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Mapping research trends and collaboration networks in extrusion cooking: A PRISMA-based Bibliometric analysis of Indian publications (2023-2026)

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Abstract

This study aims to provide a systematic and bibliometric overview of the research on extrusion cooking in India, covering the period between 2023 and 2026, using publications listed in the Scopus database. Out of the selected publications, 64 were retrieved after applying the PRISMA protocol for selecting publications. This study used various methods of bibliometric analysis, such as co-authorship, co-citation, and keyword co-occurrence, using the VOSviewer software. The results show that there has been an increased interest in conducting research on extrusion cooking, especially on functional foods, millets, and nutritional enhancement. The results show that there are prominent researchers, institutions, and collaborations in the field of extrusion cooking in India, as well as international collaborations. The results also show that there is an increased interest in health-oriented food products and sustainable processing technologies.

Keywords: Extrusion cooking, Bibliometric analysis, PRISMA, functional foods, research trends

1. Introduction

Extrusion cooking is an important food processing technology used for the production of various food products such as ready-to-eat (RTE) snack food, breakfast cereals, texturized vegetable proteins, and functional food products. It is a high-temperature short-time (HTST) food process by which several food processes such as mixing, cooking, kneading, and shaping are integrated into a single process. This makes extrusion cooking a highly efficient and cost-effective food process^[1, 2]. One of the important advantages of extrusion cooking is the ability to improve the physicochemical, structural, and nutritional properties of food materials such as starch gelatinization, protein denaturation, and reduction of ant nutritional factors^[3, 4]. In addition to this, the extrusion cooking process is known for producing minimal waste, energy efficiency, and the ability to process a wide variety of food materials^[5].

In recent times, the extrusion cooking process has received considerable importance in the food industry of India with respect to the utilization of underutilized food resources such as millets, pulses, and native food grains, which are rich in bioactive compounds and essential nutrients^[6, 7]. The recent emphasis on functional food products, nutritional security, and sustainable food systems has created a thrust for research in this area. The extrusion cooking process has been explored as a potential food technology for the development of value-added food products with improved digestibility, nutrient bioavailability, and desirable food attributes^[8]. In addition to this, with the recent emphasis on sustainable food processing and development of climate-resilient food crops, the extrusion cooking process provides an excellent opportunity to transform underutilized food resources into nutritionally enriched food products.

The surge in scientific publications demands the need to apply quantitative approaches to understand the trends, intellectual structures, and collaborative networks of a particular domain of research. Bibliometric analysis has become a powerful approach to understand the scientific knowledge landscape, helping to evaluate publication trends, citation impact, and research themes^[9, 10]. It helps to understand the evolution of a research domain by identifying key authors, institutions, and countries contributing to the development of the research field. It helps to uncover emerging trends and research gaps.

The integration of bibliometric analysis with the PRISMA framework helps to establish methodological rigor, transparency, and reproducibility of the literature selection process^[11].

Despite the surge in extrusion cooking research, very few studies have explored the research landscape of extrusion cooking in the Indian scenario by applying an integrated approach of bibliometric analysis and network visualization. Most of the studies are focused on global trends and applications of extrusion cooking, with less emphasis on country-specific research landscapes. Therefore, the aim of this study is to visualize the research trends, key contributors, and collaborative networks of extrusion cooking research in the Indian scenario from 2023 to 2026 by applying the PRISMA-based bibliometric approach. The findings of the study are expected to provide valuable insights into the evolution of the research field.

2. Methodology

The data for this study were retrieved from the Scopus database, one of the most comprehensive and widely recognized indexing platforms for peer-reviewed scientific literature, using the following search query: (TITLE-ABS-KEY("Extrusion cooking") AND PUBYEAR > 2022 AND PUBYEAR < 2027 AND (LIMIT-TO(SUBJAREA, "AGRI") OR LIMIT-TO(SUBJAREA, "ENGI") OR LIMIT-TO(SUBJAREA, "CHEM") OR LIMIT-TO(SUBJAREA, "CENG")) AND (LIMIT-TO(DOCTYPE, "ar") OR LIMIT-TO(DOCTYPE, "re") OR LIMIT-TO(DOCTYPE, "ch")) AND LIMIT-TO(LANGUAGE, "English") AND LIMIT-TO(AFFILCOUNTRY, "India")). This search strategy was designed to ensure comprehensive coverage of extrusion cooking research within relevant subject domains while maintaining consistency in document type and language^[12]. The search yielded a total of 64 records. A PRISMA (Preferred Reporting Items for

Systematic Reviews and Meta-Analyses) framework was adopted to ensure a systematic, transparent, and reproducible selection process^[11]. Duplicate records were first identified and removed, followed by title and abstract screening to exclude studies not directly relevant to extrusion cooking or food processing applications. After this initial screening, 46 records were retained for full-text eligibility assessment. Subsequently, studies that did not meet the inclusion criteria, such as those lacking sufficient methodological detail, relevance, or focus on extrusion-based systems, were excluded, resulting in a final dataset of 34 studies for bibliometric analysis.

