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Bibliometric analysis on pseudocereals

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ABSTRACT

A bibliometric analysis on scientific documents regarding pseudocereals was performed. The literature was extracted from Web of Science database with limitations on language and index, resulting in 438 documents published until 2022. The bibliographic data were analyzed using Bibliometrix package and Biblioshiny interface available on R statistical language. The first source on pseudocereals was published in 1982 according to our data collection, and there was an increased trend of publications over the time with annual production above 11 %. The core group consisted of 11 out of 175 journals publishing on the field. Italy made the largest contribution, followed by Spain, Mexico, USA, China, among others. Collaboration network analysis was run to map associations between top countries on pseudocereals research. Six distinct sub-clusters of countries tending to collaborate together were detected. All of the publications of Israel on the area were in collaboration with other countries, whereas Argentina and Turkey published only single country publications. The most commonly used author keywords displayed with the word cloud after pseudocereals were quinoa, amaranth, buckwheat, and gluten-free. Other notable keywords were food composition, antioxidant activity, fermentation, bread, celiac disease, lactic acid bacteria, *etc*. The objective of the current study is to illustrate emerging trends in journal performance, collaboration networks, research constituents, intellectual structure, and evolutionary nuances of the field, thus also supporting policy development to promote research on pseudocereals utilizing bibliometrics approach.

Introduction

Plant biodiversity is a fundamental aspect of food security and healthy diet. Climate change is a major challenge affecting global crop production and food security, which is foreseen to reduce the cultivation of staple crops as wheat, rice and maize (Ali et al., 2022). More than 75 % of agricultural crop genetic diversity has been lost, therefore utilization of minor crops such as pseudocereals which can even grow in marginal areas with limited agricultural infrastructure is essential to increase environmental sustainability (Appiani et al., 2021). A pseudocereal is described as any plant that is not a member of the grass family (*Poaceae*) but generates fruits and seeds utilized as flour for staple foods including bread. Although cereals like wheat, barley and rice are monocotyledonous, pseudocereals are dicotyledonous plants but with similar seed function and composition to cereals, which is the reason behind of their description as pseudocereals. Amaranth, quinoa and buckwheat are the most well-known pseudocereals so far (Alvarez-Jubete et al., 2010; Mir et al., 2018). Quinoa (*Chenopodium quinoa Willd*), which is a native to Andean region of South America, is frost resistant and can grow in regions with low rainfall (Mir et al., 2018). Buckwheat (*Fagopyrum esculentum Monch*), native to China, can grow in almost all soil types. Amaranth can be cultivated in various

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environmental conditions where traditional cereal crops cannot perform well (Nascimento et al., 2014). The interest in pseudocereals is growing rapidly due to their nutritional and phytochemical profiles. They are rich in starch, protein, dietary fiber and high in unsaturated lipids, as well as minerals, vitamins and bioactive components including saponins, phytosterols, squalene, and polyphenols (Alvarez-Jubete et al., 2009). The buckwheat is very nutritious with high protein amount. It has the potential to prevent diabetes and reduce cholesterol (Mir et al., 2018). The Quinoa grain is very rich in phosphorus and magnesium as well as contains saponins bitter in taste which should be removed prior to consumption (Nascimento et al., 2014). Amaranth and quinoa are good sources of copper, iron, manganese and zinc nutrients (Nascimento et al., 2014). Besides their rich nutrient composition, pseudocereals are also naturally gluten free, which makes them healthy alternatives to gluten-rich grains such as wheat and barley. Celiac disease is increasingly recognized chronic autoimmune disorder, with around 1 % prevalence of the total world population, which is triggered by ingestion of gluten in genetically predispose individuals (Thakur et al., 2021). The only efficient treatment of celiac disease is gluten-free diet which does not contain wheat, barley, rye, *etc.* (Mir et al., 2018). Pseudocereals, including amaranth, quinoa and buckwheat, are evolving as an healthy alternative to gluten-containing cereals for the preparation of gluten-free food products as pasta and bread (Alvarez-Jubete et al., 2009). Gluten-free foods are becoming one of the main trends in food industry with around 9 % annual growth rate forecasted for the 2019–2025 period (Martínez-Villaluenga et al., 2020). Recent studies on pseudocereals are concentrated on improving structural and nutritional properties of gluten-free bread utilizing yeasts and lactic acid bacteria (LAB) for fermentation (Chochkov et al., 2022; Novotni et al., 2021; Păcularu-Burada et al., 2020, 2021; Păucean et al., 2019; Petrova and Petrov, 2020). Microbial fermentation of pseudocereals, especially lactic acid fermentation, is a popular approach for improving organoleptic characteristics, food preservation and safety (Petrova and Petrov, 2020). Current studies show that phenolic components of pseudocereals have potential to combat chronic illnesses such as cancer, diabetes, hypertension and cardiovascular disease. There are many studies on the nutrition and health benefits, as well as on processing aspects of pseudocereals in various functional foods (Thakur et al., 2021). Research on pseudocereals started in 1982 (according to our data collection) and showed various research directions. Therefore, analyzing the evolution of scientific production on this topic with bibliometric tools can help detect the research gaps and improvements, as well as show potential partners in the field to develop multidisciplinary collaborations in future projects. Bibliometric analysis is a popular and rigorous technique based on statistical measurement of scientific literature. This sub-branch of informetric enables tracking the evolutionary nuances of a specific scientific domain and projects emerging research topics in that field. Therefore, bibliometric reviews are useful for deciphering and mapping large literature volumes and building firm foundations to advance a scientific domain in novel and meaningful ways by pinpointing knowledge gaps and deriving novel ideas for investigation (Akin et al., 2023, 2023; Aria et al., 2022; Donthu et al., 2021). Accordingly, we endeavor to present an insight into the developments within the pseudocereals area utilizing bibliometric analysis on the extant literature, as well as provide essential findings and recommendations for future directions as guidelines and potential collaboration networks for stakeholders.

