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Pearl millet (*Pennisetum glaucum* L.) Research in India: A Scientometric Journey Through the Last Two Decades (2000-2022)

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Abstract: Pearl millet, known scientifically as *Pennisetum glaucum* (L.) R. Br., is an ideal crop to combat water scarcity and ensure food security in regions facing harsh climatic conditions due to its high drought tolerance and resource efficiency. To understand the research trends and identify gaps in pearl millet research in India, a scientometric study of 1186 documents from 2000-2022 was conducted, revealing a steady increase in research activity in this field. The study provides valuable insights for future research directions and highlights the need for continued efforts to improve pearl millet production and management. The findings of this scientometric study suggest that pearl millet research in India has gained significant momentum in the last two decades. The keywords "downy mildew" and "*Sclerospora graminicola*" emerged as the most frequent topics in the data set. The study's results will help researchers, policymakers, and other stakeholders in the field to make informed decisions and design effective strategies to enhance pearl millet production, management, and utilization in the face of climate change.

Key words: Arid, bibliometric, downy mildew, *Sclerospora graminicola.*

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Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the sixth most important cereal crop, after rice, wheat, maize, barley and sorghum, growing over 30 mha in the arid and semi-arid regions of the world (Satyavathi *et al*., 2021). In India, pearl millet is cultivated over 6.93 mha area with an average production of 8.61 mt and productivity of 1243 kg ha^{-1} (Anonymous, 2020). Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana together account for 90% of the pearl millet acreage in the country (Anonymous, 2021). The harsh agro-climatic conditions of the arid and semi-arid regions, characterized by low and erratic rainfall, high mean temperature, high potential evapotranspiration and low fertile sandy soils, make it extremely difficult for most of the crop plants to realize economic yields. However, pearl millet successfully inhabits such areas because of its unique features including the C4 metabolic machinery, high photosynthetic efficiency, high dry matter production capacity, and deep

rooting system (Anonymous, 2021), ultimately making it a "climate-resilient crop".

Climate change affects crop production by influencing various biophysical factors ranging from plant and animal growth to processing and distribution of produce (Satyavathi *et al.*, 2021). Higher temperatures and changes in precipitation patterns could lead to yield reductions and crop failures, which pose a great threat to global food security. This calls for the utilization of climate –resilient crop and animal species so as to sustain the income and food security of farming communities, especially in the arid and semi-arid belts of the world. In this context, pearl millet is highly valued because of its climate-hardiness that enables it to survive under conditions of water scarcity, high aridity and low soil fertility. Pearl millet based cropping systems have been found to be highly sustainable and profitable in the Indian arid zone under rainfed and limited water availability situations (Saxena *et al.*, 2005; Tetarwal *et al*., 2011). Besides, pearl millet being rich in proteins and micronutrients, and being gluten free, is also an excellent candidate for the nutritional security of our people. All these factors have reinforced the importance of crops like pearl millet, which gives assured yield under abiotically stressed environments, while maintaining low input costs. This renewed interest in millets, across the globe, has accelerated research and development initiatives to promote millet conservation, cultivation and consumption.

Scientometric/Bibliometric analysis is a quantitative research method used to analyze scientific literature and scholarly publications (Cobo *et al.*, 2011; Zupic and Carter, 2015; Guler *et al.*, 2016). It involves the statistical analysis of the publications, including citation counts, co-authorship patterns, keywords, and other bibliographic information to identify patterns, trends, and relationships (Börner *et al.*, 2003). A scientometric analysis on pearl millet research in India from 2000 to 2022 can provide valuable insights into the research trends, growth, and impact of pearl millet research in India. It can help identify the most prolific authors, institutions, and countries, the most frequently cited papers, the most popular research topics, and the emerging research areas. This information can be used for future research directions, funding decisions and policy initiatives related to pearl millet research in India. Furthermore, such a scientometric study can contribute to the scientific literature by providing a comprehensive and systematic overview of pearl millet research in India, which can help researchers and policy makers worldwide to better understand the state of research in this field.

Methodology

The methodology for the scientometric research involved accessing the Web of Science Core Collection (WoS at http://www.webofknowledge.com), filtering the results, executing the query on the platform, extracting and processing the data, and analyzing and visualizing the data using scientometric techniques and R software. In this study, we used scientometric techniques to analyze the literature on pearl millet research in India. To conduct the scientometric study, we followed the following steps:

Step 1: Accessing the Web of Science Search Engine

On 24 March, 2023, we accessed the Web of Science Search Engine, which is a comprehensive database of scholarly literature. We searched for relevant publications on pearl millet research using appropriate keywords and phrases and obtained 4690 results, which was filtered to 1186 documents with full record.

Step 2: Filtering the Results

The filtering process for the results was carried out in seven distinct stages. Initially, a time frame spanning from 2000 to 2023 was selected, resulting in the reduction of the number of documents to 3516. In the second stage, only articles were selected, resulting in a further reduction to 3233 documents. Non-English documents were subsequently excluded, resulting in the filtering down to 2999 documents. Next, documents were selected that focused on studies conducted in India, reducing the number of documents to 1296. The Web of Science categories related to agriculture were then selected and the results further refined to 1230. Finally, the meta-data were checked and a few documents, such as review papers, proceedings, meeting abstracts, books, and book chapters, were eliminated.