The bibliometric method was carried out using VOSviewer software, which allows for the construction and visualization of bibliometric networks^[13, 14]. Various methods were used in the analysis for the extraction of various facets of the research field. Co-authorship was used as a method for analyzing collaboration in the field, as well as identifying key individuals and institutions. Co-citation was used as a method for identifying the intellectual structure of the field, which comprises key individuals and publications that make up the body of knowledge in the field of extrusion cooking. On the other hand, keyword co-occurrence was used as a method for identifying key research areas, as well as identifying new areas of research in the field. Finally, bibliographic coupling was used as a method for analyzing the similarities in publications, which enables the identification of clusters of related publications^[15]. Network visualization was used for mapping the relationships between individuals, keywords, and publications, in which the size of the node represents the importance of the publication, as well as the strength of the connection between individuals or publications. This method enables a comprehensive understanding of the research trends in the field^[10].

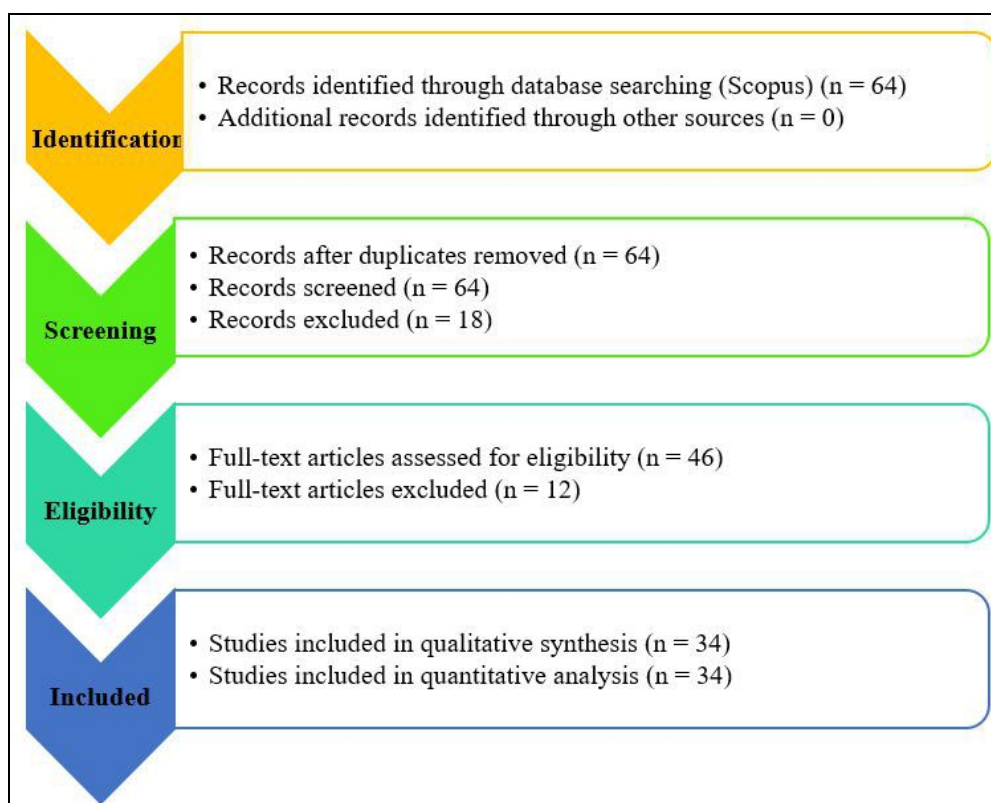


Fig 1: PRISMA flow diagram for the Scopus search TITLE-ABS-KEY ("Extrusion cooking")

3. Results and Discussion

3.1 Publication Trends

The annual trend of publications also reveals that the interest in extrusion cooking research in India increased from 2023 to 2025 and then decreased in 2026. The publications increased from 10 in 2023 to 17 in 2024 and reached the peak of 29 in 2025. This significant increase in publications over such a short period of time suggests that there is increased interest in extrusion cooking technology in India due to the emerging need to develop functional foods, ready-to-eat products, and sustainable extrusion cooking technologies.

The increased trend in extrusion cooking research from 2023 to 2025 may also be related to the increased funding support and the development of millet-based products by the Government of India by declaring the year 2023 as the 'International Year of Millets' and the increased awareness of nutritional security in India.

The increased publications in the year 2025 also suggest that this was the peak of extrusion cooking research in India over the past few years, which could be related to the culmination of ongoing research projects initiated over the past few years. The availability of extrusion cooking technology and the development of innovative extrusion cooking techniques by incorporating the concepts of food science, technology, and engineering could also be the reason behind the increased publications.