Materials and methods

The largest two scientific literature databases are Web of Science (WoS) from Clarivate Analytics (https://www.webofscience.com/) and Scopus from Elsevier (https://www.scopus.com/) (Forliano et al., 2021). Researchers have recognized WoS as showing better quality standards than Scopus by demonstrating fewer false positive results based on authors and keyword disambiguation due to Keywords Plus. Keywords Plus are keywords that are automatically formed from the WoS database by the terms that show up more than once in a publication's reference collection and do not produce comparison issues such as acronyms, or single/plural forms. Therefore, WoS is the most appropriate bibliographic database to conduct bibliometric studies (Forliano et al., 2021; Thelwall, 2008; Waltman and Van Eck, 2012).

In this study, WoS Core Collection was accessed for data extraction using the search string pseudoceral* in the topic field, thus documents with the selected keyword in title, abstract, author keywords and keywords plus were filtrated. Wildcard was used to find sources with plural and singular form of the selected term. The search was performed on May 7th, 2022, and included all documents released before 2022 and published in English language. The final data was examined through bibliometric analysis using Bibliometrix package and Biblioshiny interface in R studio (Aria et al., 2022; R Core Team, 2022).

Performance analysis and science mapping approaches were mainly adopted to assess scientific production in pseudocereals. Besides providing descriptive statistics of the data including annual scientific production, journal, and country activity; a word cloud was generated to display the most frequently used author keywords.

Thematic evolution map in compliance with annual scientific publication distribution was generated using author keywords for demonstrating a static picture and progress of the field throughout time. The intellectual and conceptual framework of the pseudocereals research was explored together with the social network structure of countries.

Results and discussion

There were 438 documents consisting mainly of original research articles (363), reviews (65), editorial materials (3), meeting abstracts (3), proceeding papers (2), note (1), and book chapter (1). The bibliometric data were extracted from 175 sources (journals, books, *etc.*) belonging to WoS Core Collection. These documents comprised 1218 author keywords and 1384 keywords plus. The bibliographic literature was authored by 1588 researchers. There were 15 single-authored documents, and the estimated co-authors for the rest of the documents were around 4.68 %. International co-authorship was around 28 %. The average years from publication (average document age) was 6.15 with average citations per document 26.03. The first source on pseudocereals was published in 1982 based on our data collection. There was an increasing publication trend with annual growth of 11.12 %. Significant increases of publications were notable in 2013 (from 17 to 25 documents) and 2019 (from 33 to 59 documents) (Fig. 1). A bibliometric study conducted on the effect of agronomic practices on quinoa (*Chenopodium quinoa* Willd) under field conditions showed fluctuating annual publication growth with a highest number of publications in 2019 (Sellami et al., 2020). Publication activity on Amaranth (*Amaranthus* species) research experienced a steady growth over the years with a peak in 2019 (Jimoh et al., 2022). Studies on wheat and barley displayed continuous growth with a prominent increase during the second half of the twentieth century (Giraldo et al., 2019).

The literature related to climate change and paddy research published between 1970 and 2020 showed rise with notable increases in 1995, 2013, 2016 and 2019 (Ali et al., 2022). The core group consisted of 11 out of 175 journals based on Bradford's Law (Bradford, 1934) with *Food Chemistry* and *Foods* journals (25 documents) being the most productive in the field, followed by *Journal of Cereal Science* (22 documents), *International Journal of Food Science and Technology* (13 documents), *etc.* (Figs. 2 and 3). This high number of journals with diverse publishing focus implies the emerging and immense popularity of pseudocereal research. *Journal of Agronomy and Crop Science* was the leading journal publishing on agronomic practices on quinoa under field conditions (Sellami et al., 2020). *Theoretical and Applied Genetics, Euphytica*, and *Plant and Soil* journals published both wheat and barley research (Giraldo et al., 2019). *Weed Technology* and *Weed Science* had the highest publication number on Amaranth research (Jimoh et al., 2022). *Climatic Change* and *Field Crops Research* recorded the highest