The total number of documents utilized in this study amounted to 1186.

Step 3: Query on Web of Science

To execute the search, we used the following query on the Web of Science platform: (((TS=(pearl millet)) OR TS=(pearlmillet)) OR TS=(pearl-millet)) OR TS=(*Pennisetum glaucum*) and Article (Document Types) and English (Languages) and INDIA (Countries/Regions) and Agronomy or Plant Sciences or Food Science Technology or Agriculture Multidisciplinary or Biochemistry Molecular Biology or Genetics Heredity or Multidisciplinary Sciences or Environmental Sciences or Biotechnology Applied Microbiology or Soil Science or Horticulture or Agriculture Dairy Animal Science or Nutrition Dietetics or Entomology or Meteorology Atmospheric Sciences or Microbiology or Ecology or Agricultural Engineering or Biology or Water Resources or Remote Sensing or Geosciences Multi disciplinary or Environmental Studies or Biochemical Research Methods or Physiology or Veterinary Sciences or Agricultural Economics Policy or Mycology or Toxicology or Biodiversity Conservation (Web of Science Categories) and 2022 or 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015 or 2014 or 2013 or 2012 or 2011 or 2010 or 2009 or 2008 or 2007 or 2006 or 2005 or 2004 or 2003 or 2002 or 2001 or 2000 (Publication Years)

Step 4: Data Extraction and Processing

The metadata were exported as CSV files and tab-delimited files. The raw files were then imported into R software and a series of codes using R-package bibliometrix, were run to clean and process the data (Aria and Cuccurullo, 2017).

Step 5: Analysis and Visualization

Using scientometric techniques and R software (bibliometrix package), we analyzed the data to reveal patterns and trends in pearl millet research. We generated several visualizations using VosViewer (van Eck and Waltman, 2010), which is a software tool for constructing and visualizing scientometric networks.

Several parameters such as annual scientific production, average citations per year, three-field plot, relevant sources, Bradford's Law, source dynamics, most relevant authors (based on articles fractionalized), most relevant affiliations, most globally cited documents, most frequent keywords, trending topics, thematic map and factorial analysis were studied. Bradford's Law is a scientometric principle that describes the distribution of information sources in a given field (Bradford, 1934). In scientometrics, fractionalized articles refer to publications that have multiple authors. In the case of the most relevant authors section, the number of articles attributed to each author is calculated based on their contribution to the publication. For example, if a publication has three authors, each author is assigned one-third of the credit for that article. This approach allows for a more accurate representation of an author's research output and contribution to the field.

Results and Discussion

Main information

The present scientometric study aimed to investigate the state of research on pearl millet in India from 2000 to 2022. The study analyzed a total of 1,186 documents from 313 different sources. The annual growth rate of documents on pearl millet research in India was found to be 3.09%, indicating a steady increase in research activity in this field over the past two decades. The average number of citations per document was 14.7, indicating that research on pearl millet in India is well-established and widely recognized, with many papers citing earlier work in the field. The data show that a total of 2,658 keywords plus and 3,211 author's keywords were identified in the documents analyzed in the scientometric study, indicating a diverse range of topics and areas of interest in pearl millet research in India. In bibliometrics, Keywords Plus refers to a list of keywords that are identified by the Web of Science database as being highly related to the original keywords used in a particular research article. These keywords are generated using a computational algorithm that analyzes the titles, abstracts, and bibliographic data of the articles in the Web of Science database. Out of 1,186 documents analyzed in the scientometric study, 22 were authored by single authors, while the remaining documents had an average of 5 co-authors per document. Furthermore, the study found that 21.08% of the co-authors were from international institutions, indicating

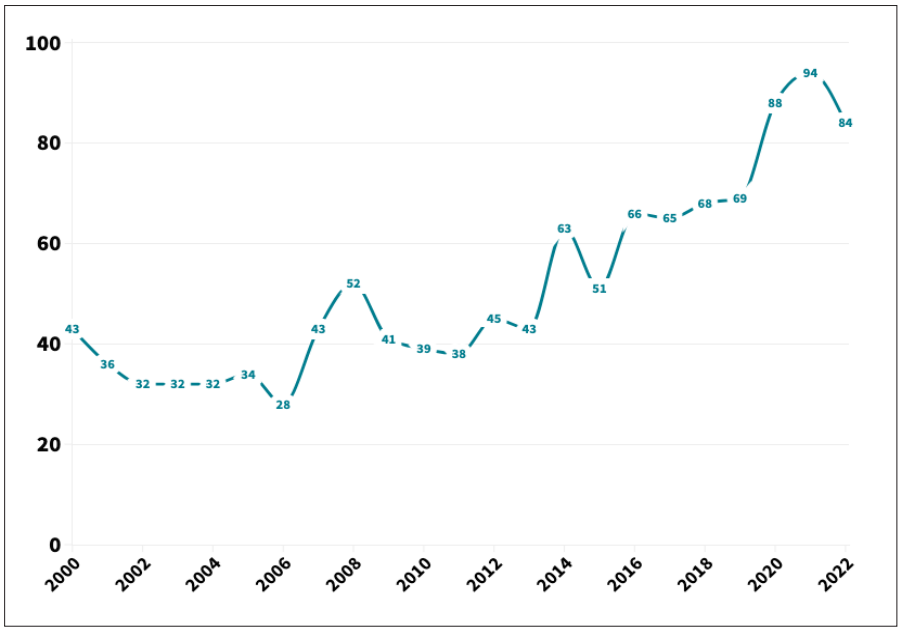

Fig. 1. Trends in scientific production on pearl millet research in India (2000-2022)

a significant level of international collaboration in pearl millet research in India. These findings suggest that pearl millet research is a collaborative and international endeavor that draws on expertise and resources from diverse sources.