However, the decreased trend in extrusion cooking publications in the year 2026, with only 8 publications, should be viewed with caution as this could not be related to the decreased interest in extrusion cooking technology in

India. It is likely that the publications indexed in the Scopus database may not have increased in the recent past due to the lag in the indexing of the articles published in the recent past.

Similar trends have also been reported by other researchers in the context of the analysis of publications using the Scopus database, where the publications reported in the recent past are less than the publications reported in the previous years due to the lag in the updation of the Scopus database^[10].

With respect to the nature of the document, journal articles dominate the publications, followed by review articles and book chapters. This also reflects the preference towards publication in peer-reviewed journals to achieve greater visibility and credibility. The inclusion of review articles also reflects the consolidation of the research domain, where existing knowledge is being used to identify the gaps in the area of research.

Overall, the trend in publications reflects the rapidly changing scenario in the area of research related to extrusion cooking in India, characterized by increased output, diversification of the area of research, and its growing relevance to the academic and industrial community. The trend in publications is in line with the global scenario related to the development of the area of food processing technology, as extrusion technology is gaining importance due to its efficiency and the possibility of developing nutritious foods.

The trend in the annual publications is depicted in Figure 2, which clearly reflects the trend and the variation in the output of the research over the years.

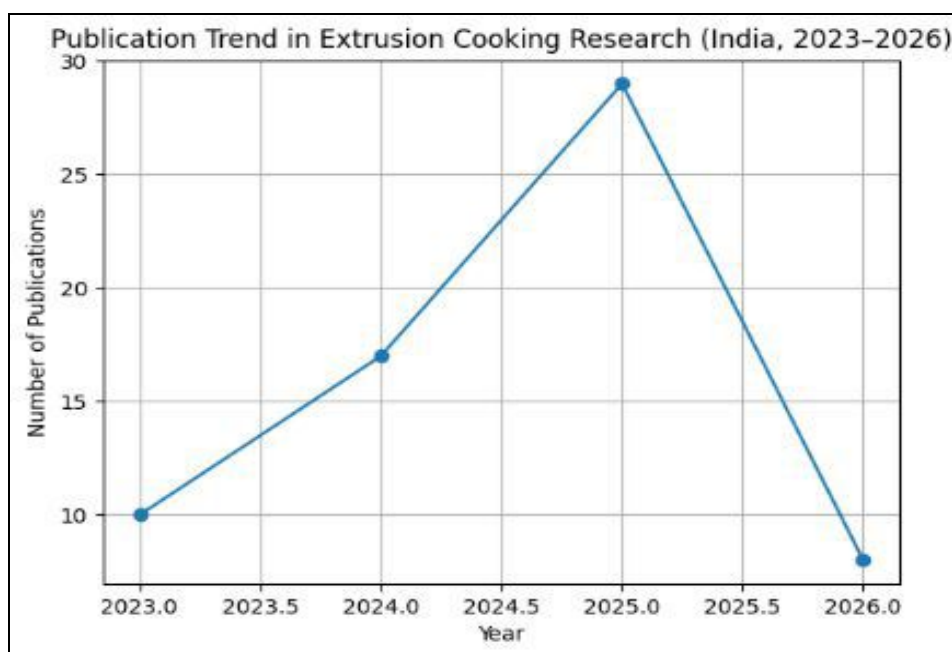


Fig 2: Annual publication trends in extrusion cooking research in India (2023-2026)

3.2 Co-authorship Analysis

From the co-authorship network, it is clear that there are several collaborative clusters, implying that there are several research groups that are actively involved in research activities and contributing to the field of extrusion cooking in India. Some of the prominent authors, such as Manzoor (2023), Sunil (2024), and Vissamsetti (2024), have also been identified as key nodes with higher link strength and larger node sizes. This implies that these authors have

contributed significantly to research and have also been highly collaborative. The visualization of the network also shows that collaboration has mainly been limited to specific research groups or institutions, resulting in isolated clusters. This implies that although collaboration has been strong within these specific research groups or institutions, collaboration across these institutions or nationwide has been limited. This could be a hindrance for research and could also hinder the adoption of diverse research ideas and

multidisciplinary approaches. This kind of collaboration has also been identified in other research domains, where research networks have been reported to be affected by geographical proximity, institutional factors, and availability of funds^[13].

From the network, it is also clear that young and early-stage researchers have been identified as being part of research groups and collaborating with other prominent authors. This

kind of hierarchical collaboration has also been identified as common in research networks and has played an important role in research. However, from the network, it is also clear that there has been limited international co-authorship, implying that research collaboration at the international level is still evolving. This could be beneficial for research and could also help in enhancing research visibility and access to advanced technologies.

