Research Article

Bioactive Peptides from Protein Hydrolysate: A Bibliometric Approach

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ABSTRACT

This study presents a bibliometric analysis of research on bioactive peptides derived from protein hydrolysates, highlighting their importance in nutritional science, sustainable food production, and human health. As global demand for sustainable and health-promoting food components continues to grow, bioactive peptides have gained attention for their potential health benefits. Data were obtained from the Scopus database and analyzed using VOSviewer software. The analysis examined publication trends, citation patterns, leading authors, research themes, and collaboration networks. This approach provides an overview of the development of this research field over time. The results show a clear increase in research activity within the study period (2020–2024), where the number of publications peaked in 2022. Major contributions were identified from authors, particularly from China and the United States. The findings also indicate that this research area is multidisciplinary, with Agricultural and Biological Sciences and Chemistry as the main subject areas. This reflects the broad scope of research related to the production, characterization, and application of bioactive peptides. In addition, "antioxidant activity" and "enzymatic hydrolysis" were identified as key research themes, showing a strong focus on both the functional properties and production processes of bioactive peptides. Overall, this study highlights the growth, key contributors, and evolving trends in this field. The findings provide useful insights for future research and emphasize the importance of interdisciplinary collaboration in advancing the use of bioactive peptides from protein hydrolysates.

Keywords: [antioxidant activity; bibliometric analysis; bioactive peptides; enzymatic hydrolysis protein; hydrolysates

1. Introduction

In recent years, there has been growing interest in exploring bioactive peptides derived from protein hydrolysates, driven by their potential health benefits and wide-ranging applications (Chen *et al.*, 2022; Ucak *et al.*, 2021; Zhou *et al.*, 2023). These peptides, produced through enzymatic hydrolysis of proteins from various biological sources, have demonstrated significant bioactivity with implications for human health, including antioxidant, antimicrobial, anti-inflammatory, and antihypertensive properties (Cao *et al.*, 2022; Rauf *et al.*, 2022; Wu *et al.*, 2022).

The rapid expansion of this research area is reflected in the substantial increase in global scientific publications over the past decade, largely driven by advancements in food biotechnology, protein processing technologies, and the development of functional foods. This growth highlights a strong interdisciplinary interest spanning food science, biochemistry, nutrition, and pharmaceutical sciences. Furthermore, increasing international collaboration has been observed, particularly among countries with advanced research infrastructure, indicating the global relevance of bioactive peptide research. Despite this progress, the literature remains fragmented, with diverse research focuses, methodologies, and application targets, underscoring the need for a comprehensive bibliometric analysis to map knowledge structures, identify key contributors, and reveal emerging trends and research gaps.

Proteins from diverse biological sources represent rich substrates for the generation of bioactive peptides (Corona *et al.*, 2023; Lemos & Dantas, 2023; Portero *et al.*, 2022). Enzymatic hydrolysis techniques, particularly protease digestion, enable the breakdown of complex protein structures into smaller peptide sequences, typically consisting of 2 to 20 amino acids. These peptides often exhibit enhanced bioavailability and functional properties compared to their parent proteins. In parallel, increasing attention has been directed toward the valorisation of protein-rich by-products, aligning with global sustainability goals and circular bioeconomy principles. This has further stimulated both academic and industrial interest in the development and application of bioactive peptides.

One of the key attributes of bioactive peptides lies in their diverse health-promoting effects. Numerous studies have reported strong antioxidant activity, which plays a critical role in mitigating oxidative stress associated with chronic diseases (Franco *et al.*, 2021; Gil-Cardoso *et al.*, 2022; Kimball *et al.*, 2021). In addition, antimicrobial properties highlight their potential in food preservation and as alternatives to conventional antimicrobial agents. Their anti-inflammatory effects have also attracted attention for potential therapeutic applications in inflammatory disorders (Xin *et al.*, 2019; Kerner *et al.*, 2023; Jogpal *et al.*, 2022), while antihypertensive activities support their use in functional foods targeting cardiovascular health. Alongside these developments, there is a growing trend of industry–academia collaboration aimed at translating laboratory findings into commercial nutraceutical and functional food products, although challenges related to standardization, scalability, and regulatory approval remain.

Recent studies further demonstrate the functional potential of bioactive peptides derived from protein hydrolysates. For example, Ishak *et al.* (2021) reported the purification and molecular docking analysis of an angiotensin-I converting enzyme (ACE) inhibitory peptide, highlighting its antihypertensive potential. Similarly, Wei *et al.* (2022) showed that soluble protein hydrolysates can ameliorate gastrointestinal inflammation in experimental models, while Henaux *et al.* (2021) identified peptide fractions with glucoregulatory and anti-inflammatory activities, suggesting po tential applications in metabolic disorder management. These findings collectively reinforce the significance of bioactive peptides as functional ingredients for health promotion.

Despite the expanding body of research, there remains a lack of systematic evaluation of publication trends, citation networks, and thematic development within this field. Such analyses are essential for understanding the maturity, structure, and future direction of research on bioactive peptides derived from protein hydrolysates. Therefore, a bibliometric approach is necessary to provide a comprehensive overview of the research landscape, including patterns of scientific output, collaboration networks, influential contributors, and emerging research themes. This will not only enhance understanding of the field but also support strategic development in both academic and industrial contexts.

2. Literature Review

Bioactive peptides derived from protein hydrolysates have attracted considerable attention due to their wide-ranging applications across the food, nutraceutical, and pharmaceutical industries. These peptides, typically produced through enzymatic hydrolysis, exhibit diverse biological

activities, including antioxidant, antihypertensive, antimicrobial, and anticancer properties. For instance, Xu *et al.* (2021) investigated protein hydrolysates encapsulated in nanoliposomes and demonstrated enhanced stability and bioavailability of antioxidant peptides under simulated gastrointestinal conditions, highlighting their potential in functional food applications. Similarly, Siddiqui *et al.* (2023) explored fermentation-based approaches for valorizing protein-rich by-products, emphasizing their effectiveness in generating bioactive peptides while supporting sustainable resource utilization and waste reduction. The functional properties of bioactive peptides, particularly their antioxidant potential, have been widely reported. Gautam *et al.* (2022) highlighted the role of these peptides as natural antioxidants with promising applications in nutraceutical and pharmaceutical products. Supporting this, Yang *et al.* (2020) demonstrated the effectiveness of antioxidant peptides derived from protein hydrolysates in mitigating oxidative stress, a key contributor to aging and chronic diseases. Additional studies (Yang *et al.*, 2020; Zhang *et al.*, 2023) have further explored the multifunctionality of these peptides, including their roles in flavor enhancement, such as umami taste, and cytoprotective effects, thereby illustrating their versatility in both food quality improvement and health promotion.

Sustainability has also emerged as a central theme in bioactive peptide research. The valorization of protein rich by-products through hydrolysis processes offers an environmentally friendly approach to resource utilization. Studies by Nikoo (2021) and Ghosh *et al.* (2022) emphasize the importance of integrating sustainable practices within biorefinery systems to recover valuable compounds and produce functional ingredients. In addition, Navarro-Peraza *et al.* (2020) provided a comprehensive review of the structural and biological properties of protein hydrolysates derived from industrial effluents, highlighting their potential as alternative sources of bioactive peptides for nutraceutical and functional food development. Earlier reviews, such as Halim *et al.* (2016), have comprehensively summarized the functional and bioactive properties of protein hydrolysates, particularly their antioxidant, antimicrobial, and antihypertensive activities. These studies underscore the significance of bioactive peptides in food and health-related applications, reinforcing their role in promoting human health and disease prevention. Beyond traditional applications, Venkatesan *et al.* (2017) examined the potential of protein-derived bioactive compounds in the cosmeceutical industry, demonstrating their effectiveness in antioxidation, tissue regeneration, and anti-photoaging. This expands the scope of bioactive peptide applications into skincare and cosmetic formulations. In terms of production techniques, Castañeda-Valbuena *et al.* (2022) reviewed the generation of bioactive peptides through enzymatic hydrolysis, particularly using pepsin, and highlighted their nutritional, pharmacological, and technological potential. The study emphasizes the importance of optimizing hydrolysis processes to enhance peptide functionality and broaden their industrial applications.

Overall, existing studies collectively demonstrate the significant potential of bioactive peptides derived from protein hydrolysates across multiple domains, including food quality enhancement, health promotion, and industrial applications. At the same time, integrating sustainable practices for the utilization of protein-rich by-products further strengthens the relevance of this research area. These findings highlight the growing importance of bioactive peptides and support the need for systematic analyses to better understand research trends, collaboration patterns, and future directions in this field.

3. Research Question

A review of the existing literature on bioactive peptides derived from protein hydrolysates shows that this field has received increasing attention from the scientific community. Previous studies, including bibliometric analyses and review articles, indicate a steady growth in research output in recent years. This

increase reflects the field's growing importance in both scientific and practical contexts. The growing interest may also be linked to global health challenges, particularly during the COVID-19 pandemic, where issues related to immunity, nutrition, and chronic disease management became more prominent.

In this context, the present study aims to conduct a bibliometric analysis of research on bioactive peptides derived from protein hydrolysates published between 2020 and 2024. The study analyzes bibliometric data to examine keywords, authorship patterns, country contributions, citation structures, publication outputs, and journal distributions. This approach is used to identify key trends, major contributors, and emerging research areas within this field.

Accordingly, this study addresses the following research questions:

1. What are the current research trends in this field, and how have they changed over time based on the year of publication?
2. Who are the top 10 authors based on citation count?
3. What are the main subject areas in this research field?
4. Which authors have contributed to the most highly cited publications?
5. What does the co-authorship network reveal about research collaboration?
6. Which keywords occur most frequently in this field?
7. How do countries collaborate in terms of co-authorship?
8. What insights can be obtained from citation network mapping at the country level?
9. How is bibliographic coupling distributed among countries involved in this research area?