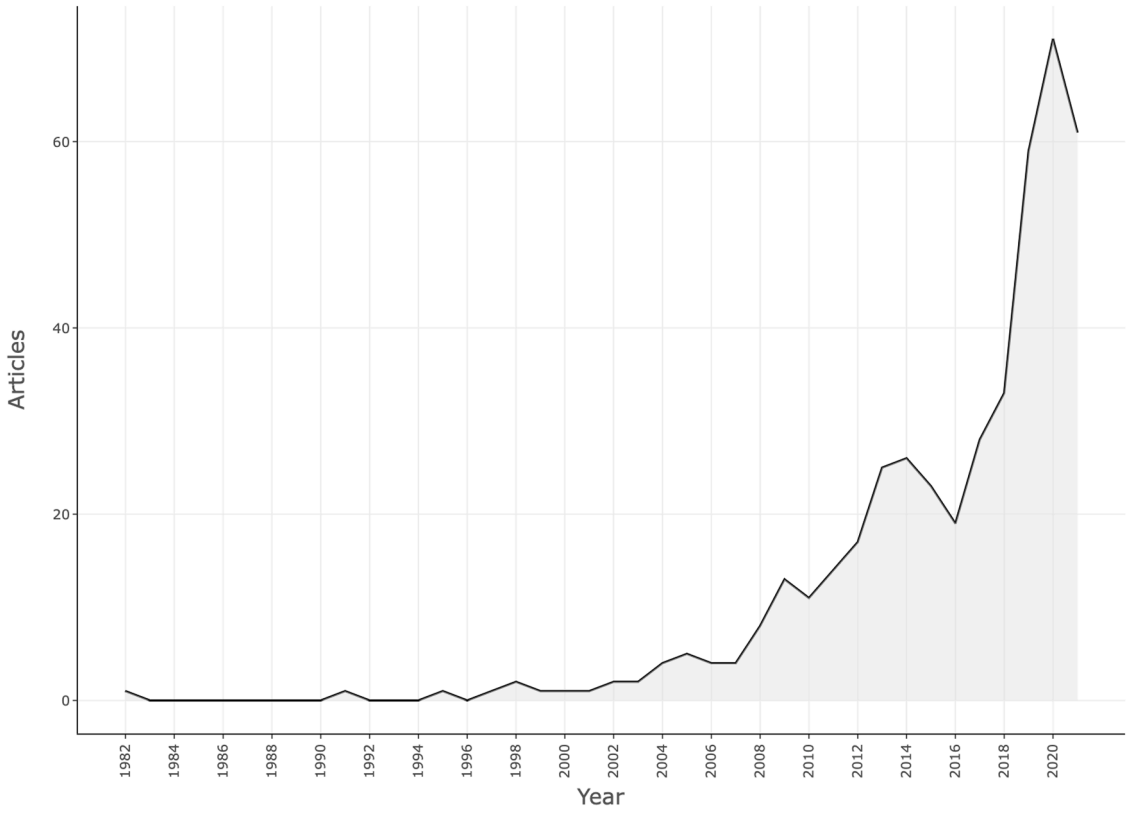

Fig. 1. Annual scientific production on pseudocereals.

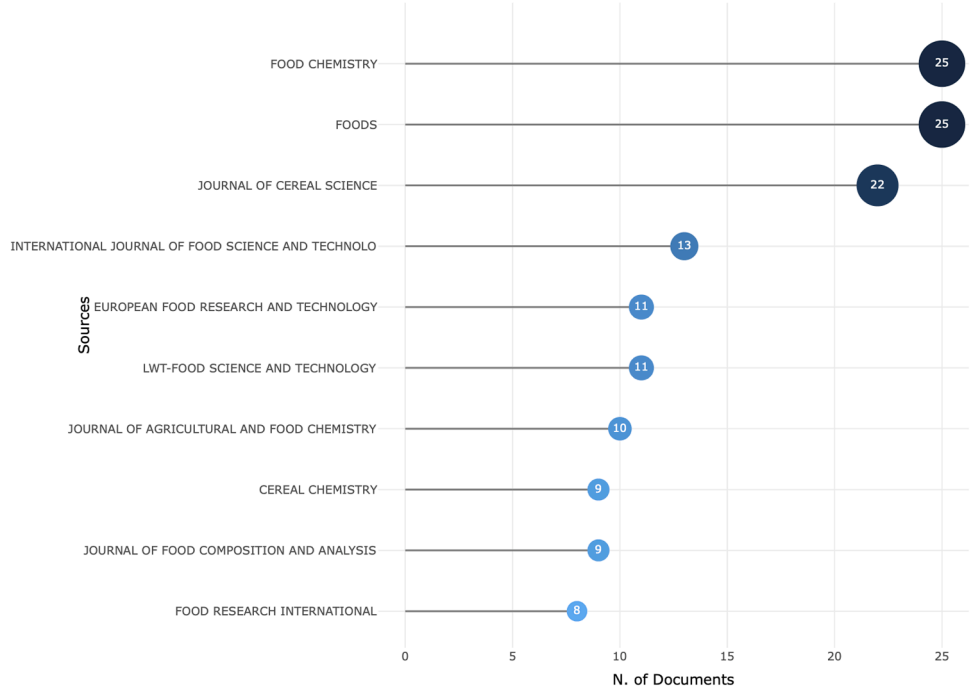

Fig. 2. Most productive journals on pseudocereals literature.

number of publications on climate change and paddy research (Ali et al., 2022). Italy made the largest contribution (124 documents) on pseudocereals research, followed by Spain (87 documents), Mexico (52 documents), USA (52 documents), China (48 documents), *etc*. There are lots of gray shaded countries on the world map corresponding to no publications in pseudocereals based on our data collection (Fig. 4). Europe, followed by Africa and Asia, published the highest number of documents on agronomic practices and performances of quinoa under field conditions, and no publication was available by Australian continent (Sellami et al., 2020). Despite the USA made the highest contribution on wheat and barley research, the interest in wheat and barley research was not equally represented among countries. Barley research