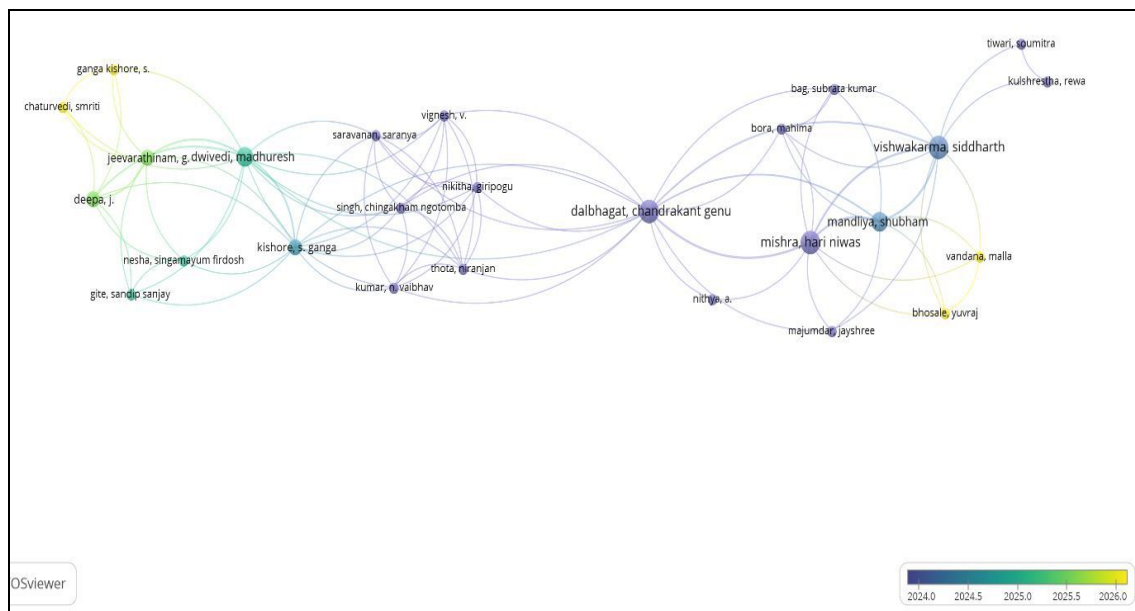


Fig 3: Co-authorship network of authors in extrusion cooking research generated using VOSviewer

The co-authorship also echoes the findings of the research done on extrusion cooking, as it consists of a mix of food science, agricultural engineering, and nutrition. However, even as the network reveals the interdisciplinary of the research, it also reveals that the integration of the disciplines has not yet reached the desired level. More emphasis needs to be put on interdisciplinary in order to bridge the gaps.

To recap, the co-authorship network reveals the positives and negatives of the present research scenario. There are positives in the local clusters, but much scope remains to be explored in the cross-institutional, cross-discipline, and cross-national dimensions in order to build an even better research environment as a whole. Figure 3 reveals the co-authorship network, including the clusters, the nodes, the connections, and the collaborative links in the field of extrusion cooking.

3.3 Co-citation Analysis

Co-citation analysis is instrumental in offering valuable insights regarding the intellectual base of extrusion cooking as a discipline by highlighting the key authors and publications that are more frequently co-cited and which cumulatively contribute to the knowledge base of the discipline. The key nodes in the network diagram represent the more frequently co-cited publications that cumulatively contribute to the knowledge base of the discipline. These publications are likely to be the key publications related to

the mechanisms of extrusion cooking processes, physicochemical changes in food materials, and the development of more functional and nutritious food products.

The clusters of co-cited publications indicate the presence of different but related domains of knowledge within the discipline of extrusion cooking. The major clusters can be related to the domains of knowledge such as process optimization, food chemistry and structural changes, and nutritional enhancement and development of more functional foods. The significant inter-links between the clusters indicate the multidisciplinary nature of the discipline of extrusion cooking, which integrates the principles of chemical engineering with the principles of food science and nutrition.

The density of the co-citation network also suggests the relatively well-developed nature of the knowledge base of the discipline of extrusion cooking. The presence of clusters within the network suggests the relatively consistent nature of the discipline with the majority of the researchers relying on the same set of publications as the knowledge base of the discipline. The relatively newer nodes that are more closely related to the established clusters suggest the relatively newer trends in the discipline of extrusion cooking, particularly with regards to the development of more nutritious and healthier foods by retaining bioactive compounds with antioxidant properties.