Annual Scientific production

The annual scientific production on pearl millet research in India from 2000 to 2022 was analyzed in this study to identify trends and patterns over time (Fig. 1). The data revealed that the annual scientific production in the early 2000s was relatively stable, with an average of 34 publications per year between 2000 and 2006. However, there was a marked increase in scientific production from 2007 to 2014, with the number of publications almost doubling from 43 in 2007 to 63 in 2014. After 2014, the scientific production remained high, with an average of 65 publications per year between 2014 and 2020. However, there was a sharp increase in 2020 and 2021, with 88 and 94 publications, respectively, indicating a surge in research activity in the field of pearl millet research in India.

The data suggest that pearl millet research in India has seen a steady increase in scientific production over the past two decades, with a significant spike in recent years. This could be due to various factors, such as increased funding, growing interest in the topic, or new technological advancements that have made research more accessible. These findings can help inform future research efforts and provide valuable insights into the growth and development of pearl millet research in India.

Average citations per year

The average citations per year for pearl millet research in India from 2000 to 2022 were analyzed to identify trends and patterns over time (Fig. 2). The data showed a general trend of increasing citations per year until 2011, followed by a sharp decrease in the following years. In 2000, the average citations per article were 10.35, and it increased steadily, reaching a peak of 37.55 in 2011. However, after 2011, the average citations per article started to decrease and reached a low of 1.75 in 2022.

The three-field plot consisting of the top ten sources, top ten authors, and keywords provides a comprehensive visualization of the most significant contributors and sources in Pearl Millet research in India from 2000 to 2022 (Fig. 3).

Relevant sources

The Indian Journal of Agricultural Sciences is the leading source, publishing 97 articles on the topic, followed by the Journal of Food Science and Technology-Mysore with 50 articles. The next three sources in the ranking are Frontiers in Plant Science, Field Crops Research, and

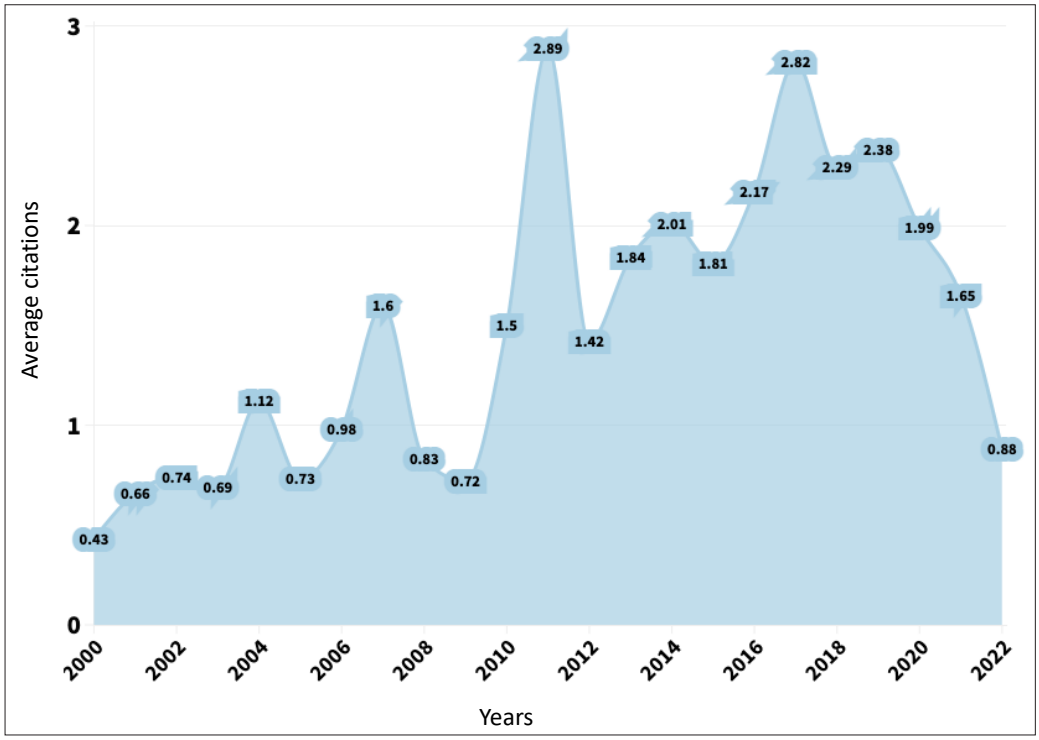

Fig. 2. Average citations of scientific articles on pearl millet research in India (2000-2022).