4. Methodology

Bibliometrics refers to the systematic process of collecting, organizing, and analyzing bibliographic data derived from scientific publications (Alves *et al.*, 2021; Assyakur & Rosa, 2022; Verbeek *et al.*, 2002; Wu & Wu, 2017). It encompasses both advanced analytical techniques, such as document co-citation analysis, and descriptive indicators, including publication sources, publication year, and authorship patterns. This approach enables a comprehensive evaluation of research trends, intellectual structures, and the development of a scientific field.

A rigorous bibliometric study requires an iterative process that involves identifying relevant keywords, conducting systematic literature searches, and performing detailed data analysis to ensure the reliability and completeness of the dataset (Fahimnia *et al.*, 2015). In this study, emphasis was placed on high-quality publications to capture meaningful insights into the theoretical and developmental aspects of the field.

Data were collected from Elsevier's Scopus database, which is widely recognized for its extensive and comprehensive coverage of peer-reviewed literature (Al-Khoury *et al.*, 2022; di Stefano *et al.*, 2010; Khiste & Paithankar, 2017). The dataset includes publications spanning from 1962 to February 2024. To ensure data quality and consistency, only articles published in peer-reviewed academic journals were included in the analysis (Gu *et al.*, 2019). Overall, this methodological approach ensures a reliable and structured analysis of the research landscape, enabling the identification of publication trends, collaboration patterns, and key developments within the field of bioactive peptides derived from protein hydrolysates.

4.1 Data search strategy

A systematic search strategy was applied to identify relevant publications for this study. The Scopus database was used as the primary source for data retrieval. An initial search yielded 21,444 records. The

search string was then refined to focus on the scope of this study, using the terms: peptide AND (seafood* OR fish* OR prawn) AND hydrolysate (Table 1a).

After applying this search query and relevant filters, a total of 1,127 articles were identified and included for bibliometric analysis. The search was limited to publications between 2020 and February 2024 and restricted to peer-reviewed journal articles. The final dataset was selected based on predefined inclusion criteria, ensuring that only relevant and high-quality publications were included. The detailed search strategy and selection criteria are presented in Table 1 (b).

Table 1 (a). The search string.

Scopus	**ALL (peptide* AND (seafood* OR fish* OR prawn) AND hydrolysate*) AND PUBYEAR > 2019 AND PUBYEAR < 2025 AND LIMIT-TO (LANGUAGE, "English") AND LIMIT-TO (EXACTKEYWORD, "Peptides") OR LIMIT-TO (EXACTKEYWORD, "Fish")**

Table 1 (b). The selection criteria in searching.

Criterion	Inclusion	Exclusion
Language	English	Non-English
Document Type	Article	Non-Article
Subject area	Agriculture and biological science	None
Year	2020-2024	Below 2020 and after 2024
Keywords	Peptides, fish, hydrolyasate	

4.2 Data Analysis

VOSviewer, a widely used bibliometric analysis software developed by Nees Jan van Eck and Ludo Waltman at Leiden University, the Netherlands (Van Eck & Waltman, 2010, 2017), was employed to visualize and analyze the bibliometric data in this study. The software provides advanced features for constructing and visualizing bibliometric networks, including co-authorship, co-citation, and keyword co-occurrence analyses. It enables the identification of relationships among publications, authors, and research themes through intuitive network visualizations, clustering techniques, and density maps.

A key strength of VOSviewer lies in its ability to transform complex bibliometric data into clear and interpretable visual representations. Its clustering functionality allows for the identification of related research groups and thematic structures, while density visualization highlights the concentration of research activities within specific areas. In addition, the software supports large-scale data processing and offers customizable visualization options, facilitating a comprehensive exploration of research trends and intellectual structures.

In this study, bibliometric data were analyzed using VOSviewer (version 1.6.19). Bibliographic data were exported from the Scopus database in Plain Text format, including publication year, title, authors, journal, citations, and keywords for the period between 2020 and 2024. These data were then imported into VOSviewer, where clustering and mapping techniques were applied to generate visual representations of the relationships within the dataset.

Unlike traditional Multidimensional Scaling (MDS), VOSviewer arranges items in a low-dimensional space such that the distance between any two items reflects their degree of relatedness and similarity (Van Eck & Waltman, 2010). Although it shares some conceptual similarities with MDS (Appio *et al.*, 2014), VOSviewer applies a different approach for data normalization. In contrast to MDS, which commonly relies on similarity measures such as cosine and Jaccard indices, VOSviewer uses the association strength method to normalize co-occurrence frequencies (Van Eck & Waltman, 2007). The association strength between items *i* and *j* (AS_{ij}) is defined as:

$$AS_{ij} = \frac{C_{ij}}{w_i w_j}$$

where C_{ij} represents the number of co-occurrences between items *i* and *j*, and w_i and w_j represent the total occurrences of items *i* and *j*, respectively.

This method is proportional to the ratio between the observed number of co-occurrences of items *i* and *j* and the expected number of co-occurrences under the assumption of statistical independence. Using this approach, VOSviewer constructs visual maps by minimizing the weighted sum of squared distances between all pairs of items, allowing for an accurate representation of their relational proximity.

5. Result and finding

5.1 What Are the Current Research Trends in This Field, and How Have They Changed over Time Based on the Year of Publication?

The bibliometric analysis of research trends on bioactive peptides from protein hydrolysates, based on the Scopus analyzer, is presented in Figure 1(a). The results show a clear and dynamic evolution in publication output over recent years, reflecting changes in scientific interest and research funding.

The year 2022 represents the peak of publication activity, with 313 articles, accounting for 27.77% of the total publications in this field. This increase may be attributed to growing recognition of the potential health benefits and applications of bioactive peptides, supported by advancements in protein hydrolysis technologies and a stronger focus on sustainable food sources. In the following year, 2023, the number of publications slightly decreased to 254 (22.54%), suggesting a stabilization in research activity after the peak (Figure 1a). This trend may indicate a transition toward more focused and in-depth studies.

Figure 1(a) also shows publication trends before and after the peak, providing further insight into the development of research interest in this area. In 2020 and 2021, the number of publications increased to 208 (18.46%) and 253 (22.45%), respectively, indicating steady growth. This upward trend may be linked to increased interest in nutritional science and sustainable food systems. In contrast, 2024 shows a decline to 99 publications (8.78%), which may suggest a period of stabilization or a shift in research priorities.

Overall, these variations highlight the changing nature of research activity over time and emphasize the influence of external factors such as global health concerns, funding availability, and technological advancements. The fluctuation in publication volume reflects how the research community responds to emerging scientific evidence and evolving societal needs.

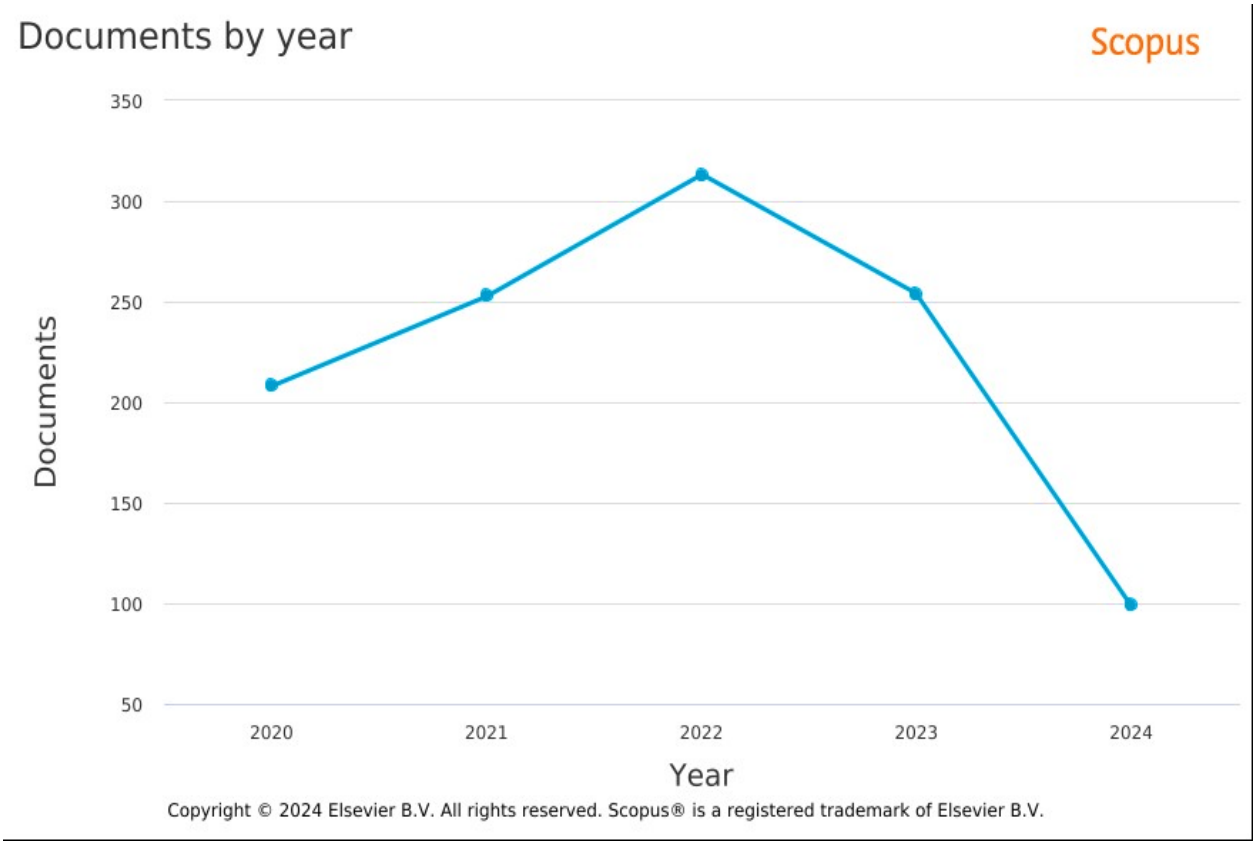


Figure 1 (a). Plotting document publication by years

5.2 Who Are the Top 10 Authors Based on Citation Count?

The bibliometric analysis of research on bioactive peptides derived from protein hydrolysates indicates a relatively concentrated research landscape, characterized by a core group of highly productive authors. As shown in Figure 1(b), Lin, S. is the most prolific contributor, with 29 publications, representing 2.75% of the total output in this field. This suggests a consistent research focus and a potentially influential role.