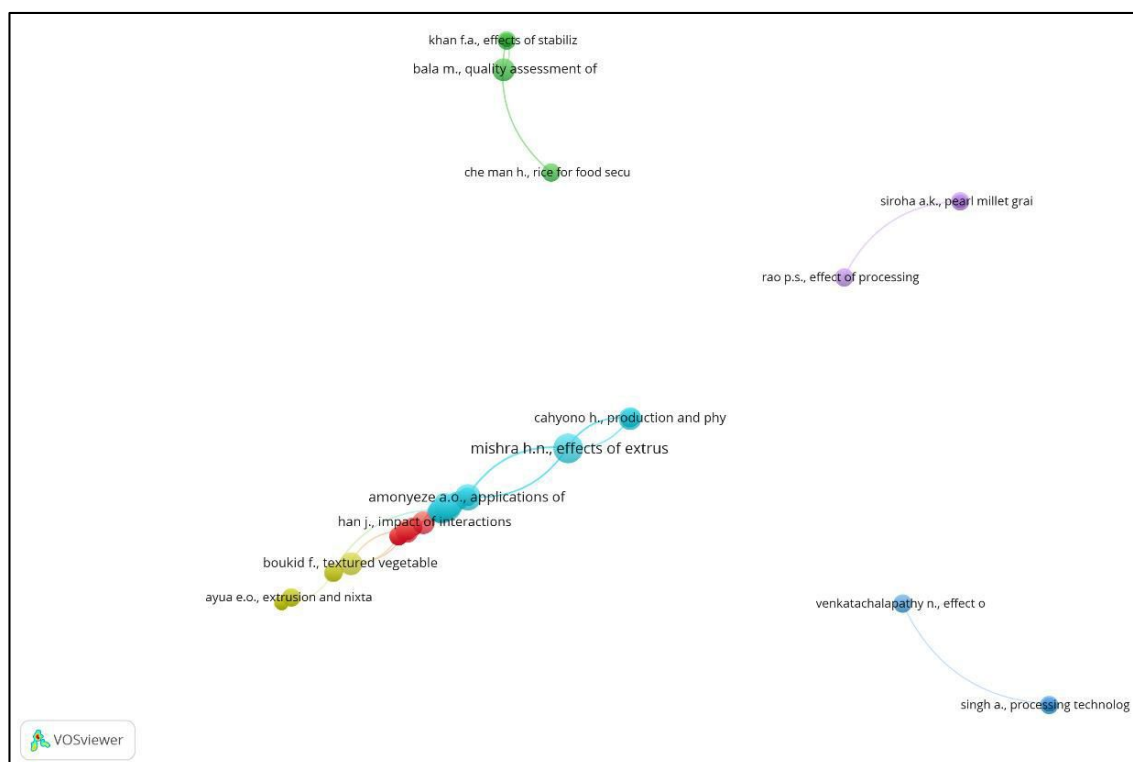


Figure 3. Co-citation network showing the intellectual structure of extrusion cooking research

From a knowledge evolution point of view, co-citation analysis reveals that there has been a shift in research focus from basic studies on extrusion technology and materials to more application-based studies on functional foods and sustainable processing. The shift is a reflection of the growing importance of extrusion cooking in meeting the challenges of nutritional security and value addition to agricultural commodities. As cited, "the intellectual backbone of a research field is largely constituted by frequently co-cited publications." The study findings validate that a sound and well-developed theoretical framework backs indeed extrusion cooking research^[16].

Thus, co-citation analysis has been able to highlight the maturity and coherence of extrusion cooking research in India, besides bringing out new areas that are broadening the intellectual boundaries of extrusion cooking research. The co-citation network visualization is shown in Figure 4, which illustrates the relationships between prominent

authors and documents, as well as prominent research themes.

3.4 Bibliographic Coupling

3.4 Bibliographic Coupling

Analysis of bibliographic coupling is used to study the interrelation of documents with respect to the number of shared references, hence showing similarity in the focus of research as well as the thematic consistency of various studies published at a particular time. Unlike co-citation analysis, which shows the historical intellectual base of a particular field of study, bibliographic coupling shows the current research front, hence very useful in showing emerging trends in the field of study [15]. In the current study, the bibliographic coupling network has shown well-defined clusters, hence showing that the recent publications in the field of extrusion cooking research are centered around closely related thematic domains.