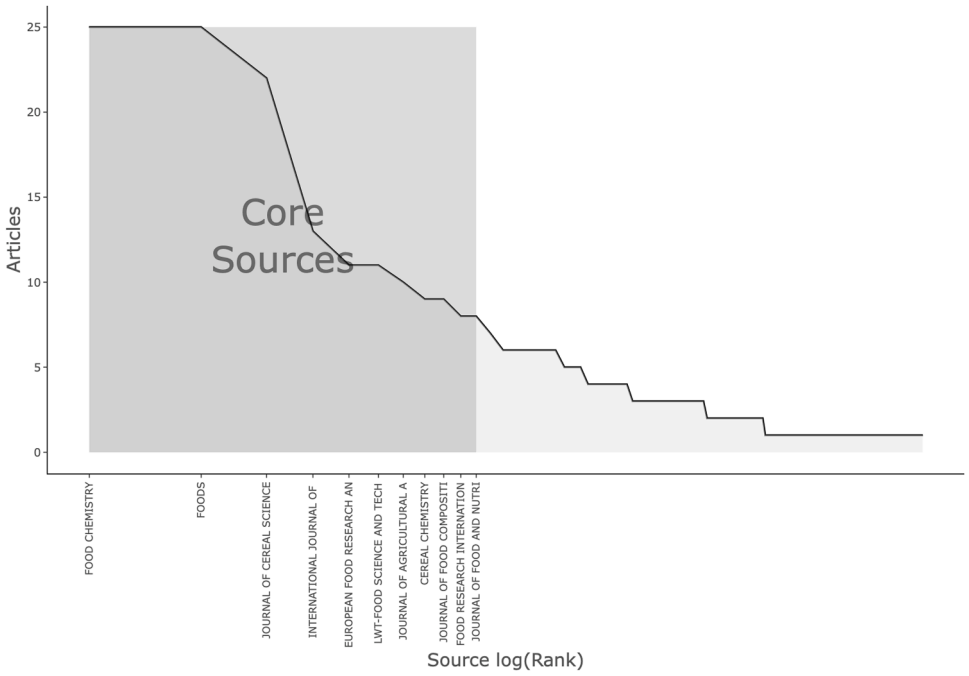

Fig. 3. Core journal group publishing pseudocereals research based on Bradford's Law.

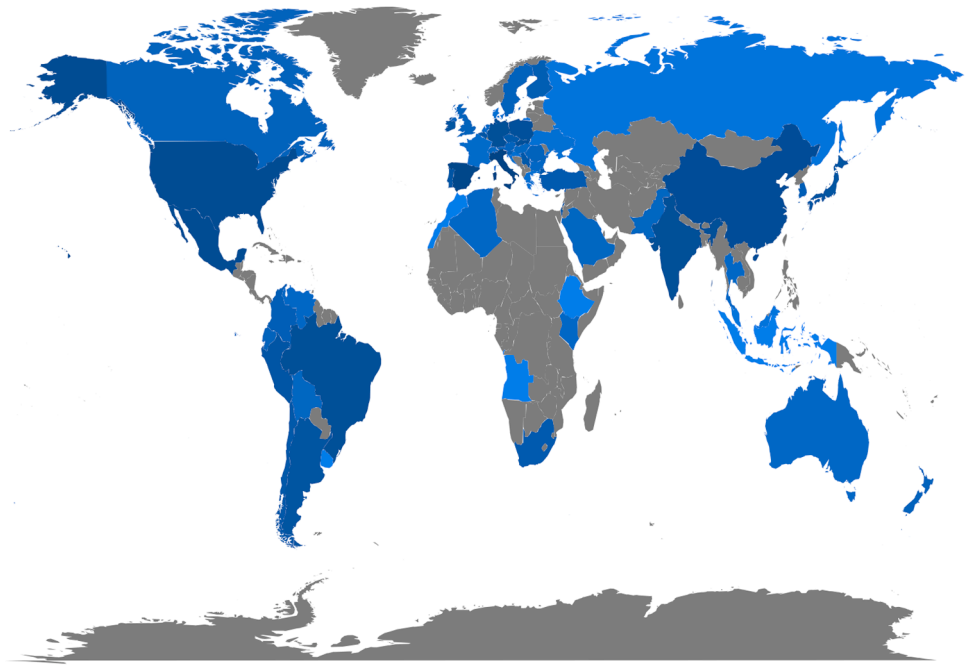

Fig. 4. World map of publication number per country. The color concentration is proportional to publication number. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

was mainly published by European countries, whereas China and India were among the leading contributors on wheat literature (Giraldo et al., 2019). China had the highest number of publications on climate change and paddy, followed by India, USA and Japan (Ali et al., 2022). Some of these countries are important actors in our data collection as well.

