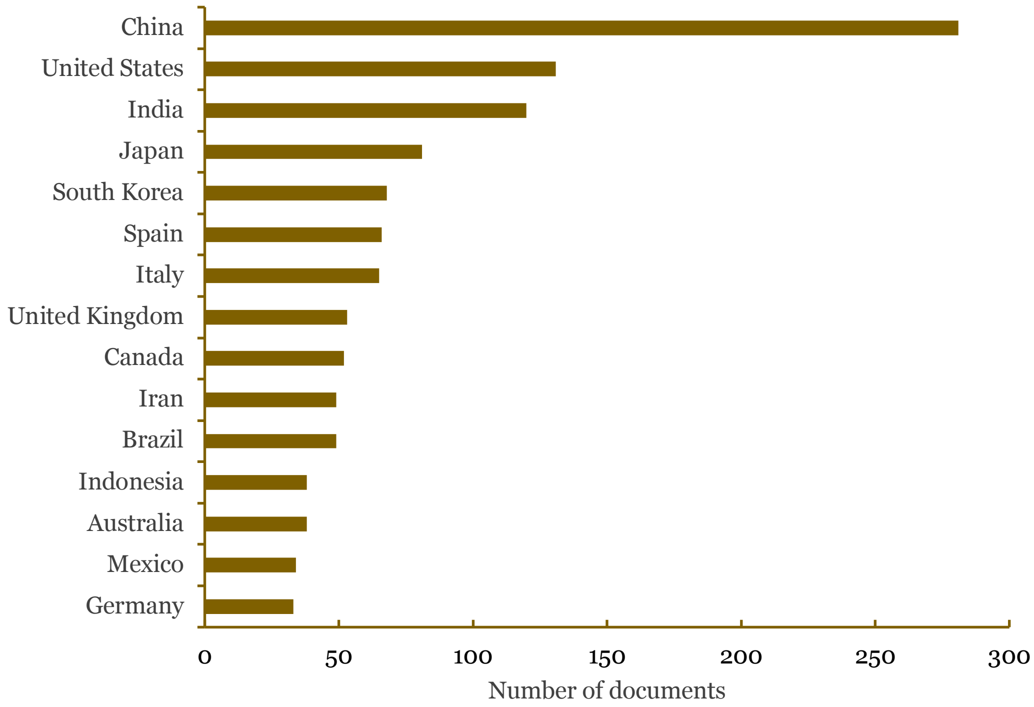

Figure 5. Top fifteen countries in the area of functional foods and diabetes research worldwide.

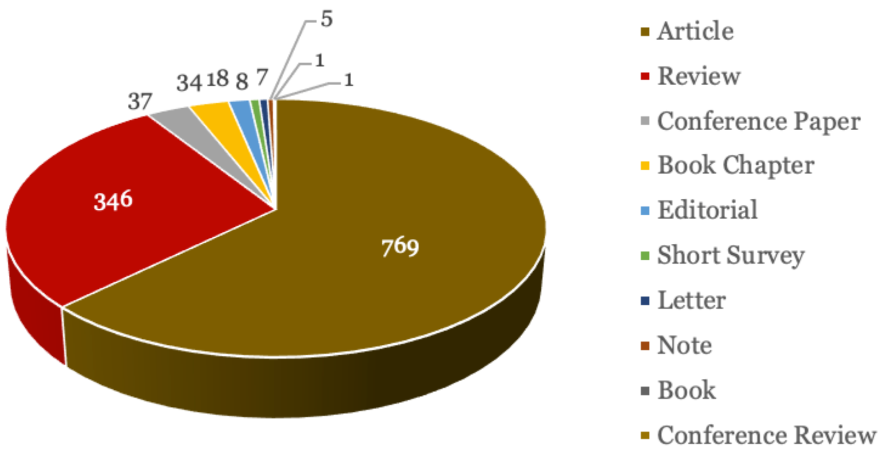

Figure 6. Type of documents that published in functional foods for diabetes.

Network visualization of co-occurrence

The VOSviewer tool was used to visualize the keywords associated with functional foods and diabetes research themes. By default, the visualization represented the keywords as circles (**Figure 7**). The size of each circle corresponded to the frequency of a keyword, and its significance. The keywords "diabetes mellitus" (146 occurrences) and "functional food" (127 occurrences) emerged as the top research topics due to their high frequency. To enhance clarity, colors were assigned to each circle based on their respective clusters [24].

The result was obtained using the frequency of keywords based on bibliographic data with VOSviewer. A keyword minimum occurrence number of five was defined. The search yielded a total of 2908 keywords but only 135 met the inclusion criteria. After analyzing the outcome, six groupings were formed as research trends on functional foods and diabetes, which were denoted by different colors. Based on the results, "functional food and diabetes mellitus" were the most emphasized terms not only in cluster 1 but throughout the entire network.