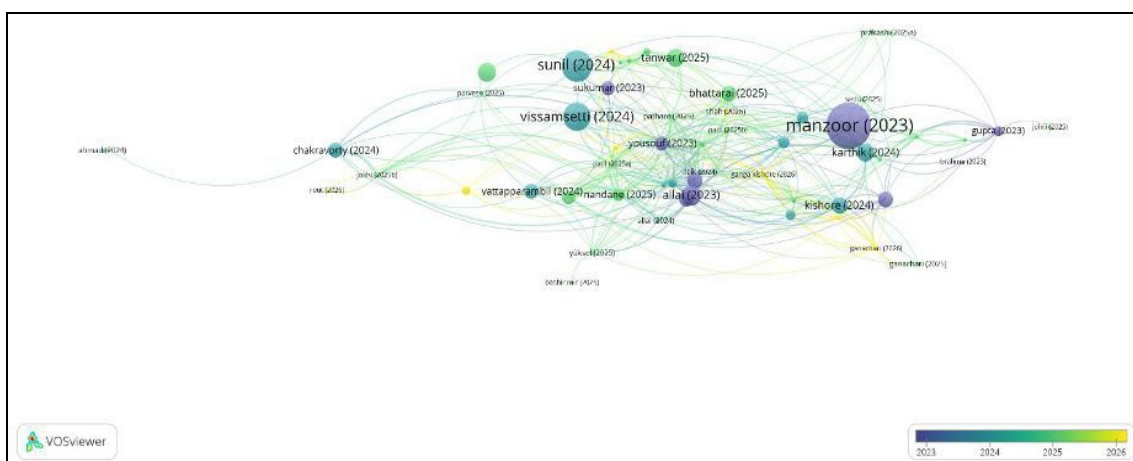


Fig 4: Bibliographic coupling network illustrating relationships among publications based on shared references

The existence of strong coupling clusters indicates that a substantial portion of literature is focused on key research themes, including functional food product development, optimization of extrusion process parameters, and improvement of nutritional and physicochemical properties. The strong coupling clusters also indicate an increased trend towards enhancing product quality properties such as texture, expansion ratio, water absorption index, and sensory acceptability, as these properties play an important role in the acceptability of extruded products by consumers. Furthermore, a substantial portion of literature has also focused on incorporating bioactive compounds, dietary fiber, and protein-rich ingredients, indicating an increased trend towards nutritionally enriched and health-promoting food products.

The network also indicates that each of these strong coupling clusters is highly interconnected, indicating that research is being conducted based on common literature and methodologies. This is also an indication of converging research interests towards common objectives, including the development of value-added food products through extrusion technology. However, the existence of several strong coupling clusters with different levels of interconnectedness also indicates that research is being conducted in parallel streams, including process optimization, functionality of ingredients, and application-oriented research.

In addition, analysis using bibliographic coupling shows that recent studies are becoming more interdisciplinary, with more emphasis on integrating food science, agricultural engineering, and nutrition concepts. The bibliographic coupling analysis also shows that recent studies on millet-based crops and underutilized crops, with emphasis on extrusion as a means of improving nutritional content, are more interdisciplinary. The overall pattern also shows that there is a shift from experimental-based studies to more application-based studies that focus on food security, sustainability, and health benefits.

Overall, the results of the bibliographic coupling analysis point to a dynamic and changing research landscape with a strong thematic convergence and application-based studies. The analysis has confirmed that extrusion cooking research in India is shifting towards innovation-driven studies that focus on developing sustainable, nutritious, and acceptable food products. The bibliographic coupling network is shown in Figure 5, with the figure showing relationships between publications based on shared references as well as highlighting thematic clusters in the research area.

3.5 Keyword Co-occurrence Analysis

Keyword co-occurrence analysis enables an overall understanding of prominent research themes and new research trends in the field of extrusion cooking research through an examination of author keywords and their co-occurrence. The resulting network shows several distinct and well-defined clusters, each representing a specific area of research. The prominent occurrence of keywords such as “extrusion,” “nutrition,” “functional food,” “millets,” and “antioxidants” indicates an increased and consistent research

interest in health-oriented food product development. The high frequency and prominence of these keywords suggest that these form an essential part of current research activities and are highly interconnected.

The prominence of “millets” as an essential keyword also indicates an increased research interest in this area of research, particularly in the field of Indian food research. The increased research interest in millets is also consistent with national and global initiatives promoting millet-based foods due to their high fiber and nutrient content and their ability to thrive in harsh environmental conditions. The inclusion of millets as an essential part of value-added products using an extrusion cooking process represents an attempt to produce value-added, ready-to-eat products with enhanced nutritional benefits.

Besides the dominant themes, the analysis also reveals the existence of “emerging keywords” such as “food security,” “bioactive compounds,” “high temperature processing,” and “functional properties.” These keywords suggest the direction in which the research in the field of extrusion cooking may be moving, i.e., toward the understanding of the role that extrusion cooking plays in the preservation or improvement of bioactive compounds, improving the digestibility of foodstuffs, and optimizing the processing conditions to obtain the desired product characteristics. The rising frequency of these keywords may also suggest the shift in the focus of the research in the field of extrusion cooking from traditional process-oriented research to application-oriented research, addressing the needs of society in terms of malnutrition, health, and the environment.

The clustering pattern also reveals the interdisciplinary nature of the research in the field of extrusion cooking, as concepts in food science, nutrition, and engineering are found to be closely related in the field of extrusion cooking. Keywords dealing with the process parameters, i.e., temperature, moisture content, and screw speed, are found to be closely related to the keywords dealing with the quality of the product, i.e., texture, expansion, and antioxidant activity. Moreover, the density and connectivity of the keyword network suggest a mature yet evolving research field, where established themes continue to be explored while new topics are gradually emerging. The presence of tightly connected clusters indicates strong thematic cohesion, whereas the appearance of new and less connected keywords points to emerging research frontiers. Such patterns are consistent with bibliometric studies that emphasize the role of keyword analysis in identifying research trends and future directions^[10].