Collaboration in publications is important for knowledge transfer and higher research quality standards by bringing high-skilled scholars together (Jimoh et al., 2022; Montoya et al., 2018). Argentina and Turkey did not have international collaboration on the pseudocereal literature that they published, whereas all publications of Israel were in collaboration with other countries according to our data collection. The top countries doing research on pseudocereals generally did not show high international collaboration based on corresponding author country (Fig. 5). China, USA and India represented highest international cooperation on climate change and rice farming followed by Philippines, Germany, France, *etc.* (Ali et al., 2022). Six distinct collaboration networks of the top ranked countries were projected (Fig. 6). The size of a circle refers to the publication frequency of a country through international collaboration. The size of the circle increases with document number on the field. The line width depicts collaborative frequency,

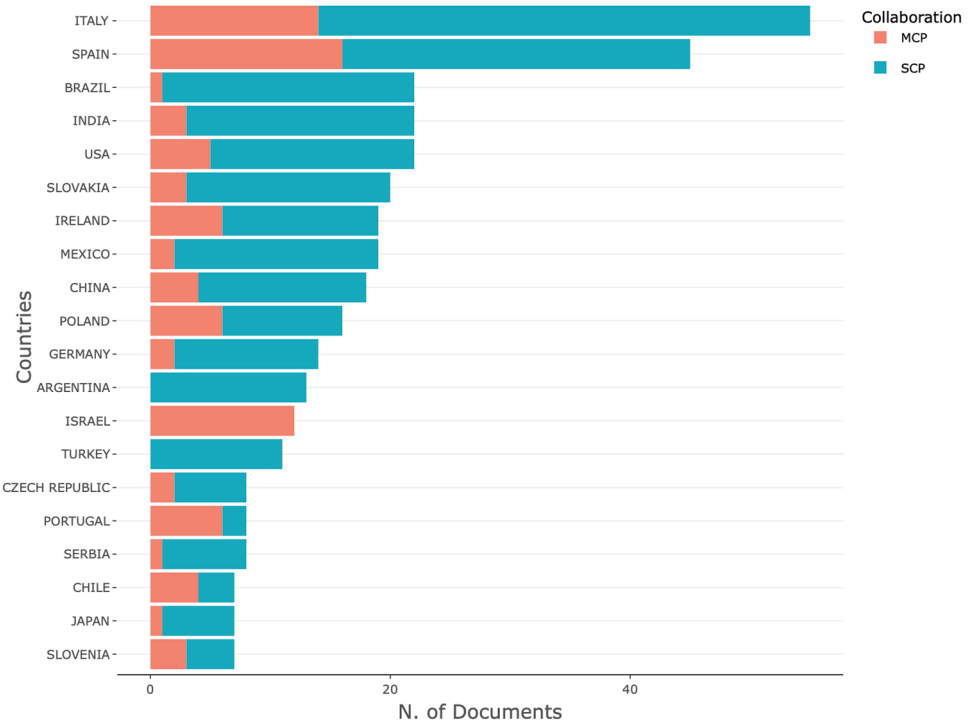

Fig. 5. International colloboration graph on pseudocereals based on corresponding author country. SCP: single country publication, MCP: multiple country publication.

thicker line means closer relationship. The largest international collaboration subgroup consists of Italy, Spain, Brazil, Argentina, Peru, Portugal, Chile, Serbia, Finland, Austria, Hungary, Netherlands, Venezuela and Denmark, with the Italy and Spain having the highest collaboration frequency with the group members (Fig. 6). Another collaboration cluster includes Germany, Mexico, Poland, Japan, Israel, Columbia, Korea, Slovenia and Thailand with Germany having the highest number of publications within the group. Switzerland, Sweden, France and Bolivia are a small network tending to collaborate together (Fig. 6). Eight collaboration subgroups were projected in *Amaranthus* research, and the USA dominated the network with the highest international collaboration (Jimoh et al., 2022).

Keywords are phrases that reflect the underlying research topic of a literature. Consequently, keyword analysis enables projecting research hotspots and helps defining research direction and gaps in a particular field (Jimoh et al., 2022; Xiang et al., 2017). The keyword analysis mapped pseudocereals as the most frequently used author keyword, followed by quinoa, amaranth, buckwheat, cereals, and gluten-free with other notable keywords as food composition, antioxidant activity, bread, fermentation, nutritional value, celiac disease, functional properties, lactic acid bacteria, *etc*. We can interpret the frequent use of these keywords as follow: quinoa, amaranth and buckwheat were the most popular pseudocereals studied pinpointing gluten-free properties, and their role in human nutrition associated with celiac-disease. Another most used term was functional properties of pseudocereals which can be improved by lactic acid fermentation, a process which also increases the nutritional, safety and organoleptic properties of the final product (Păcularu-Burada et al., 2020). Optimizing gluten-free food formulations for improved bioactive, sensory and technological characteristics is still a challenge requiring further research (Graziano et al., 2022). Gluten-free breads generally show poor nutritional and sensory characteristics. Studies with celiac and other consumers without gluten disorders state that the flavor and texture are the major reasons for disliking the gluten-free breads, pinpointing the desire for better flavored and tasting, also healthier gluten-free breads. Pseudocereals are gluten-free grains with rich profile of proteins, amino acids, fatty acids, dietary fibers, minerals and bioactive compounds showing antioxidant properties with potential health benefits including antidiabetic, anti-cancerous and cholesterol-decreasing effects. Pseudocereal flours is a promising alternative to ameliorate the nutritional and physical profiles of gluten-free bread. There is also a gap of knowledge regarding the relationship between gluten-free dough indicators, physical features and sensory acceptability of gluten-free bread, consequently it is crucial to detect reliable factors to optimize quality of gluten free bread (Aguiar et al., 2021). Studies on food composition, functional properties, antioxidant activity, breadmaking and fermentation of pseudocereals were also among the trending topics. Antioxidant was one of the most frequent keywords in *Amaranthus* research. Other frequent keywords were also antimicrobial, detoxification, herbicide resistance, taxonomy, *etc.* (Jimoh et al., 2022). *Triticum* was the highly represented keyword in wheat literature, and *Hordeum* was among the most frequent keywords of barley documents. Genetics was a highly used keyword in both plant species, showing the pivotal role of heredity and plant trait variation studies. Another important keyword was chemistry, pinpointing studies on nutritional quality on wheat and barley (Giraldo et al., 2019). Genetics and breeding were not among the most frequent keywords of our word cloud results, thus implying the gap of genetic variability and breeding studies on pseudocereals (Fig. 7).