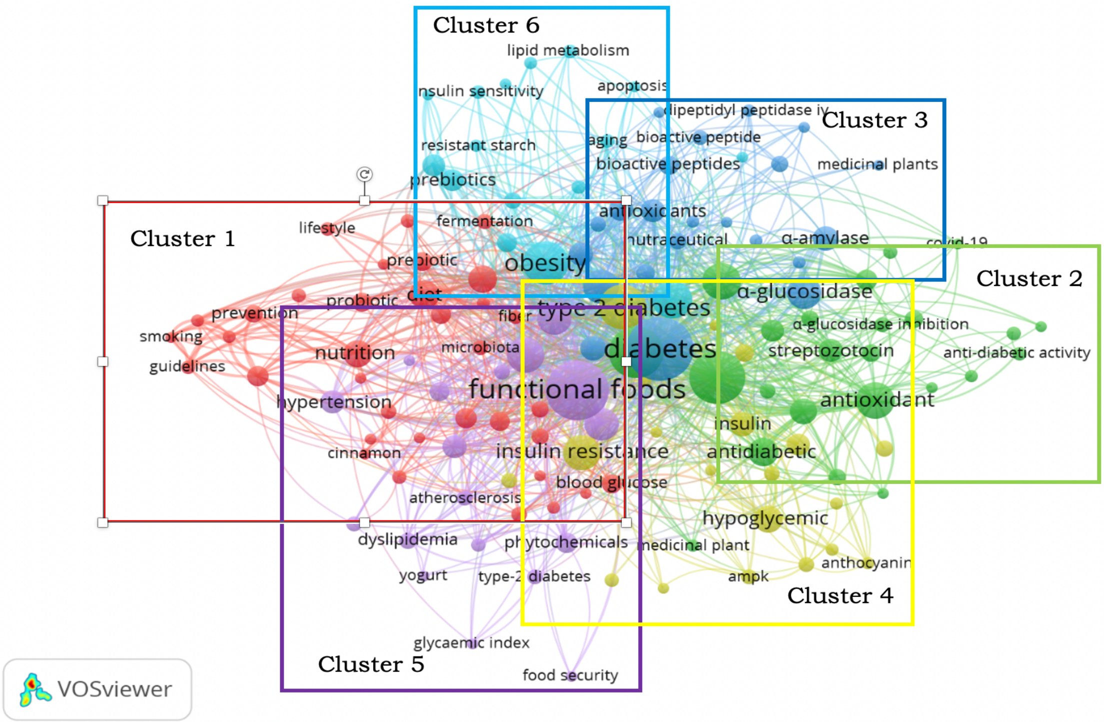

Figure 7. Network visualization of functional foods for diabetes publication co-occurrence map using VOSviewer.

The network visualization describes six clusters and their linkages among examined areas is presented in **Figure 7**. Each cluster consisted of numerous keywords with a high agreement in the map structure. There were specific high-frequency occurrences of keywords signifying the research topic pursued in the past for each cluster. The top three clusters with the highest frequency of occurrence in their respective keywords were identified. The first cluster included the following terms: diet (30), gut microbiota (27), and nutrition (27), while the second consisted of diabetes mellitus (101), functional food (96), and oxidative stress (49) as the most prominent common term. The third cluster comprised diabetes (146), polyphenols (41), and α-glucosidase (38). Detailed information regarding the result of cluster analysis is documented in **Table 2.**

Table 2. Result of cluster analysis

Cluster	Most frequent keywords	Keywords
Red-35 items	diet (30), gut microbiota (27) nutrition (27)	Dietary fiber (16), blood pressure (15), probiotic (14), blood glucose (13), cholesterol (13), health (13), prebiotic (13), prevention (11), flaxseed (10), glycemic index (10), fermentation (9), phytochemical (9), microbiota (8), nuts (8), body weight (7), fiber (7), guidelines (7), lactic acid bacteria (7), lifestyle (7), prediabetes (7), dietary fiber (6), lipid (6), microbiome (6), physical activity (6), cinnamon (5), food (5), glycemic control (5), lipids (5), omega-3 fatty acids (5), phytosterols (5), polyunsaturated fatty acids (5)
Green-24 items	diabetes mellitus (101), functional foods (96), oxidative stress (49)	Antioxidant (47), antidiabetic (29), hyperglycemia (25), streptozotocin (19), antioxidant activity (18), phenolic compounds (16), anti-inflammatory (11), hypoglycemic activity (11), anticancer, (10 antidiabetic activity (10), hyperlipidemia (8), α-glucosidase inhibition (8), anti-diabetic activity (7), diabetic nephropathy (7), response surface (7) methodology (6), medicinal plant (6), polyphenol (5), anti-inflammation (5), COVID-19 (5), HPLC (5), α-glucosidase inhibitor (5)
Dark Blue-22 items	Diabetes (146), Polyphenols (41), α-glucosidase (38)	Bioactive compounds (21), α-amylase (21), antioxidants (20), cancer (20), flavonoids (20), bioactive peptides (14), health benefits (11), molecular docking (10), nutraceutical (10), anthocyanins (8), bioactive peptide (8), barley (6), dipeptidyl