Overall, the keyword co-occurrence analysis reveals a clear shift toward functional, sustainable, and health-oriented food systems, with extrusion cooking playing a central role in enabling these advancements. The findings highlight the growing emphasis on developing nutrient-dense, shelf-stable, and consumer-acceptable food products using innovative processing approaches. The keyword co-occurrence network is illustrated in Figure 6, which depicts the major thematic clusters and emerging research topics within the field.

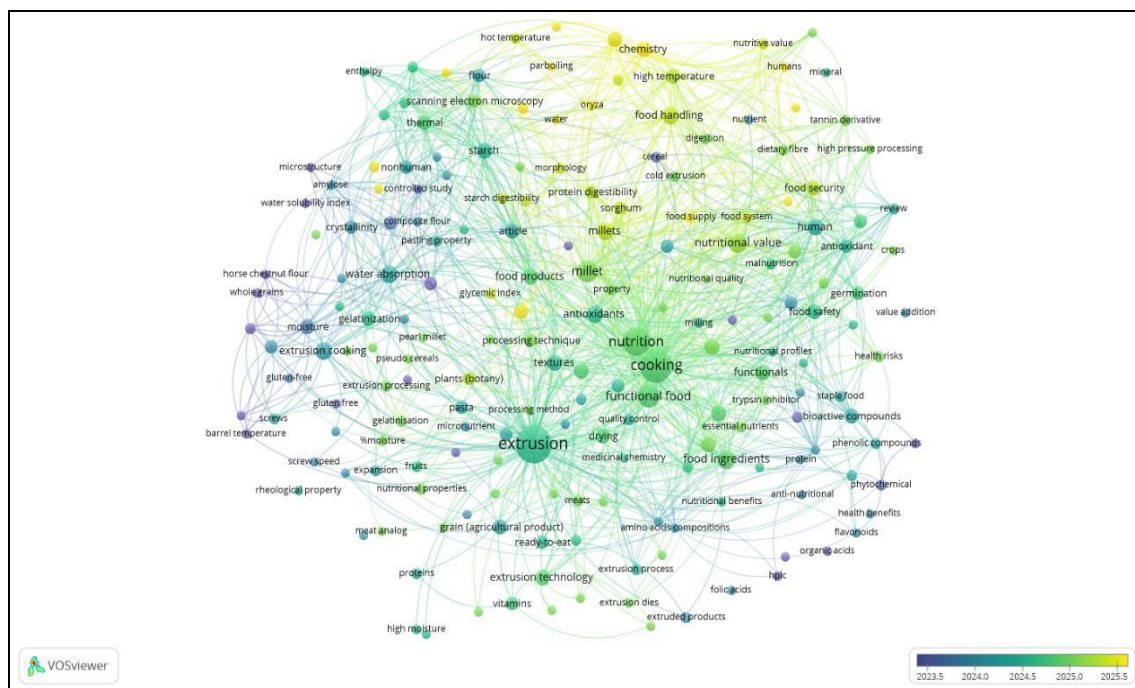


Fig 5: Keyword co-occurrence network showing major research themes and emerging topics.

3.6 Research Trends and Thematic Evolution

The thematic evolution of extrusion cooking research in India has shown a clear and progressive pattern from basic processing studies to application-oriented, interdisciplinary, and impact-driven research. In the initial period, research studies were more focused on understanding the basic aspects of extrusion processing, such as optimizing the extrusion process, equipment design, physicochemical transformations, starch gelatinization, protein denaturation, texture modification, etc. These studies laid a scientific foundation for controlling various extrusion parameters such as temperature, screw speed, feed moisture content, etc., which are critical in determining product quality and processing efficiency.

However, recent studies on extrusion processing in India have shown a clear shift toward the development of functional food products, which is more in tune with global food innovation research trends. The shift in research focus is strongly supported by the findings of the keyword co-occurrence analysis (Figure 5) and bibliographic coupling analysis (Figure 6), wherein prominent keywords such as "functional food," "bioactive compounds," "millets," etc., are more prominently associated with recent studies. The use of millets and other underutilized crops in extruded food products has been given significant importance due to their nutritional value, hardness, adaptability to changing climates, and contribution to sustainable agriculture. These crops are being increasingly promoted by national and international agencies as "climate-resilient crops" that contribute significantly to food and nutritional security.