Indian Journal of Agronomy, each with over 20 articles published. The remaining sources in the top ten include Range Management and Agroforestry, Indian Journal of Genetics and Plant Breeding, Research on Crops, Crop Science, and Current Science, with relatively fewer articles published (Fig. 4). These sources demonstrate the prominence of agricultural and plant science journals in publishing research on Pearl Millet in India.

Bradford's Law

According to Bradford's Law, the literature of a subject can be divided into three zones.

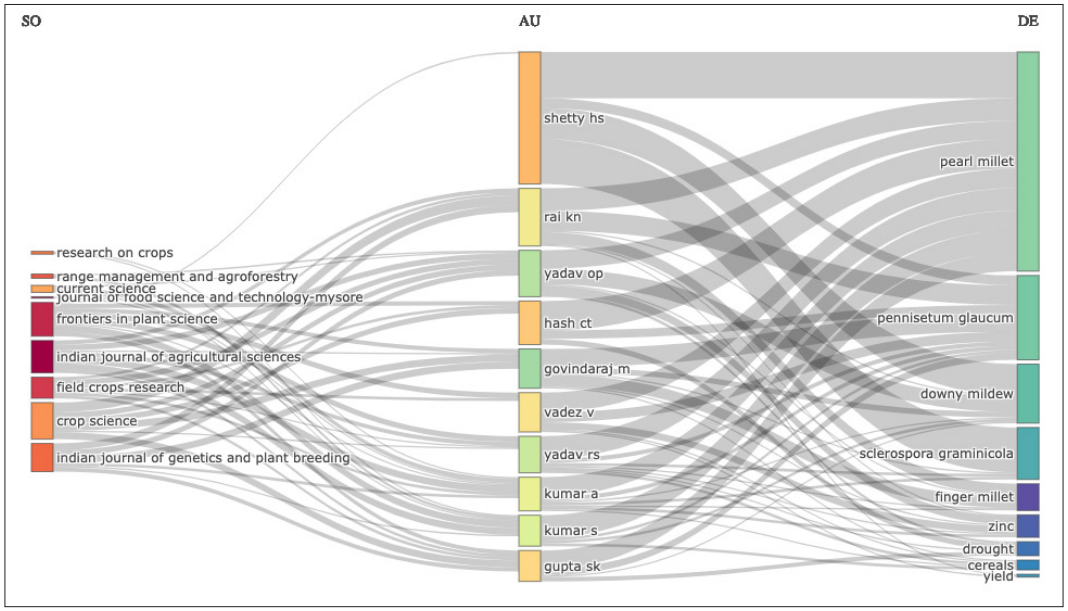

Fig. 3. Three-field plot showing the relevant sources (left), top authors (middle) and keywords (right) on pearl millet research in India (2000-2022).

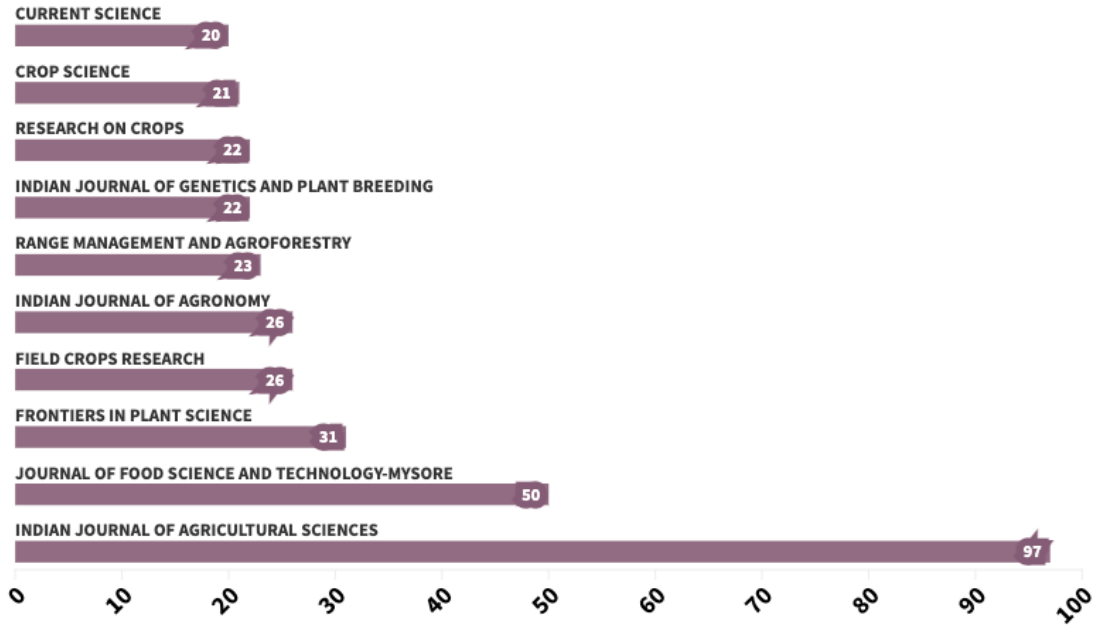

Fig. 4. Top journals with highest number of articles on pearl millet research in India (2000-2022).