Higher article citation reflects the scientific impact of an article on a particular field (Jimoh et al., 2022). The most cited document in our data collection was *"Polyphenol composition and* in vitro *antioxidant activity of amaranth, quinoa buckwheat and wheat as affected by sprouting and baking"*(Alvarez-Jubete et al., 2010), which was published in *Food Chemistry* journal. *"Nutritive value of pseudocereals and their increasing use as functional gluten-free ingredients"* (Alvarez-Jubete, Arendt, et al., 2010), published in *Trends in Food Science and Technology* journal was the second most cited document in pseudocereals. The third most influential paper was *"Anthocyanins, total polyphenols and antioxidant activity in amaranth and quinoa seeds and sprouts during their growth"* (Paśko et al., 2009), published in *Food Chemistry* journal. These three papers support the author keyword analysis results and most prolific journals in the field of pseudocereals (Figs. 2 and 7). As can be seen they

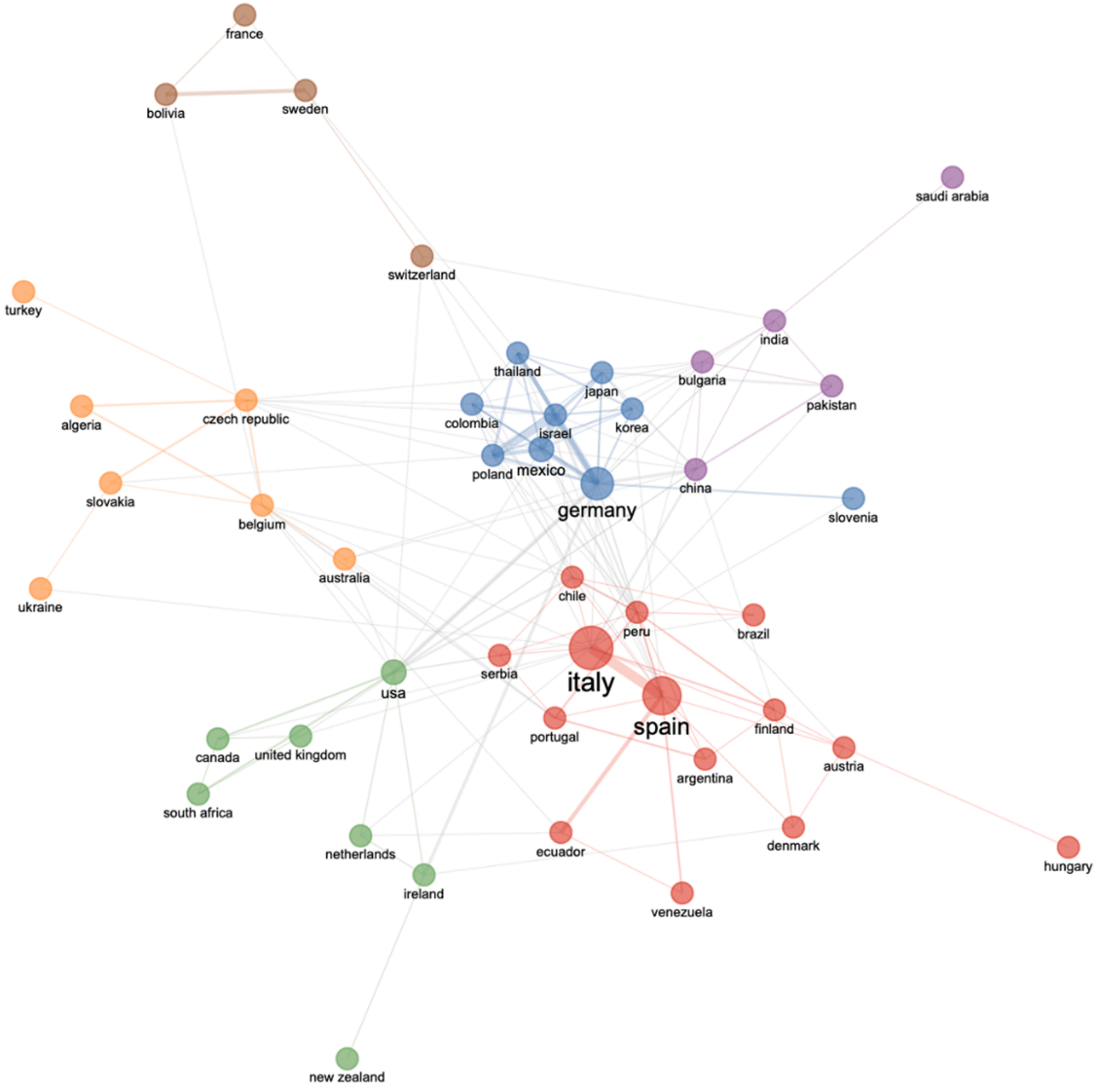

Fig. 6. Country collaboration sub-groups on pseudocereals.