The thematic evolution of extrusion processing research in India has also shown a clear shift toward nutritional enhancement and health aspects. Recent studies on extrusion processing have investigated the effects of extrusion on digestibility, glycemic index, retention of minerals, retention of bioactive compounds such as polyphenols, antioxidants, etc. These studies reflect a clear shift toward developing processed food products with specific health benefits, meeting consumer demand for functional food products that can provide health benefits. These studies reflect a clear

shift toward integrating food processing with nutritional science and health goals.

Furthermore, the concept of sustainability has also gained prominence as an important theme in recent extrusion cooking research. There has been an increased focus on the development of an energy-efficient processing technology that also minimizes the environmental impact, as well as the use of agro-industrial by-products and food wastes. The application of the extrusion technology for the development of value-added products from cheaper raw materials has also gained prominence in recent times, contributing to the concept of the circular economy in the food industry. This has also been indicated by the appearance of new keywords such as "food security," "sustainability," and "high temperature processing," which show the expansion of the research scope beyond the traditional boundaries of food processing.

The evolution of the themes in the recent past also shows an increased focus on interdisciplinary research, including the application of the principles of food engineering, material science, nutrition, and agricultural science, which has also enabled the development of more holistic approaches in the development of food products, where the processing, material, and nutritional properties are optimized together. The complexity and variety of the themes also show that the field of extrusion cooking is no longer restricted to a single area but has expanded into an area with multifaceted applications.

4. Conclusion

This study aims to provide an extensive bibliometric analysis of the research on extrusion cooking in India between 2023 and 2026, utilizing the PRISMA protocol as the basis of the analysis. The study shows an upward trend in the research output, with the major drivers of this trend being the increasing interest in functional foods, the development of products from millet, and the interest in green food processing technologies. The major focus of the study is the emphasis on the keywords that are associated with the study of nutrition, antioxidants, and bioactive

compounds, which shows a paradigm shift in the conventional applications of extrusion cooking towards health-focused, value-added food products. This shows an emerging trend that is in line with the priorities of the international community, which focus on the improvement of the nutritional value of foods as well as the improvement of the food security situation in the country, as highlighted [4, 5].

The co-authorship of the papers shows the existence of key authors, which is an indicator of the existence of research groups that are actively collaborating with each other, although this is not widespread across the entire Indian community of scientists working on the subject of extrusion cooking. The co-authorship shows the existence of clusters of research groups, with the majority of the co-authorship taking place within the clusters, which shows that the Indian scientists are highly collaborating with their colleagues, although the inter-institutional as well as international collaborations are lacking, which is an indicator of the opportunities that exist for the scientists, as shown [10]. Additionally, the co-citation analysis as well as the bibliographic coupling analysis show that the Indian scientists have a well-structured intellectual base, as shown by the existence of the foundational studies that were done on the subject of extrusion processing, food chemistry, as well as the enhancement of the nutritional value of foods, which shows that the Indian scientists are converging towards the emerging themes of functional foods as well as green food processing, which is an indicator of the emerging trend of the application of the extrusion cooking process as a solution to the emerging challenges that are affecting the world, including malnutrition, climate, as well as the efficient use of resources.

5. Future Research Directions

In light of these findings from the bibliometric study, some of the important research directions for future research have been identified. Firstly, there is an urgent need for integrating extrusion cooking with other modern and innovative technologies, including microwave-assisted processing, high-moisture extrusion, and 3D printing of foods. This hybrid approach has shown tremendous potential for enhancing the functionality of processed foods [8].

Secondly, future research should be focused on the production of functional and nutraceutical food products from indigenous and underutilized crops, especially millets and pulses. These crops contain good amounts of dietary fiber and nutrients. This research area is particularly important for India, where these crops could be used for enhancing nutritional and environmental sustainability [7].

Thirdly, sustainability and energy efficiency of the extrusion cooking process should be explored further. Future research should be focused more on optimization of the process, reduction of energy consumption, and utilization of agro-industrial by-products. This area of research has tremendous potential for developing more sustainable and eco-friendly extrusion technologies, which could play an important role in promoting the concept of a circular economy [5].

Lastly, future research should be focused more on enhancing national and international research collaborations. This could be done through collaborative research involving academia, industry, and research organizations. This approach could play an important role in enhancing the

research quality and visibility of research globally. This could also be helpful for integrating food science, engineering, and nutrition for addressing some of the critical challenges of the food system [10].

6. Conflict of Interest: The author(s) do not have any conflict of interest.

7. Data Availability Statement: The data supporting the findings of this study were obtained from the Scopus database using a predefined search strategy. The dataset generated and analyzed during the current study is available from the corresponding author upon reasonable request.

8. Author Contributions:

- **Nani Gopal Mudoi:** Conceptualization, Methodology, Writing-Original Draft.
- **Mriganka Shekhar Borah:** Data Collection, Analysis, Writing-Review & Editing.
- **Ajita Tiwari:** Visualization, Supervision, Project Administration.

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