The first zone contains a small number of core journals that publish a disproportionately high number of articles on the subject (Fig. 5). The second zone contains a larger number of journals that publish fewer articles than those in the core, but still more than the rest. The third zone contains a long tail of scattered publications, such as conference proceedings or

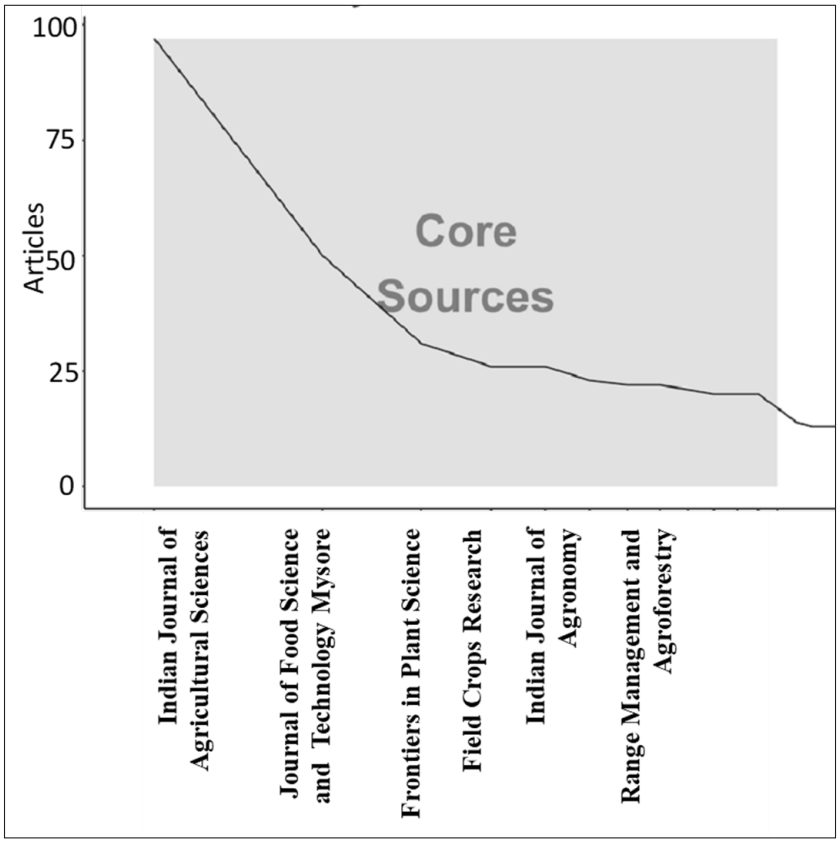

Fig. 5. Top Core Sources that publish the majority of articles in pearl millet research in India (2000-2022).

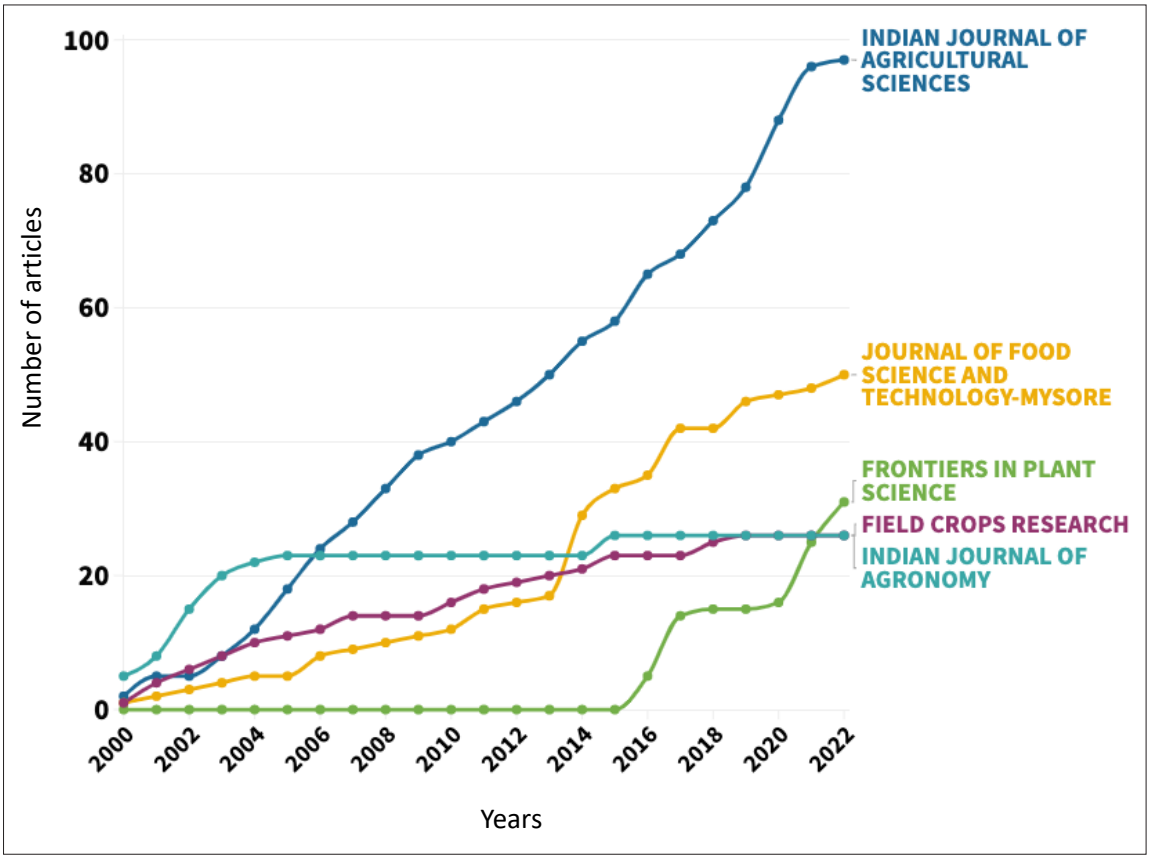

Fig. 6. The growth of number of articles (related to pearl millet research in India) in few top sources during 2000-2022.

reports, that publish only a few articles on the subject. This law helps researchers to identify the most important journals in a particular field and to save time and resources by focusing on the core journals.