Lin, S. is followed by Du, M. and Li, J., with 21 and 18 publications, respectively, further highlighting their significant contributions to the development of this research area. Collectively, the top ten authors account for 173 publications. Although this represents a modest proportion of the total literature, these authors form a key group that contributes consistently to research activity in this field.

The proportion of total publications attributed to these leading authors ranges from 2.75% to 0.72%, indicating a competitive and distributed research landscape. The relatively small differences among the lower-ranked authors. For example, Cheng, S. (0.75%), Luo, Y. (0.76%), and Li, X. (0.72%), suggest that multiple researchers are contributing at a similar level (Figure 1b). This pattern reflects a balanced distribution of contributions across the field.

Overall, this distribution indicates diversity in research contributions, which supports the development of new ideas and approaches. In addition, the presence of multiple authors with similar publication outputs suggests opportunities for collaboration, which may further enhance research progress in the study of bioactive peptides derived from protein hydrolysates.

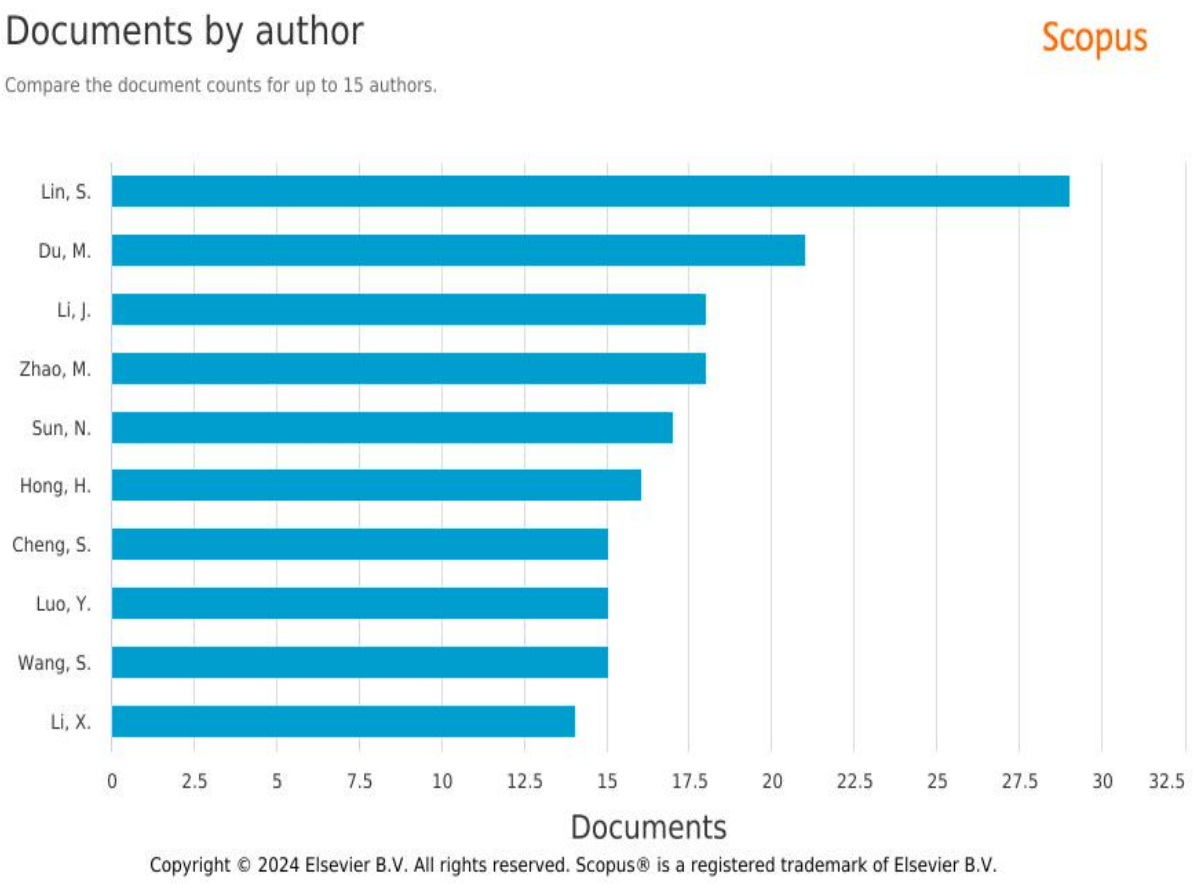


Figure 1 (b). The top 10 authors based on citation by research

5.3 What Are the Main Subject Areas in This Research Field?

The bibliometric analysis of research on bioactive peptides derived from protein hydrolysates, based on Scopus analyser data, reveals a diverse distribution across multiple subject areas. As shown in Figure 1(c), Agricultural and Biological Sciences dominate the field with 1,127 publications, accounting for 52.37% of the total output. This is followed by Chemistry (18.5%), Engineering (6.7%), Biochemistry, Genetics and Molecular Biology (6.6%), and Chemical Engineering (5.9%). Smaller contributions are observed in Nursing (2.5%), Pharmacology, Toxicology and Pharmaceutics (2.2%), Immunology and Microbiology (1.8%), Environmental Science (0.8%), and Veterinary Science (0.6%), while other subject areas collectively account for 1.5% of the publications.

This distribution reflects the multidisciplinary nature of research on bioactive peptides, which involves areas such as food science, nutrition, and biological activity. The dominance of Agricultural and Biological Sciences highlights its central role in understanding the functional properties and applications of bioactive peptides in health and nutrition.

Chemistry, which accounts for a substantial proportion of publications, emphasizes the importance of chemical analysis in identifying, characterizing, and understanding the mechanisms of bioactive peptides. This further demonstrates the collaborative nature of the field, where both biological and chemical approaches are essential.

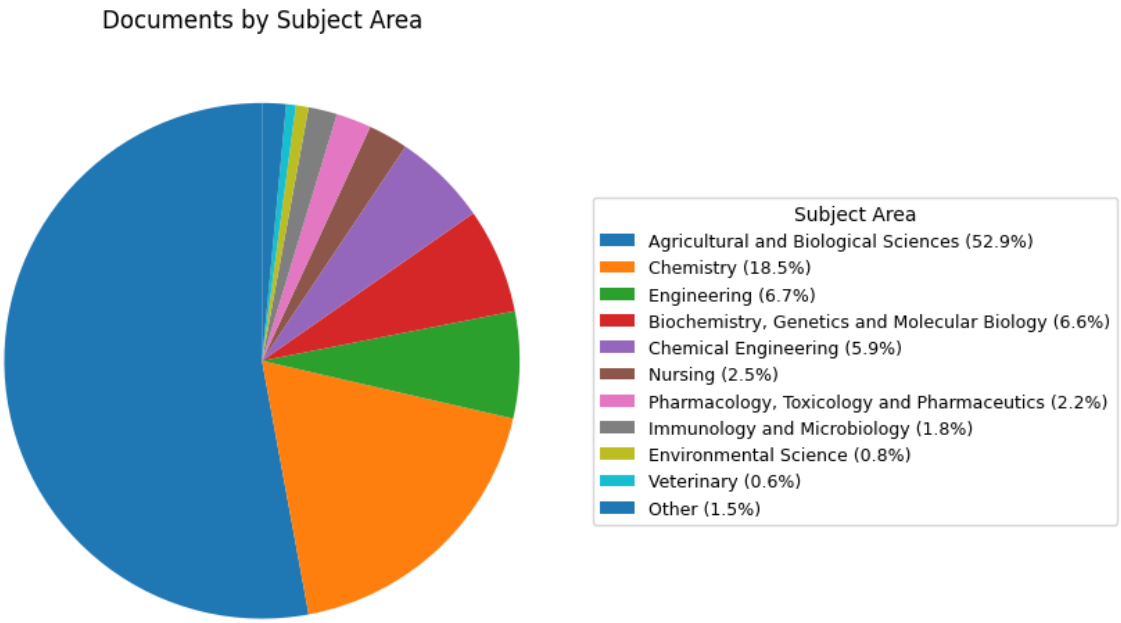


Figure 1 (c). The documents by subject area (Source: Data retrieved from the Scopus database. © 2024 Elsevier B.V. All rights reserved)

The contributions from Engineering, Biochemistry, Genetics and Molecular Biology, and Chemical Engineering further support the multidisciplinary nature of this research area (Figure 1c). Engineering fields, particularly Chemical Engineering, are important for developing scalable production and processing methods, while Biochemistry and Molecular Biology provide insights into the mechanisms and biological effects of these compounds.

Although fields such as Nursing, Pharmacology, Toxicology and Pharmaceutics, and Immunology and Microbiology contribute a smaller number of publications, their presence indicates the expanding scope of research into clinical, therapeutic, and safety-related applications. Overall, the wide distribution across subject areas highlights the broad applicability of bioactive peptides and the importance of interdisciplinary collaboration in advancing this field.

5.4 Which Authors Have Contributed to the Most Highly Cited Publications?

The bibliometric analysis of the most frequently cited publications on bioactive peptides derived from protein hydrolysates, based on Scopus data (Table 2), provides valuable insights into key contributors and research trends in this field. Kumar *et al.* (2022) are identified as the most cited authors, with their study on plant-based proteins and industrial applications receiving 92 citations. This highlights the increasing interest in alternative protein sources and their functional properties.