Cluster	Most frequent keywords	Keywords
		peptidase iv (6) peptides (6), seaweed (6), buckwheat (5), hemoprevention (5), glycation (5), medicinal plants (5)
Yellow-20 items	type 2 diabetes (71), insulin resistance (44), hypoglycemic (27)	Insulin (23), polysaccharides (17), anti-diabetic (11), hypoglycemic effect (10), T2DM (9), AMPK (8), glucose uptake (8), polysaccharide (8), PI3K/Akt signaling pathway (7), anthocyanin (6), biomarkers (6), hypolipidemic (6), medicinal mushrooms (6), bioactives (5), intestinal microbiota (5), mechanism (5), mice (5)
Violet-18 items	functional foods (127), metabolic syndrome (45), inflammation (39)	Nutraceuticals (38), cardiovascular disease (20), hypertension (20), phytochemicals (15), mediterranean diet (13), dyslipidemia (10), atherosclerosis (9), chronic disease (8), lipid profile (8), type-2 diabetes (8), dietary supplements (7), food security (5), glycemic index (5), green tea (5), yogurt (5)
Light blue-16 items	Obesity (66), type 2 diabetes mellitus (51), prebiotics (17)	Probiotics (17), cardiovascular diseases (13), glucose (10), aging (7), chronic diseases (7), insulin sensitivity (7), lipid metabolism (7), non-alcoholic fatty liver disease (6), resistant starch (5), apoptosis (5), insulin secretion (5), short-chain fatty acids (5), symbiotics (5)

Discussion

Diabetes, specifically type 2 is a complex metabolic disease with both short and long-term complications. Despite the numerous pharmacological treatments involving oral hypoglycemic drugs and insulin therapy, there is an alarming increase in the incidence of undesirable complications among diabetic patients. Recent evidence suggested the use of functional foods and their bioactive compounds as an additional therapy for type 2 diabetes due to their biological properties [5].

Functional foods have gained recognition for their potential in preventing and managing diabetes, attributed to the antioxidant, anti-inflammatory, and insulin sensitivity properties [25]. These foods may alleviate the symptoms of diabetes through various mechanisms, including elimination of free radicals, reduction of inflammation, as well as promotion of insulin secretion and signaling [26]. Other mechanisms include the regulation of hepatic gluconeogenesis and glycogen storage metabolism, as well as the modulation of the intestinal microbiome [26].

The Mediterranean diet, rich in monounsaturated fatty acids, fiber, and antioxidant-rich food, was reportedly associated with a lower risk of diabetes by improving insulin sensitivity and reducing obesity [27]. Specific functional foods such as *Momordica charantia* and cabbage have been researched for their hypoglycemic effects as well as the ability to regulate glucose homeostasis and prevent complications associated with diabetes [28].

The development of functional foods ingredients as oral therapy has showed promising results in controlling carbohydrate metabolism, hyperglycemia, and preventing diabetes-related complications [29]. By targeting oxidative stress, inflammation, insulin resistance, and glucose regulation, functional foods offer potential mechanisms for the prevention and management of type 2 diabetes [25,26,30].

The primary limitation of this bibliometric analysis was the use of a single database. Consequently, some relevant publications on functional foods and diabetes may not have been included. Scopus was chosen over other medical databases because it offered a much broader range of content and search analysis tools. Conducting simultaneous searches in multiple medical databases could marginally improve the results of the literature search. Despite these limitations, the results provide valuable insights into the significant contributions to diabetes-related functional foods research, providing a framework for further investigations

Conclusion

A bibliometric analysis was conducted on 1226 articles obtained from the Scopus database to analyze the research trends on functional foods for diabetes mellitus. The analysis aimed to identify the most productive country/territory, journals, authors, and potential future topic of this research field. Based on the results, the year 2012 experienced the highest significant growth, China was the most productive nation, while Food and Function was identified as the most prestigious journal in this field. Additionally, Singh, R.B. and Zengin, G. made the greatest research contributions. The mechanisms of functional foods modulating anti-oxidant activity and gut microbiota, while inhibiting α-amylase were found as topics warranting more in-depth investigation in the future. These bibliometric findings might serve as a framework for future studies, particularly focusing on key areas influenced by functional foods such as antioxidants and gut microbiota. It will contribute to the development of functional foods and support their broader utilization.

Ethics approval

Not required.

Acknowledgments

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Competing interests

The authors declare that there are no conflicts of interest.

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Underlying data

Derived data supporting the findings of this study are available from the corresponding author on request.

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