The Indian Journal of Agricultural Sciences, Journal of Food Science and Technology-Mysore, and Frontiers in Plant Science are in Zone 1 with the highest frequency and rank, followed by Field Crops Research, Indian Journal of Agronomy, and Range Management and Agroforestry. The remaining sources including Indian Journal of Genetics and Plant Breeding, Research on Crops, Crop Science, and Current Science are also present in Zone 1 with relatively lower frequency and rank.

Source dynamics

Among the top five sources, Indian Journal of Agricultural Sciences showed the highest growth from 2 in 2000 to 97 in 2022, which is a significant increase in the number of articles published. Similarly, Journal of Food Science and Technology-Mysore and Field Crops Research also showed considerable growth in the number of articles published in the last decade. Frontiers in Plant Science started publishing a significant number of articles after 2015, reaching 31 by 2022. In contrast, the number of articles published in Indian Journal of Agronomy remained relatively stable throughout the years (Fig. 6). Overall, the data suggests that the Indian Journal of Agricultural Sciences is the most popular source among the top five sources and is increasing in popularity over time.

Most relevant authors

Among the authors, "Shetty HS" has the highest number of articles at 66 and the highest fractionalized articles at 15.91. The second most productive author in terms of fractionalized articles is "Yadav OP" with 12.60 fractionalized articles from 31 total articles. Therefore, the top five most relevant authors are Shetty HS, Yadav OP, VadezV, Rai KN, and Hash CT, who have 15.91, 12.60, 8.33, 8.25, and 7.60 fractionalized articles, respectively. Overall, the data suggests that these authors have made significant contributions in their

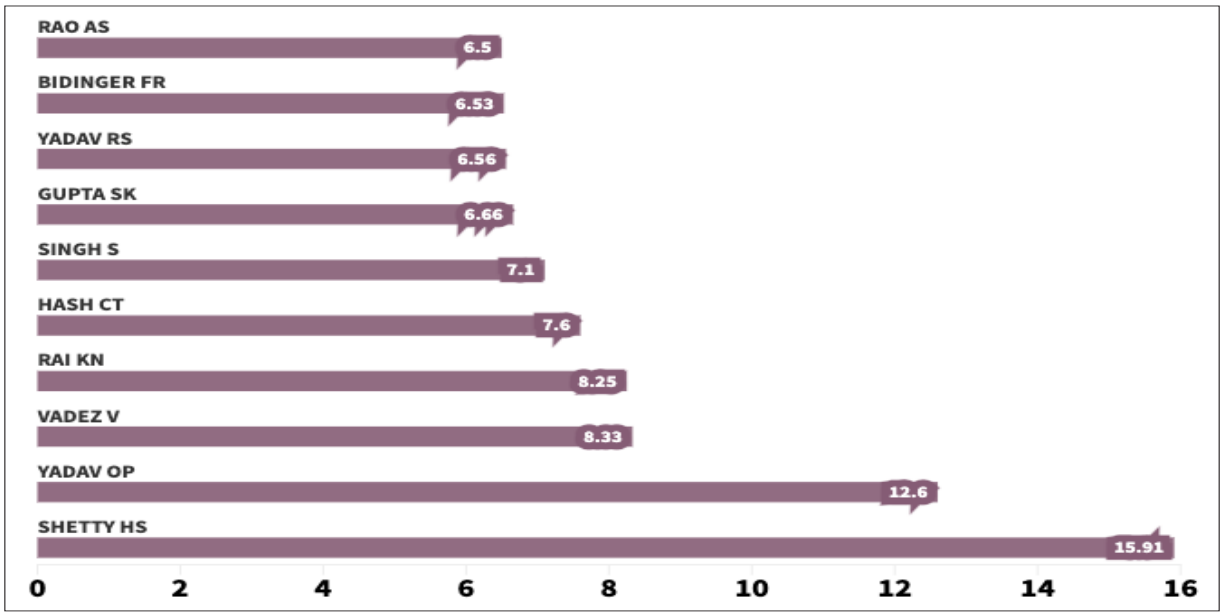

Fig. 7. Top relevant authors on pearl millet research in India during 2000-2022. These authors are sorted based on fractionalized articles (not the number of total articles).

respective fields and have produced a large number of articles, with a considerable fraction of them being highly relevant. If we consider only the number of articles published by each author, Shetty HS holds the first position with 66 articles, followed by Hash CT, Gupta SK, Vadez V, and Rai KN, who have published 48, 40, 40, and 39 articles, respectively. Kumar A, Kumar S, Yadav RS, Yadav OP, and Govindaraj M complete the list with 36, 34, 32, 31, and 30 articles, respectively (Fig. 7).