Following this, studies by Wen *et al.* (2020) and Xu *et al.* (2021) have received 88 and 87 citations, respectively. These studies report significant progress in the identification and application of antioxidant and angiotensin-I converting enzyme (ACE) inhibitory peptides. By focusing on sources such as watermelon seed protein hydrolysates and soybean protein isolate, these highly cited works demonstrate the expanding scope of research beyond a single protein source, emphasizing the broader potential of diverse raw materials for bioactive peptide production.

Table 2. Most cited articles

Authors	Title	Year	Source title	Cited by
Kumar M., Tomar M., Punia S., Dhakane-Lad J., Dhumal SChangan S., Senapathy M., Berwal M., Sampathrajan V., Sayed AChandran D., Pandiselvam R., Rais NMahato D., Udikeri SSatankar V., Anitha T., ReetuRadhaSingh S., Amarowicz R., Kennedy J.	Plant-based proteins and their multifaceted industrial applications	2022	LWT	92
Wen C., Zhang J., Feng Y., Duan Y., Ma H., Zhang H.	Purification and identification of novel antioxidant peptides from watermelon seed protein hydrolysates and their cytoprotective effects on H2O2-induced oxidative stress	2020	Food Chemistry	88
Xu Z., Wu C., Sun-Waterhouse D., Zhao T., Waterhouse G.I.N., Zhao M., Su G.	Identification of post-digestion angiotensin-I converting enzyme (ACE) inhibitory peptides from soybean protein Isolate: Their production conditions and in silico molecular docking with ACE	2021	Food Chemistry	87
Li X., Xie X., Wang J., Xu Y., Yi S., Zhu W., Mi H., Li T., Li J.	Identification, taste characteristics and molecular docking study of novel umami peptides derived from the aqueous extract of the clam meretrix meretrix Linnaeus	2020	Food Chemistry	85
Wang L., Ma M., Yu Z., Du S.-K.	Preparation and identification of antioxidant peptides from cottonseed proteins	2021	Food Chemistry	84
Wu S., Yang J., Dong H., Liu Q., Li X., Zeng X., Bai W.	Key aroma compounds of Chinese dry-cured Spanish mackerel	2021	Food Chemistry	79

	(Scomberomorus niphonius) and their potential metabolic mechanisms			
Sarabandi K., Jafari S.M.	Effect of chitosan coating on the properties of nanoliposomes loaded with flaxseed-peptide fractions: Stability during spray-drying	2020	Food Chemistry	79
Zhang Y., He S., Bonneil É., Simpson B.K.	Generation of antioxidative peptides from Atlantic sea cucumber using alcalase versus trypsin: In vitro activity, de novo sequencing, and in silico docking for in vivo function prediction	2020	Food Chemistry	78
Chen J., Jayachandran M., Bai W., Xu B.	A critical review on the health benefits of fish consumption and its bioactive constituents	2022	Food Chemistry	77
Zamorano-Apodaca J.C., García-Sifuentes C.O., Carvajal-Millán E., Vallejo-Galland B., Scheuren-Acevedo S.M., Lugo-Sánchez M.E.	Biological and functional properties of peptide fractions obtained from collagen hydrolysate derived from mixed by-products of different fish species	2020	Food Chemistry	77

In addition, other highly cited studies, such as those by Li *et al.* (2020) and Wu *et al.* (2021), highlight the functional properties of peptides, including antioxidant activity, umami taste, and aroma characteristics in food applications. This reflects a multidisciplinary research approach that integrates food science, chemistry, and technology to address both fundamental and applied aspects of bioactive peptides.

Overall, the diversity of topics among the most cited articles—from peptide purification and identification to their applications in food and nutrition, indicates that this is a dynamic and evolving research field. These studies contribute to a deeper understanding of bioactive peptides and highlight their potential in areas such as food preservation, flavor enhancement, and health-promoting dietary products.

5.5 What Does the Co-Authorship Map Reveal?

The bibliometric analysis generated using VOSviewer provides an overview of co-authorship patterns among researchers working on bioactive peptides derived from protein hydrolysates (Figure 2a). The

accompanying table summarizes key indicators for each author, including the number of publications, total citations, and total link strength, which reflects the level of collaboration within the research network.

Among the contributors, Sarabandi K. and Jafari S.M. stand out as the most highly cited authors, with a total of 136 citations across three publications. This suggests a strong research impact and a notable presence in the field. Similarly, Rivero-Pino F., Espejo-Carpio F.J., and Guadix E.M. show significant influence, with 111 citations from three publications. The high citation counts of these authors indicate that their work is widely recognized and frequently referenced, highlighting its importance and relevance.

In contrast, the total link strength is reported as 0 for all authors. This suggests that the analysis did not detect strong co-authorship or co-citation links within the network. This may indicate that the research field is relatively dispersed, with researchers working independently or with limited collaboration, and with minimal overlap in cited literature.

Other authors, including Bu Y., Liu Y., Luan H., Zhu W., Li X., and Li J., have moderate citation counts of 34 across two publications, indicating a reasonable level of research impact despite a smaller number of studies. Meanwhile, authors such as Göksu A.G., Çakır B., and Gülseren İ. have lower citation counts, which may suggest that their work is more recent, more specialized, or less widely recognized within the field.

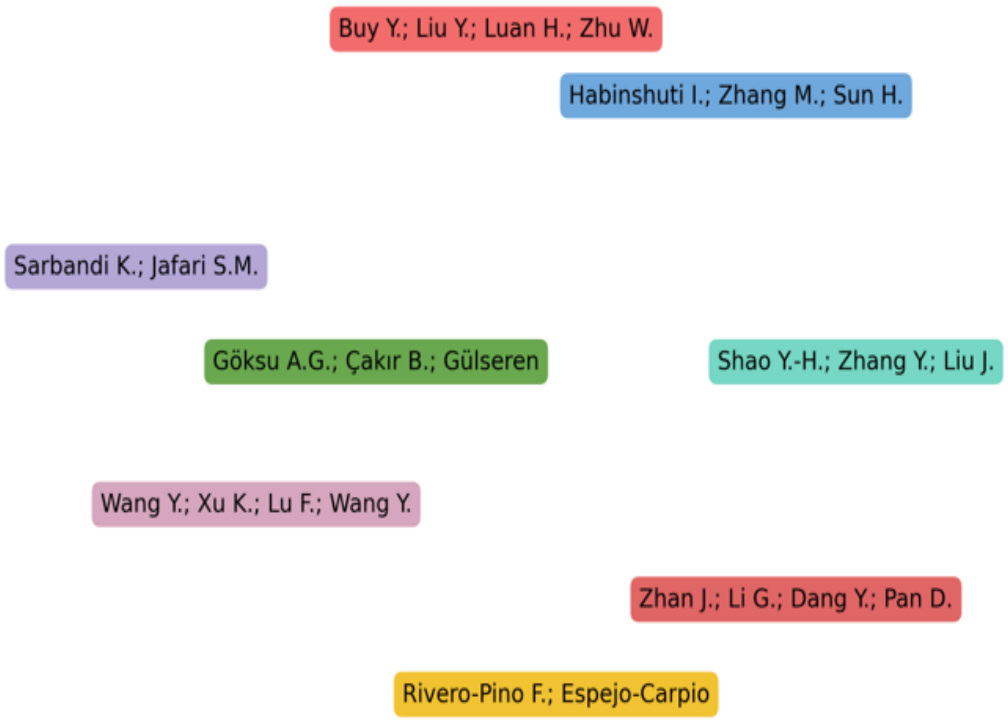


Figure 2 (a). Network visualization of the co-authorship structure (source: VOSviewer)

5.6 What Are the Popular Keywords Related to the Study?

The bibliometric analysis conducted using VOSviewer provides insights into the research landscape of bioactive peptides derived from protein hydrolysates. As shown in Figure 2(b), several keywords appear frequently, with "antioxidant activity" being the most prominent, followed by "peptides" and "bioactive peptides." This indicates a strong research focus on the antioxidant properties of these compounds and their potential health benefits and functional applications.

The keyword "molecular docking" shows a notably high total link strength of 183, despite appearing 119 times. This suggests strong connections with other research topics and reflects growing interest in computational approaches to study peptide interactions at the molecular level. Such approaches are important for understanding interaction mechanisms and evaluating potential therapeutic applications.

In addition, keywords such as "enzymatic hydrolysis," "protein hydrolysate," and "peptidomics" are also frequently observed, indicating active research in the production and analytical processes of bioactive peptides. The term "antioxidant activity" appears 79 times with a total link strength of 119, highlighting a focused effort to explore its role in areas such as food preservation, nutraceutical development, and therapeutic applications