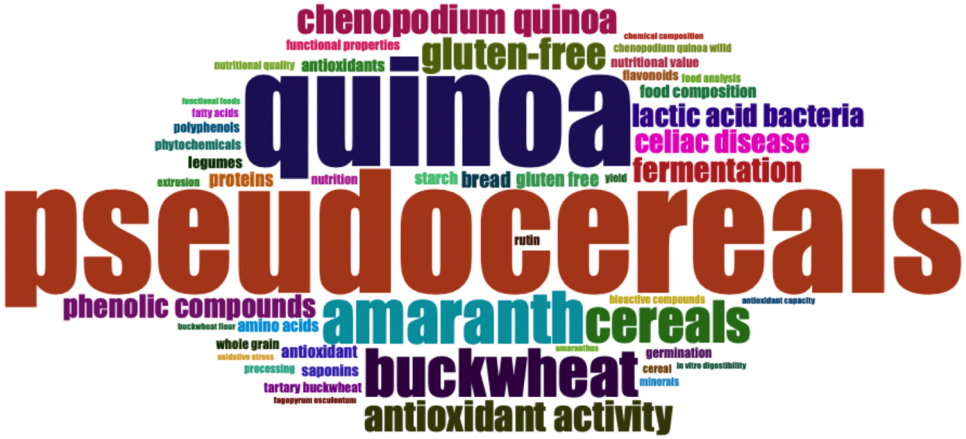

Fig. 7. Word cloud projecting most used author keywords.

are related to polyphenol composition and antioxidant activity, nutritive value and functional properties.

Clustering algorithm was applied to the author keyword network to generate a thematic evolution map for deeper understanding of the pseudocereals topic and highlight conceptual structure of the subject. Different time slices were described (1987–2007, 2008–2014,

2015–2016, 2017–2021 time periods) to shed light on the field evolution. This strategic map is composed of Callon density (y-axis) and Callon centrality (x-axis). Density shows the theme development, whereas centrality accounts for theme importance within the entire research field (Aria et al., 2022; Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011). The graph consists of four main clusters/themes including motor themes, niche themes, emerging or declining themes, and basic/transversal themes. Motor themes shows the well-developed research sub-branches within the topic. Niche themes corresponds to highly developed and isolated niche topics within the field. Emerging or declining themes represents research topics that has just emerged or is about to disappear. Basic themes are sub-topics that are very important to the field which has not been well developed (Wang et al., 2022). Each circle on the map represents a keyword cluster. The circle name corresponds to the keyword with higher occurring frequency within the network/cluster, and the circle size is proportional to the cluster keyword frequency. The circle position is set according to keyword group Callon centrality and density (Aria et al., 2022; Cobo et al., 2011). The thematic evolution map was in consistence with keyword analysis (Figs. 7 and 8). Cereals, pseudocereals, gluten-free, whole-grain and oxidative stress represented the motor themes. Quinoa, amaranth and buckwheat were among the basic themes, whereas gluten-free, celiac disease and functional properties, as well as polyphenols, antioxidant and food metabolomics were among emerging trends. Lactic acid bacteria, fermentation and pasta were allocated both as niche and emerging trends. Genetic variability or breeding were not among these topics which shows the research gap on these fields. The topic evolution over time was mainly concentrated on nutritional and functional properties of pseudocereals with emphasis on celiac disease as well (Fig. 8). As also supported by the Keyword analysis and Clustering algorithm, pseudocereals are gaining popularity in human diet as gluten-free grains with high nutritional and nutraceutical properties. Pseudocereals are rich in proteins, starch, fiber, minerals, vitamins and phytochemicals including polyphenols, saponins, phytosterols and betalains with potential positive effects on human health. Beyond their high nutritional composition, these grains are also gluten-free which makes them a good alternative for the development of new gluten-free products that provide an adequate intake of nutrients in individuals with celiac disease whose number is constantly increasing (Martínez-Villaluenga et al., 2020). Quinoa, amaranth and buckwheat can grow in various environmental conditions and are becoming a current trend among consumers and scientists worldwide (Pirzadah and Malik, 2020). However, the utilization of pseudocereals is hampered due to poorer organoleptic and technological characteristics of their products in comparison with their gluten-containing counterparts. Improving bioactive, organoleptic and technological characteristics of gluten-free foods is still a challenge. Further research is required to optimize gluten-free formulations to satisfy sensory and textural demands of contemporary consumers (Graziano et al., 2022). Pseudocereals contain myriad bioactive compounds such as phenolics, saponins, phytosterols, polysaccharides, peptides and proteins. The potential health benefits of pseudocereals (including reducing risk of various chronic disorders, such as diabetes, cardiovascular diseases, cancer, and aging) are mainly associated with these compounds. However, the scientific evidence on the mechanism by which these bioactive compounds improve health remains limited and needs further investigation (Martínez-Villaluenga et al., 2020).