In scientometrics, the number of articles refers to the total number of articles published by a particular author in a given field or topic. On the other hand, the articles fractionalized metric takes into account the number of authors contributing to a particular article, and divides the credit for that article among them based on a predetermined formula. The difference between the number of articles and articles fractionalized is that the former only considers the total number of articles published by an author, regardless of the number of co-authors on each article, while the latter takes into account the collaborative nature of research and credits each author with a fraction of the article based on their contribution.In other words, the number of articles metric gives equal weight

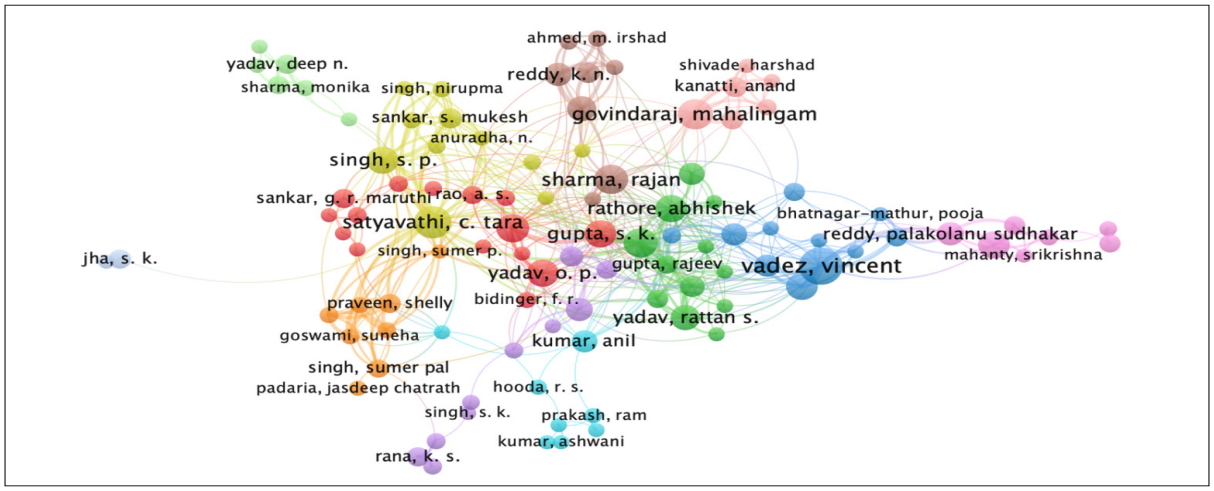

Fig. 8. Network analysis showing the collaboration of relevant authors on pearl millet research in India during 2000-2022. The size of the bubbles represents the contribution of each author in their respective clusters.

to all articles, regardless of the number of co-authors, while articles fractionalized accounts for the varying degrees of contribution made by each author on a per-article basis. Further, we could find the collaborations of these relevant authors in several articles, which is presented in Fig. 8.

Most relevant affiliations

Out of the total articles analyzed, 292 articles were affiliated with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), making it the most prominent affiliation in the dataset. Following ICRISAT, the University of Mysore had the second highest number of articles with 123, while ICAR-Indian Agricultural Research Institute (ICAR-IARI) had 169 articles. The affiliation with the lowest number of articles was Anand Agricultural University (AAU), Anand, with only 26 articles (Fig. 9). It is worth noting that some articles may have multiple affiliations, and therefore the total number of articles exceeds the number of affiliations listed. Overall, this data can be useful in identifying prominent research institutions and understanding their contribution to specific research areas.

Most globally cited documents

The study by Varshney *et al.* (2017) in Nature Biotechnology has received the highest number of citations with 228. The paper discussed the pearl millet genome sequence that could provide a resource to improve agronomic traits in arid environments. This is followed by Ghosh *et al.* (2004) with 186 citations. Ghosh *et al.* (2004) assessed yield, competition and economics in a groundnut/cereal fodder intercropping system compared with mono-cropped groundnut. Maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* L.) were grown for fodder. The study by Kholová *et al.* (2010a) and Kholová *et al.* (2010b) in the Journal of Experimental Botany received 183 and 170 citations, respectively. Kholová *et al.* (2010a) tested whether the terminal drought-tolerant pearl millet have high leaf ABA and limit transpiration at high vapour pressure deficit. Kholová *et al.* (2010b) investigated whether the control of water loss under non-limiting water conditions is involved in the terminal drought tolerance of pearl millet. Masto *et al.* (2007) and Masto *et al.* (2008) received 175 and