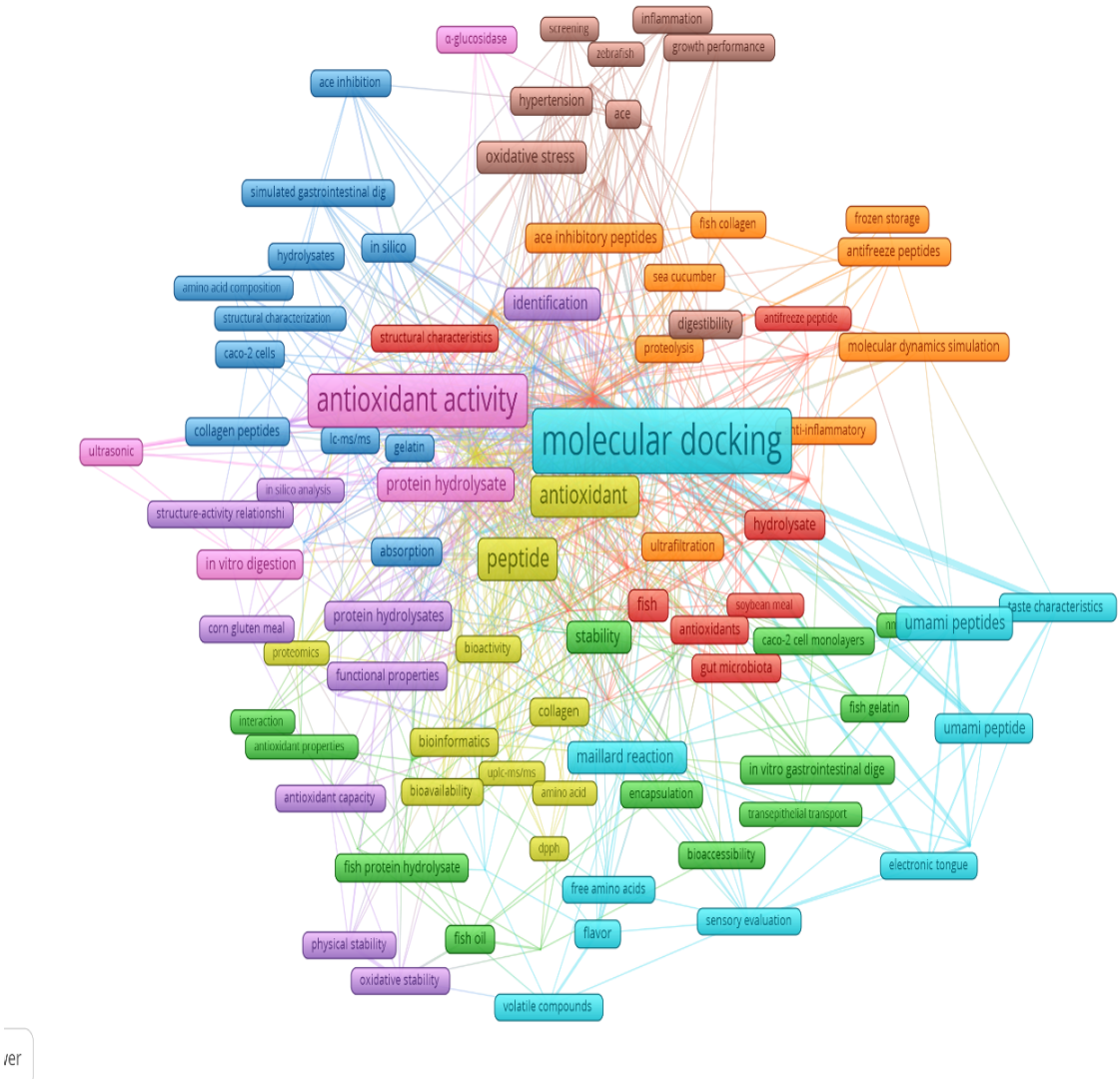


Figure 2 (b). Network visualization of keyword co-occurrence

Overall, the data suggest that this research field is multifaceted, covering areas from bioactivity and bioavailability to production and analysis methods. The frequent occurrence of keywords related to "hydrolysis," "digestion," and "fermentation" indicates a strong emphasis on processing techniques, which are essential for practical applications. In general, the keyword distribution reflects a dynamic research field with a strong focus on antioxidant properties and molecular-level interactions of bioactive peptides.

5.7 How Do Countries Collaborate in Terms of Co-Authorship?

The VOSviewer-based analysis illustrates the global research landscape on bioactive peptides derived from protein hydrolysates by summarizing each country's publication output, total citations, and total link strength. As shown in Figure 2(c), total link strength serves as an important indicator of international collaboration, reflecting the extent to which a country's research is connected within the global scientific network.

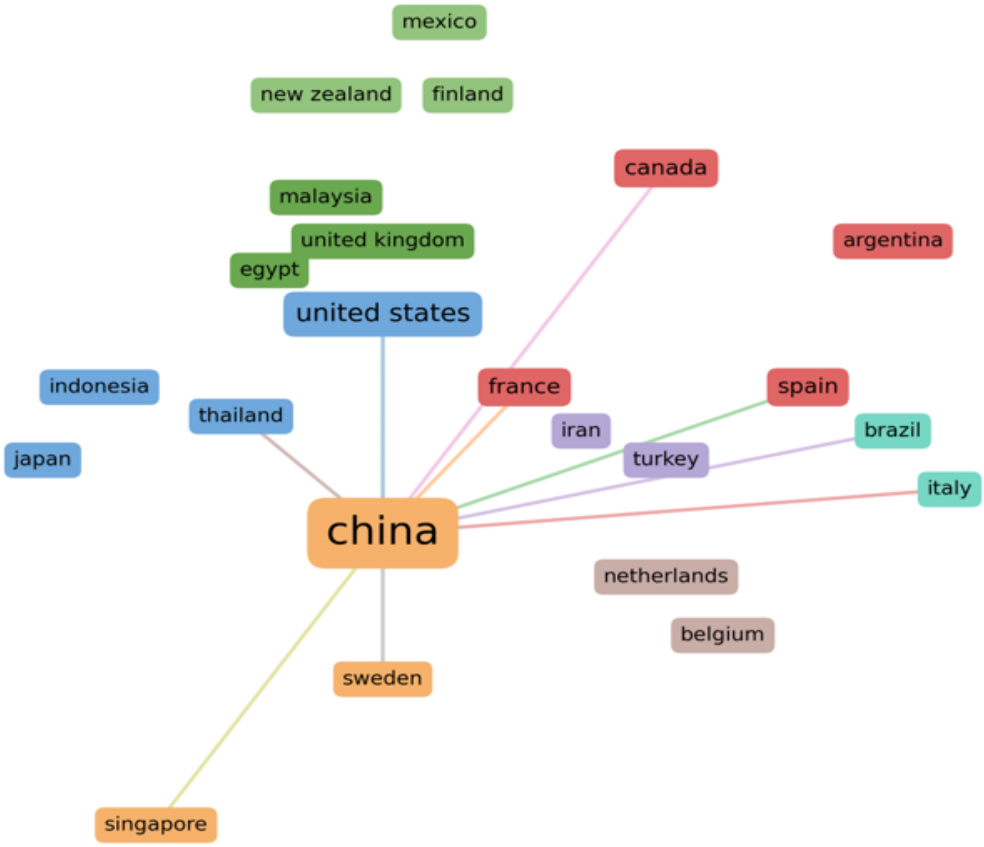


Figure 2 (c). Co-authorship countries' collaboration (source: VOSviewer)

China leads the field with 711 publications, 8,926 citations, and a total link strength of 137 (Figure 2c). This indicates not only a high research output but also strong engagement in international collaboration. The United States follows with 76 publications and 1,177 citations, supported by a total link strength of 82, highlighting both the quality and global influence of its research.

Other key contributors include Canada and Spain. Canada has produced 40 publications with 518 citations and a total link strength of 30, while Spain has contributed 52 publications with 713 citations and a total link strength of 32. These values suggest active collaboration and a solid presence in the international research community.

Overall, the findings indicate that research in this field is supported by strong international collaboration, with several leading countries contributing significantly to its development. The variation in publication output and link strength reflects differences in research capacity, collaboration networks, and global influence among countries.

5.8 What Does the Citation-Based Network Mapping by Country Reveal?

The citation-based network mapping provides insight into the global distribution of research productivity and influence in the field of bioactive peptides derived from protein hydrolysates. As shown in Figure 3(a), there is a clear disparity among countries in terms of publication output and citation impact, indicating differences in research capacity and scientific influence.

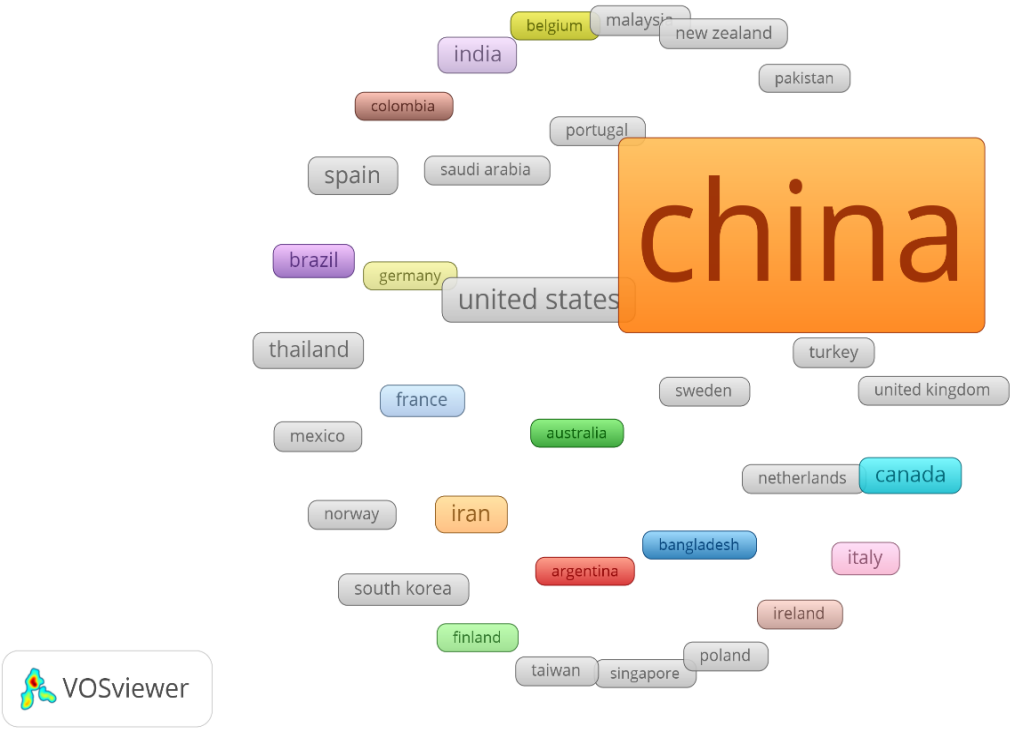


Figure 3 (a). Citation-based network mapping by country

China leads the field with 711 publications and 8,926 citations, demonstrating both high productivity and strong scholarly impact (Figure 3a). This dominant position reflects broader global trends, where China has emerged as a major contributor to scientific research, supported by substantial investment in research and development (R&D), a large scientific workforce, and strong institutional support (Arana-Barbier, 2020; Tang & Du, 2016). These factors have enabled China to achieve high publication output and increased citation visibility across disciplines.