Conclusions

The first source on pseudocereals based on our literature collection was in 1982, and there was an increased trend of publications throughout time with annual production over 11 %. The pseudocereals research was published in a very diverse collection of journals (over 170 sources) with Food Chemistry and Foods being the most productive in the field. This vast number of journals covering various topics implies the versatility and immense popularity of this area. Italy had the highest number of publications on pseudocereals, followed by Spain, Mexico, USA, China, among others. The top countries doing research on this field published generally single country publications, whereas all of the publications of Israel on this domain were in collaboration with other

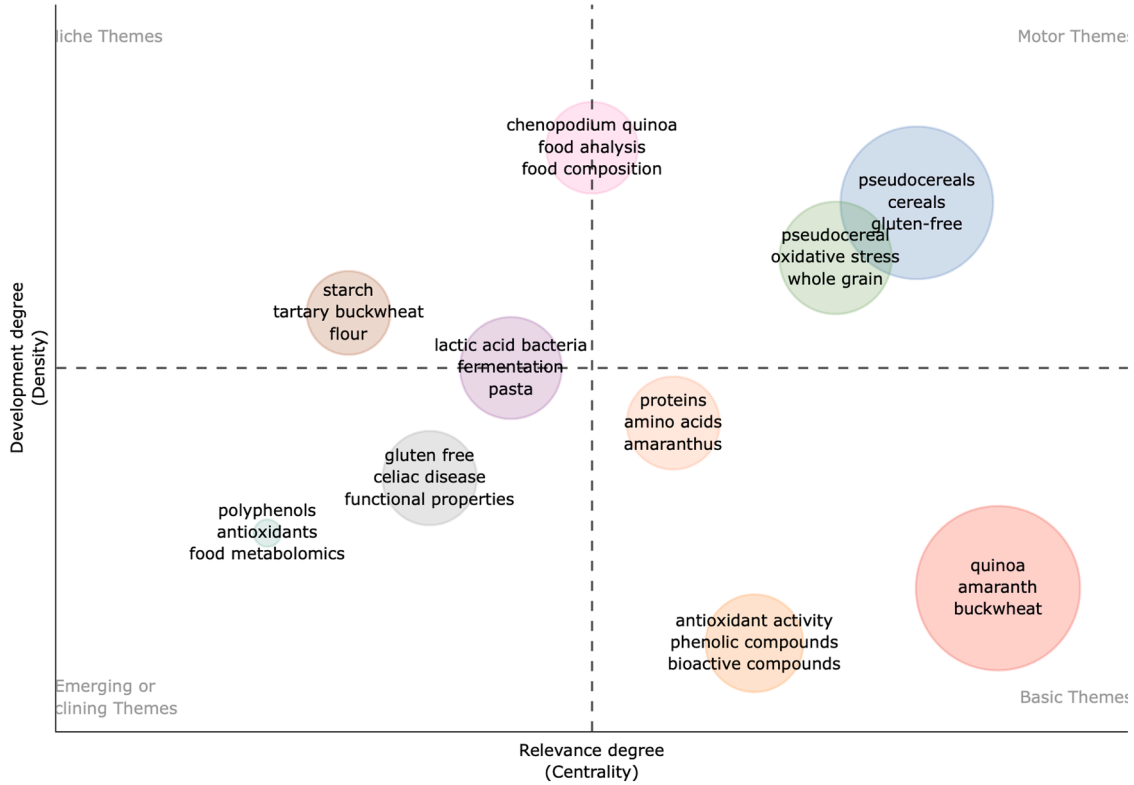

Fig. 8. Topic evolution of pseudocereal research over time.

countries. Collaboration network analysis demonstrating the associations between top countries on the area resulted in six distinct subnetworks confirming that research collaboration is not limited by language or borders. The keyword analysis demonstrated that the most used author keyword after pseudocereals were quinoa, amaranth, buckwheat, cereals and gluten-free, with other notable keywords as food composition, antioxidant activity, fermentation, celiac disease, lactic acid bacteria, *etc*. Thematic evolution of pseudocereal research showed that there was a development from more general to more specific research topics as the recent trending topics were gluten-free, celiac disease, functional properties, polyphenols, antioxidants and food metabolomics. Lactic acid bacteria, fermentation and pasta were allocated both as niche and emerging trends. It was notable that there was a research gap on genetic variability and breeding on pseudocereals, implying a future research call on these topics. We believe that the present study will be a useful source for scholars and practitioners approaching the pseudocereals topic and want to have a general overlook of the existing scientific literature, international collaborations and popular topics in the field, as well as potential journals to publish their research.

Compliance with ethics requirements

This article does not contain any studies with human subjects.

CRediT authorship contribution statement

Melekşen Akın: Conceptualization, Methodology, Formal analysis, Validation, Investigation, Resources, Writing – original draft. **Sadiye Peral Eyduran:** Validation, Writing – review & editing. **Maria Papageorgiou:** Writing – review & editing. **Elena Bartkiene:** Writing – review & editing. **Joao Miguel Rocha:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that there are no potential conflicts of interest regarding the research, authorship and publication of this manuscript.

Data availability

Data will be made available on request.

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