The United States ranks second, with 76 publications and 1,177 citations, highlighting its continued strength in producing high-impact research. This is largely supported by its well-established academic infrastructure and long-standing emphasis on scientific innovation. Other countries, including Spain (52 publications, 713 citations), Iran (47 publications, 654 citations), and both Canada and India (40 publications each, with 518 and 603 citations, respectively), also demonstrate notable contributions. These countries show moderate to strong citation impact, reflecting their active participation and growing influence in the research field.

Overall, the findings reveal an uneven global landscape in which a small number of countries account for a large share of research output and citations. This variation can be attributed to differences in R&D investment, human capital, research infrastructure, and strategic focus on relevant scientific areas (Cicero, 2025; Guan *et al.*, 2014; Wagner *et al.*, 2015). Despite these disparities, the presence of multiple contributing countries indicates a broadly distributed and evolving research field with increasing global participation.

5.9 How Is Bibliographic Coupling Distributed Among Countries Involved in This Research Area?

The VOSviewer-based analysis provides an overview of bibliographic coupling among countries in the field of bioactive peptides derived from protein hydrolysates. Bibliographic coupling reflects the extent to which publications share common references, with total link strength indicating the degree of intellectual connectivity and similarity in research foundations. As shown in Figure 3(b), the distribution of bibliographic coupling varies considerably among countries, highlighting differences in research integration and focus.

China leads the field with 711 publications and 8,926 citations, accompanied by the highest total link strength of 15,957 (Figure 3b). This indicates a highly interconnected body of research, suggesting strong alignment in referenced literature and a well-established knowledge base within the country. The United States also demonstrates substantial bibliographic coupling, with a total link strength of 6,805, alongside 76 publications and 1,177 citations. This reflects a cohesive and influential research community with strong intellectual linkages.

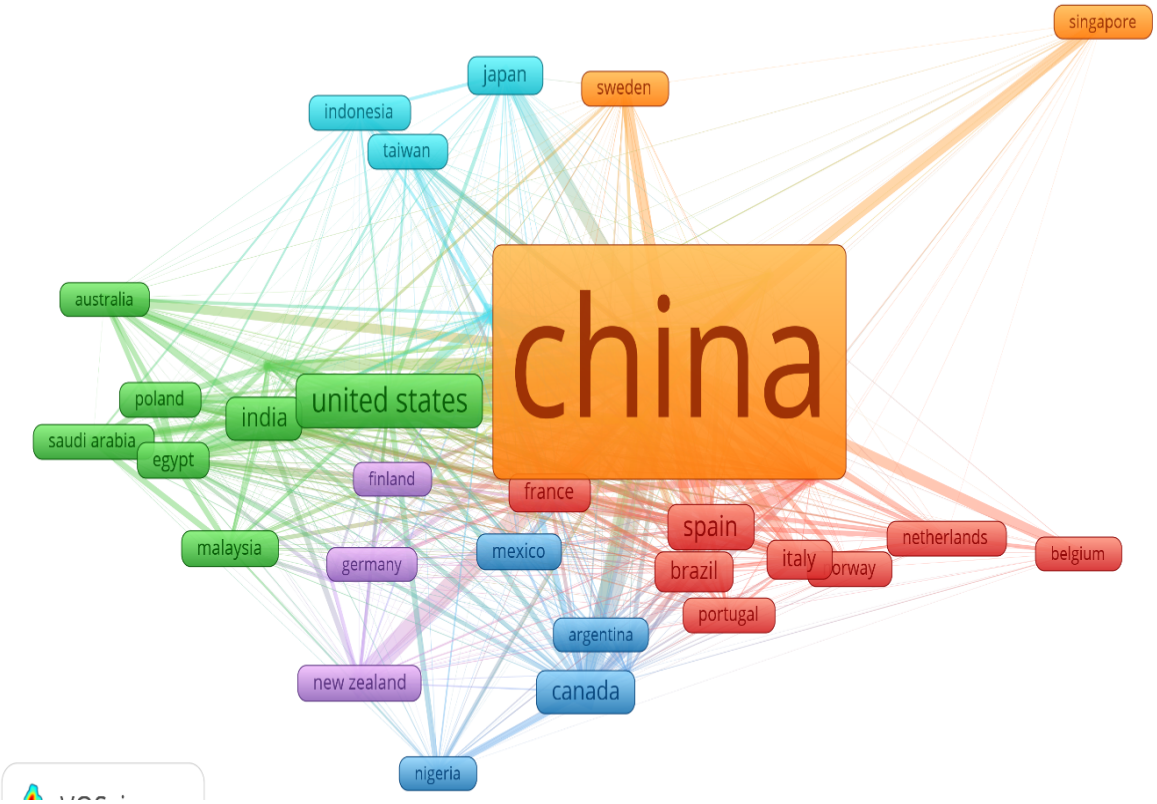


Figure 3 (b). Bibliographic coupling by countries

Other countries, including Canada (total link strength: 3,799), India (3,698), and Spain (3,746), show moderate to high levels of bibliographic coupling. Although their publication output is lower than that of China, the relatively high link strengths suggest that their research is well connected and focused within specific areas of the field. This pattern indicates the presence of shared research frameworks and common thematic interests.

Overall, the findings suggest that bibliographic coupling is concentrated among a group of leading countries, with China and the United States forming the core of the global research network. The variation in total link strength among countries reflects differences in research intensity, thematic focus, and the extent of shared knowledge bases. These results highlight the structured and interconnected nature of research development in this field, supported by both national research efforts and broader global scientific alignment.

6. Discussion and conclusion

This bibliometric analysis demonstrates that research on bioactive peptides derived from protein hydrolysates has evolved into a rapidly expanding and strategically important field, characterized by increasing scientific output, interdisciplinary integration, and growing global participation. The observed publication trends suggest that the field is transitioning from an exploratory phase of rapid growth toward a more mature stage focused on targeted and in-depth investigations.

A key conclusion from the findings is that global research activity is highly concentrated, with a small number of countries, particularly China and the United States. These two countries are dominating both productivity and influence. This concentration reflects the critical role of sustained investment in research and development, strong scientific infrastructure, and large research communities in shaping global leadership. At the same time, the presence of emerging contributors such as India, Iran, and Spain indicates a gradual diversification of the research landscape, suggesting that the field is becoming more globally distributed.

The analysis also reveals that, despite strong research output, collaboration patterns remain relatively fragmented, with several independent research clusters. This indicates that future progress in the field may depend not only on increasing research volume but also on strengthening international collaboration and knowledge integration. Enhanced cooperation across countries and disciplines could facilitate more comprehensive advancements and accelerate the translation of research into practical applications. Furthermore, the strong emphasis on functional properties, particularly antioxidant activity and bioactivity-related mechanisms, highlights the field's alignment with current demands in health, nutrition, and therapeutic development. The integration of experimental and computational approaches, such as molecular docking, further suggests a shift toward more advanced and mechanism-driven research.

Overall, the findings indicate that the future development of bioactive peptide research will likely be driven by three key factors: sustained research investment, deeper interdisciplinary collaboration, and stronger global research integration. By addressing current gaps in collaboration and expanding the diversity of research contributions, the field is well-positioned to achieve significant scientific and practical advancements.

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Conflict of interest

None of the authors of this study has any financial interest or conflict with industries or parties.

References

Al-Khoury, A., Hussein, S. A., Abdulwhab, M., Aljuboori, Z. M., Haddad, H., Ali, M. A., Abed, I. A., & Flayyih, H. H. (2022). Intellectual capital history and trends: A bibliometric analysis using Scopus database. *Sustainability (Switzerland)*, 14(18). https://doi.org/10.3390/su141811615

Alves, J. L., Borges, I. B., & De Nadae, J. (2021). Sustainability in complex projects of civil construction: Bibliometric and bibliographic review. *Gestao e Producao*, 28(4). https://doi.org/10.1590/1806-9649-2020v28e5389

Appio, F. P., Cesaroni, F., & Di Minin, A. (2014). Visualizing the structure and bridges of the intellectual property management and strategy literature: A document co-citation analysis. *Scientometrics*, 101(1), 623–661. https://doi.org/10.1007/s11192-014-1329-0

Arana-Barbier, P. J. (2020). The quantitative and qualitative scientific production: A bibliometric study of the five main Asian economies in R&D. *Malaysian Journal of Library & Information Science*, 25(2), 95–109.

Assyakur, D. S., & Rosa, E. M. (2022). Spiritual leadership in healthcare: A bibliometric analysis. *Jurnal Aisyah: Jurnal Ilmu Kesehatan*, 7(2). https://doi.org/10.30604/jika.v7i2.914

Cao, C., Xiao, Z., Tong, H., Liu, Y., Wu, Y., & Ge, C. (2022). Oral intake of chicken bone collagen peptides anti-skin aging in mice by regulating collagen degradation and synthesis, inhibiting inflammation and activating lysosomes. *Nutrients*, 14(8), 162 2.https://doi.org/10.3390/nu14081622

Cao, Y., Li, X., & Zhang, Y. (2022). Bioactive peptides from marine resources: Functional properties and applications. *Journal of Food Biochemistry*, 46(5), e14025. https://doi.org/10.1111/jfbc.14025

Castañeda-Valbuena, D., Berenguer-Murcia, Á., Fernandez-Lafuente, R., Morellon-Sterling, R., & Tacias-Pascacio, V. G. (2022). Biological activities of peptides obtained by pepsin hydrolysis of fishery products. *Process Biochemistry*, 120(May), 53–63. https://doi.org/10.1016/j.procbio.2022.05.029

Chen, H., Wang, J., Li, Y., & Zhou, K. (2022). Marine bioactive peptides: Production, bioactivities, and applications. *Food Chemistry*, 373, 131408. https://doi.org/10.1016/j.foodchem.2021.131408

Chen, J., Jayachandran, M., Bai, W., & Xu, B. (2022). A critical review on the health benefits of fish consumption and its bioactive constituents. *Food Chemistry*, 369. https://doi.org/10.1016/j.foodchem.2021.130874

Chen, Y., Chen, J., Chen, J., Yu, H., Zheng, Y., Zhao, J., & Zhu, J. (2022). Recent advances in seafood bioactive peptides and their potential for managing osteoporosis. *Critical Reviews in Food Science and Nutrition*, 62(5), 1187–1203. https://doi.org/10.1080/10408398.2020.1836606

Cicero, T. (2025). Forecasting the scientific production volumes of G7 and BRICS countries in a comparative analysis. *Publications*, 13(1), 6. https://doi.org/10.3390/publications13010006

Corona, B. E. L., Ocampo, A. G., Juárez, D. R., García, J. O., Fernández, I. M., & Puente, E. O. R. (2023). Biostimulant effect of chitosan and phenolic extracts on the phenological development of the halophyte *Salicornia bigelovii* (Torr.). *Journal of the Saudi Society of Agricultural Sciences*, 228, 584–590. https://doi.org/10.1016/j.jssas.2023.08.001

Corona, G., et al. (2023). Seafood consumption and health: Benefits and risks. *Nutrients*, 15(2), 350. https://doi.org/10.3390/nu15020350

di Stefano, G., Peteraf, M., & Veronay, G. (2010). Dynamic capabilities deconstructed: A bibliographic investigation into the origins, development, and future directions of the research domain. *Industrial and Corporate Change*, 19(4), 1187–1204. https://doi.org/10.1093/icc/dtq027

Fahimnia, B., Sarkis, J., & Davarzani, H. (2015). Green supply chain management: A review and bibliometric analysis. *International Journal of Production Economics*, 162, 101–114. https://doi.org/10.1016/j.ijpe.2015.01.003

Franco, C., et al. (2021). Antioxidant properties of marine protein hydrolysates. *Food Research International*, 144, 110348. https://doi.org/10.1016/j.foodres.2021.110348

Franco, R., Casanovas, B., Camps, J., Navarro, G., & Martínez-Pinilla, E. (2021). Antioxidant supplements versus health benefits of brief/intermittent exposure to potentially toxic physical or chemical agents. *Current Issues in Molecular Biology*, 43(2), 650-664. https://doi.org/10.3390/cimb43020047

Gautam, R. K., Kakatkar, A. S., Mishra, P. K., Kumar, V., & Chatterjee, S. (2022). Marine peptides: Potential applications as natural antioxidants. In Kim, S. K., Kyung-Hoon Shin K.H., & Venkatesan, J. (Eds.). *Marine Antioxidants: Preparations, Syntheses, and Applications* (pp. 395–408). Elsevier. https://doi.org/10.1016/B978-0-323-95086-2.00028-X

Ghosh, S., Sarkar, T., Pati, S., Kari, Z. A., Edinur, H. A., & Chakraborty, R. (2022). Novel bioactive compounds from marine sources as a tool for functional food development. *Frontiers in Marine Science*, 9. https://doi.org/10.3389/fmars.2022.832957

Gil-Cardoso, K., Del Bas, J. M., Caimari, A., Lama, C., Torres, S., Mantecón, L., & Infante, C. (2022). TetraSOD®, a unique marine microalgae ingredient, promotes an antioxidant and anti-inflammatory status in a metabolic syndrome-induced model in rats. *Nutrients*, 14(19), 4028. https://doi.org/10.3390/nu14194028

Gil-Cardoso, K., et al. (2022). Bioactive peptides and oxidative stress modulation. *Antioxidants*, 11(4), 760. https://doi.org/10.3390/antiox11040760

Gu, D., Li, T., Wang, X., Yang, X., & Yu, Z. (2019). Visualizing the intellectual structure and evolution of electronic health and telemedicine research. *International Journal of Medical Informatics*, 130. https://doi.org/10.1016/j.ijmedinf.2019.08.007

Guan, D., Reiner, D. M., & Liu, Z. (2014). China's road to a global scientific powerhouse (Cambridge Working Papers in Economics 1447). Faculty of Economics, University of Cambridge.

Halim, N. R. A., Yusof, H. M., & Sarbon, N. M. (2016). Functional and bioactive properties of fish protein hydolysates and peptides: A comprehensive review. *Trends in Food Science and Technology*, 51, 24–33. https://doi.org/10.1016/j.tifs.2016.02.007

Henaux, L., et al. (2021). Anti-diabetic and anti-inflammatory peptides from salmon hydrolysates. *Journal of Functional Foods*, 79, 104399. https://doi.org/10.1016/j.jff.2021.104399

Henaux, L., Pereira, K. D., Thibodeau, J., Pilon, G., Gill, T., Marette, A., & Bazinet, L. (2021). Glucoregulatory and anti-inflammatory activities of peptide fractions separated by electrodialysis with ultrafiltration membranes from salmon protein hydrolysate and identification of four novel glucoregulatory peptides. *Membranes*, 11(7), 1–16. https://doi.org/10.3390/membranes11070528

Ishak, N. H., Sarbon, N. M., & Bakar, J. (2021). ACE inhibitory peptides from *Decapterus macrosoma* protein hydrolysate. *Food Chemistry*, 344, 128689. https://doi.org/10.1016/j.foodchem.2020.128689

Ishak, N. H., Shaik, M. I., Yellapu, N. K., Howell, N. K., & Sarbon, N. M. (2021). Purification, characterization and molecular docking study of angiotensin-I converting enzyme (ACE) inhibitory peptide from shortfin scad (*Decapterus macrosoma*) protein hydrolysate. *Journal of Food Science and Technology*, 58(12), 4567–4577. https://doi.org/10.1007/s13197-020-04944-y

Jogpal, V., et al. (2022). Bioactive peptides and inflammation. *Critical Reviews in Food Science and Nutrition*, 62(12), 3198–3215. https://doi.org/10.1080/10408398.2020.1864167

Jogpal, V., Sanduja, M., Dutt, R., Garg, V., & Tinku. (2022). Advancement of nanomedicines in chronic inflammatory disorders. *Inflammopharmacology*, 30, 355–368. https://doi.org/10.1007/s10787-022-00927-x

Kerner, G., Neehus, A. L., Philippot, Q., Bohlen, J., Rinchai, D., Kerrouche, N., Puel, A., Zhang, S. Y., Boisson-Dupuis, S., Abel, L., Casanova, J. L., Patin, E., Laval, G., & Quintana-Murci, L. (2023). Genetic adaptation to pathogens and increased risk of inflammatory disorders in post-Neolithic Europe. *Cell Genomics*, 3. https://doi.org/10.1016/j.xgen.2022.100248

Kerner, J., et al. (2023). Anti-inflammatory potential of food-derived peptides. *Nutrients*, 15(6), 1452. https://doi.org/10.3390/nu15061452

Khiste, G. P., & Paithankar, R. R. (2017). Analysis of Bibliometric term in Scopus. *International Research Journal*, 01(32), 78–83.

Kimball, J. S., Johnson, J. P., & Carlson, D. A. (2021). Oxidative Stress and Osteoporosis. *The Journal of Bone and Joint Surgery*, 103(15), 1451-1461. https://doi.org/10.2106/JBJS.20.00989

Kimball, S. R., et al. (2021). Dietary peptides and oxidative stress. *Journal of Nutrition*, 151(3), 567–575. https://doi.org/10.1093/jn/nxaa385

Kumar, M., Tomar, M., Punia, S., Dhakane-Lad, J., Dhumal, S., Changan, S., Senapathy, M., Berwal, M. K., Sampathrajan, V., Sayed, A. A. S., Chandran, D., Pandiselvam, R., Rais, N., Mahato, D. K., Udikeri, S. S., Satankar, V., Anitha, T., Singh, S., Amarowicz, R., & Kennedy, J. F. (2022). Plant-based proteins and their multifaceted industrial applications. *LWT*, 154. https://doi.org/10.1016/j.lwt.2021.112620

Lemos, M. F. L., & Dantas, R. F. (2023). Nutritional and functional roles of seafood proteins. *Food Reviews International*. Advance online publication. https://doi.org/10.1080/87559129.2023

Lemos, M. S., & Dantas, K. G. F. (2023). Evaluation of the use of diluted formic acid in sample preparation for elemental determination in crustacean samples by MIP OES. *Biological Trace Element Research*, 201, 3513–3519. https://doi.org/10.1007/s12011-022-03409-x

Li, X., Xie, X., Wang, J., Xu, Y., Yi, S., Zhu, W., Mi, H., Li, T., & Li, J. (2020). Identification, taste characteristics and molecular docking study of novel umami peptides derived from the aqueous extract of the clam *meretrix meretrix* Linnaeus. *Food Chemistry*, 312. https://doi.org/10.1016/j.foodchem.2019.126053

Navarro-Peraza, R. S., Osuna-Ruiz, I., Lugo-Sánchez, M. E., Pacheco-Aguilar, R., Ramírez-Suárez, J. C., Burgos-Hernández, A., Martínez-Montaño, E., & Salazar-Leyva, J. A. (2020). Structural and biological properties of protein hydrolysates from seafood by-products: A review focused on fishery effluents. *Food Science and Technology (Brazil)*, 40, 1–5. https://doi.org/10.1590/fst.24719

Nikoo, M. (2021). Effective valorization of aquaculture by-products: Bioactive peptides and their application in aquafeed. In Bhat (Ed.). *Valorization of Agri-Food Wastes and By-Products: Recent Trends, Innovations and Sustainability Challenges* (pp. 579–590). Elsevier. https://doi.org/10.1016/B978-0-12-824044-1.00034-9

Portero, C. E., et al. (2022). Seafood proteins as functional ingredients. *Trends in Food Science & Technology*, 119, 34–45. https://doi.org/10.1016/j.tifs.2021.12.012

Portero, R., Cueto, M., Fernández-Gómez, M. J., & Álvarez-Fernández, E. (2022). Surf and turf. Animal resources in the human diet in Cantabrian Spain during the Mesolithic (11.5 – 7.5 Ky cal. BP). *Journal of Archaeological Science: Reports*, 45, 103635. https://doi.org/10.1016/j.jasrep.2022.103635

Rauf, A., Imran, M., & Abu-Izneid, T. (2022). Probing the therapeutic potential of marine bioactive peptides. *International Journal of Molecular Sciences*, 23(3), 1216. https://doi.org/10.3390/ijms23031216

Rauf, A., Khalil, A. A., Khan, M., Anwar, S., Alamri, A., Alqarni, A. M., Alghamdi, A., Alshammari, F., Rengasamy, K. R. R., & Wan, C. (2022). Can be marine bioactive peptides (MBAs) lead the future of foodomics for human health? In *Critical Reviews in Food Science and Nutrition*, 62(25), 7072–7116. https://doi.org/10.1080/10408398.2021.1910482

Sarabandi, K., & Jafari, S. M. (2020). Effect of chitosan coating on the properties of nanoliposomes loaded with flaxseed-peptide fractions: Stability during spray-drying. *Food Chemistry*, 310. https://doi.org/10.1016/j.foodchem.2019.125951

Siddiqui, S. A., Lakshmikanth, D., Pradhan, C., Farajinejad, Z., Castro-Muñoz, R., & Sasidharan, A. (2023). Implementing fermentation technology for comprehensive valorisation of seafood processing by-products: A critical review on recovering valuable nutrients and enhancing utilisation. *Critical Reviews in Food Science and Nutrition*, 65(5), 964–991. https://doi.org/10.1080/10408398.2023.2286623

St. Louis, T. J., & Pedroza Filho, M. X. (2021). An investigation of scientific research and patent output of major aquaculture producers and their impact on the economic growth (2001-2016): A scientometric evaluation. *Cadernos de Ciência & Tecnologia*, 38(3), e26920. https://doi.org/10.35977/0104-1096.cct2021.v38.26920

Tang, X., & Du, J. (2016). The performance of China's biomedical innovation: A scientometric analysis. *Science China Life Sciences*, 59(10), 1074–1082. https://doi.org/10.1007/s11427-016-5078-6

Ucak, I., Afreen, M., Montesano, D., Carrillo, C., & Tomasevic, I. (2021). Functional and bioactive properties of protein hydrolysates from marine processing by-products. *Food Chemistry*, 364, 130447. https://doi.org/10.1016/j.foodchem.2021.130447

Ucak, I., Afreen, M., Montesano, D., Carrillo, C., Tomasevic, I., Simal-Gandara, J., & Barba, F. J. (2021). Functional and bioactive properties of peptides derived from marine side streams. *Marine Drugs*, 19(2), 71. https://doi.org/10.3390/MD19020071

Van Eck, N. J., & Waltman, L. (2007). Bibliometric mapping of the computational intelligence field. *International Journal of Uncertainty, Fuzziness and Knowldege-Based Systems*, 15(5), 625–645. https://doi.org/10.1142/S0218488507004911

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

van Eck, N. J., & Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics*, 111(2), 1053–1070. https://doi.org/10.1007/s11192-017-2300-7

Venkatesan, J., Anil, S., Kim, S. K., & Shim, M. S. (2017). Marine fish proteins and peptides for cosmeceuticals: A review. *Marine Drugs*, 15(5), 1–18. https://doi.org/10.3390/md15050143

Verbeek, A., Debackere, K., Luwel, M., & Zimmermann, E. (2002). Measuring progress and evolution in science and technology - I: The multiple uses of bibliometric indicators. *International Journal of Management Reviews*, 4(2), 179–211. https://doi.org/10.1111/1468-2370.00083

Wagner, C. S., Park, H. W., & Leydesdorff, L. (2015). The continuing growth of global cooperation networks in research: A conundrum for national governments. PLoS ONE, 10(7), e0131816. https://doi.org/10.1371/journal.pone.013181

Wang, L., Ma, M., Yu, Z., & Du, S.-K. (2021). Preparation and identification of antioxidant peptides from cottonseed proteins. *Food Chemistry*, 352. https://doi.org/10.1016/j.foodchem.2021.129399

Wei, J., Tao, G., Xu, B., Wang, K., Liu, J., Chen, C. H., Dunn, J. C. Y., Currie, C., Framroze, B., & Sylvester, K. G. (2022). Soluble protein hydrolysate ameliorates gastrointestinal inflammation and injury in 2,4,6-trinitrobenzene sulfonic acid-induced colitis in mice. *Biomolecules*, 12(9). https://doi.org/10.3390/biom12091287

Wei, Y., Zhao, X., & Liu, Y. (2022). Salmon protein hydrolysate alleviates colitis in mice. Nutrients, 14(9), 1893. https://doi.org/10.3390/nu14091893

Wen, C., Zhang, J., Feng, Y., Duan, Y., Ma, H., & Zhang, H. (2020). Purification and identification of novel antioxidant peptides from watermelon seed protein hydrolysates and their cytoprotective effects on H2O2-induced oxidative stress. *Food Chemistry*, 327. https://doi.org/10.1016/j.foodchem.2020.127059

Wu, Q., Luo, F., Wang, X. L., Lin, Q., & Liu, G. Q. (2022). Angiotensin I-converting enzyme inhibitory peptide: an emerging candidate for vascular dysfunction therapy. In *Critical Reviews in Biotechnology*. https://doi.org/10.1080/07388551.2021.1948816

Wu, R., Wu, C., Liu, D., Yang, X., Huang, J., Zhang, J., & Liao, B. (2022). Overview of bioactive peptides derived from marine organisms. Marine Drugs, 20(2), 112. https://doi.org/10.3390/md20020112

Wu, S., Yang, J., Dong, H., Liu, Q., Li, X., Zeng, X., & Bai, W. (2021). Key aroma compounds of Chinese dry-cured Spanish mackerel (*Scomberomorus niphonius*) and their potential metabolic mechanisms. *Food Chemistry*, 342. https://doi.org/10.1016/j.foodchem.2020.128381

Wu, Y. C. J., & Wu, T. (2017). A decade of entrepreneurship education in the Asia Pacific for future directions in theory and practice. *Management Decision*, 55(7), 1333–1350. https://doi.org/10.1108/MD-05-2017-0518

Xin, Q., Yuan, R., Shi, W., Zhu, Z., Wang, Y., & Cong, W. (2019). A review for the anti-inflammatory effects of paeoniflorin in inflammatory disorders. *Life Sciences*, 237, 116925. https://doi.org/10.1016/j.lfs.2019.116925

Xin, Y., Zhang, Y., & Adhikari, B. (2019). Anti-inflammatory bioactive peptides derived from food proteins. *Food & Function*, 10(5), 2804–2816. https://doi.org/10.1039/C9FO00244A

Xu, J., Jiang, S., Liu, L., Zhao, Y., & Zeng, M. (2021). Encapsulation of oyster protein hydrolysates in nanoliposomes: Vesicle characteristics, storage stability, in vitro release, and gastrointestinal digestion. *Journal of Food Science*, 86(3), 960–968. https://doi.org/10.1111/1750-3841.15606

Xu, Z., Wu, C., Sun-Waterhouse, D., Zhao, T., Waterhouse, G. I. N., Zhao, M., & Su, G. (2021). Identification of post-digestion angiotensin-I converting enzyme (ACE) inhibitory peptides from soybean protein Isolate: Their production conditions and in silico molecular docking with ACE. *Food Chemistry*, 345. https://doi.org/10.1016/j.foodchem.2020.128855

Yang, Y., Wang, W., & Liu, Y. (2020). Umami and bitterness profile of enzymatic protein hydrolysates from cultured *Takifugu obscurus* by-products. *Journal of Food Measurement and Characterization*, 14(1), 476–484. https://doi.org/10.1007/s11694-019-00118-3

Zamorano-Apodaca, J. C., García-Sifuentes, C. O., Carvajal-Millán, E., Vallejo-Galland, B., Scheuren-Acevedo, S. M., & Lugo-Sánchez, M. E. (2020). Biological and functional properties of peptide fractions obtained from collagen hydrolysate derived from mixed by-products of different fish species. *Food Chemistry*, 331. https://doi.org/10.1016/j.foodchem.2020.127350

Zhang, X., Liang, Z., Pei, J., Cao, Y., Chen, N., Liu, H., & Zhao, Q. (2023). Preparation of umami enzymatic hydrolysate from squid processing by-products by stepwise dual-enzymatic hydrolysis. *Food and Fermentation Industries*, 49(15), 201–207. https://doi.org/10.13995/j.cnki.11-1802/ts.033502

Zhang, Y., He, S., Bonneil, É., & Simpson, B. K. (2020). Generation of antioxidative peptides from Atlantic sea cucumber using alcalase versus trypsin: *In vitro* activity, *de novo* sequencing, and *in silico* docking for *in vivo* function prediction. *Food Chemistry*, 306. https://doi.org/10.1016/j.foodchem.2019.125581

Zhou, J., Wang, M., & Li, Y. (2023). Advances in seafood-derived bioactive peptides: Preparation and applications. *Food Bioscience*, 52, 102384. https://doi.org/10.1016/j.fbio.2023.102384

Zhou, L., Mendez, R. L., & Kwon, J. Y. (2023). *In silico* prospecting for novel bioactive peptides from seafoods: A case study on pacific oyster (*Crassostrea gigas*). *Molecules*, 28(2), 651. https://doi.org/10.3390/molecules28020651