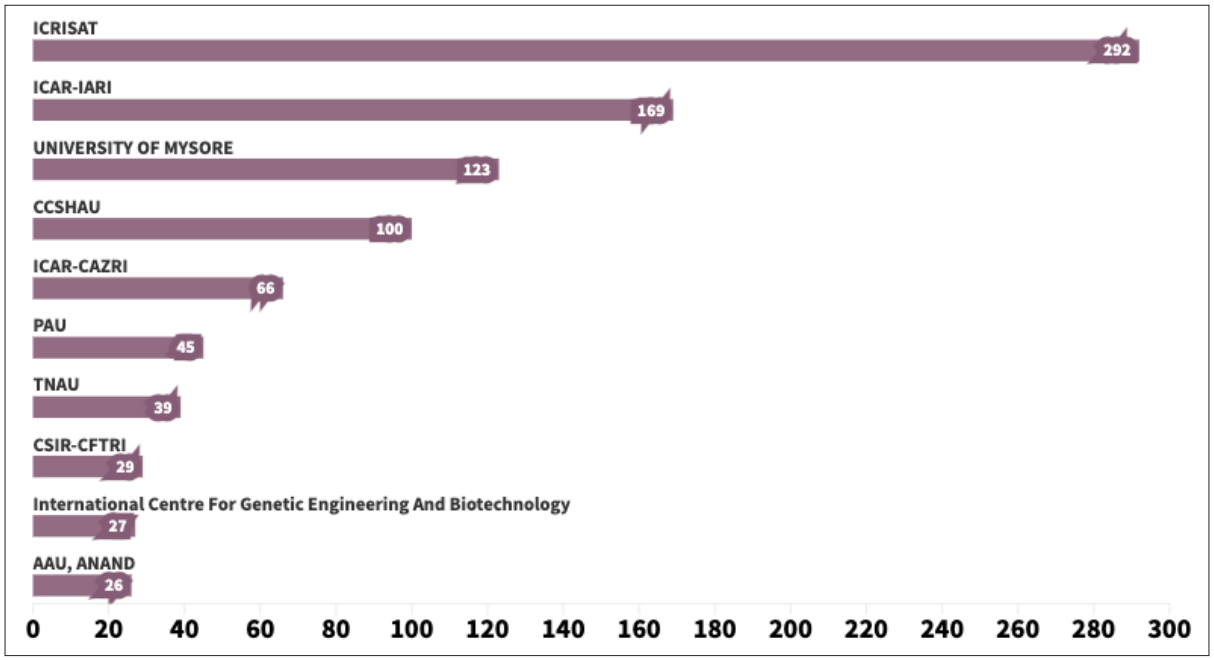

Fig. 9. Most relevant affiliations in India working on pearl millet research during 2000-2022. The numbers represent their total number of articles from 2000-2022. ICRISAT: International Crops Research Institute for the Semi-Arid Tropics; ICAR-IARI: ICAR-Indian Agricultural Research Institute, CCSHAU: Chaudhary Charan Singh Haryana Agricultural University; ICAR-CAZRI: ICAR-Central Arid Zone Research Institute; PAU: Punjab Agricultural University; TNAU: Tamil Nadu Agricultural University; CSIR-CFTRI: CSIR - Central Food Technological Research Institute; AAU, Anand: Anand Agricultural University.

Table 1. Top globally cited papers related to pearl millet research in India during 2000-2022

Paper	DOI	Total Citations
VARSHNEY RK, 2017, NAT BIOTECHNOL	10.1038/nbt.3943	228
GHOSH PK, 2004, FIELD CROP RES	10.1016/j.fcr.2004.01.015	186
KHOLOVÁJ, 2010a, J EXP BOT	10.1093/jxb/erp314	183
MASTO RE, 2007, AGR ECOSYST ENVIRON	10.1016/j.agee.2006.05.008	175
KHOLOVÁJ, 2010b, J EXP BOT	10.1093/jxb/erq013	170
MASTO RE, 2008, ENVIRON MONIT ASSESS	10.1007/s10661-007-9697-z	168
SRINIVASARAO C, 2014, LAND DEGRAD DEV	10.1002/ldr.1158	140
AGRAWAL H, 2016, FOOD CHEM	10.1016/j.foodchem.2016.02.127	137

168 citations, respectively. Masto *et al.* (2007) quantified the effects of 10 fertilizer and farm yard manure (FYM) treatments applied for 31 years to a rotation that included maize, pearl millet, wheat (*Triticum aestivum*) and cowpea (*Vigna unguiculata*). Masto *et al.* (2008) developed alternative soil quality indices for evaluating the effect of intensive cropping, fertilisation and manuring for 31 years in the semi-arid soils of India. The paper of Srinivasarao *et al.* (2014) received 140 citations in which the effects of long-term manuring and fertilizer on depletion of soil organic carbon stocks under pearl millet-cluster bean-castor rotation in western India were studied. While Agrawal *et al.* (2016) received 137 citations in which the antioxidative peptide of pearl millet protein hydrolysate was isolated, purified and characterized (Table 1). These results indicate the relevance and significance of these studies in their respective fields, and their contributions to scientific knowledge.

Frequent words

The most frequent words used in the data set are "downy mildew" and "*Sclerospora graminicola*", with 49 and 48 occurrences respectively. "Yield" is the third most frequent word, appearing 36 times, followed by "drought" and "zinc" with 23 and 22 occurrences respectively. The terms "economics" and "intercropping" are tied for sixth place with 20 occurrences, while "iron" and "productivity" each appear 19 times. Finally, the word "biofortification" appears 18 times (Fig. 10). Overall, the data suggests a focus on plant diseases and their effects on yield, as well as efforts to improve plant nutrition and productivity through the use of fertilizers and intercropping. Additionally,

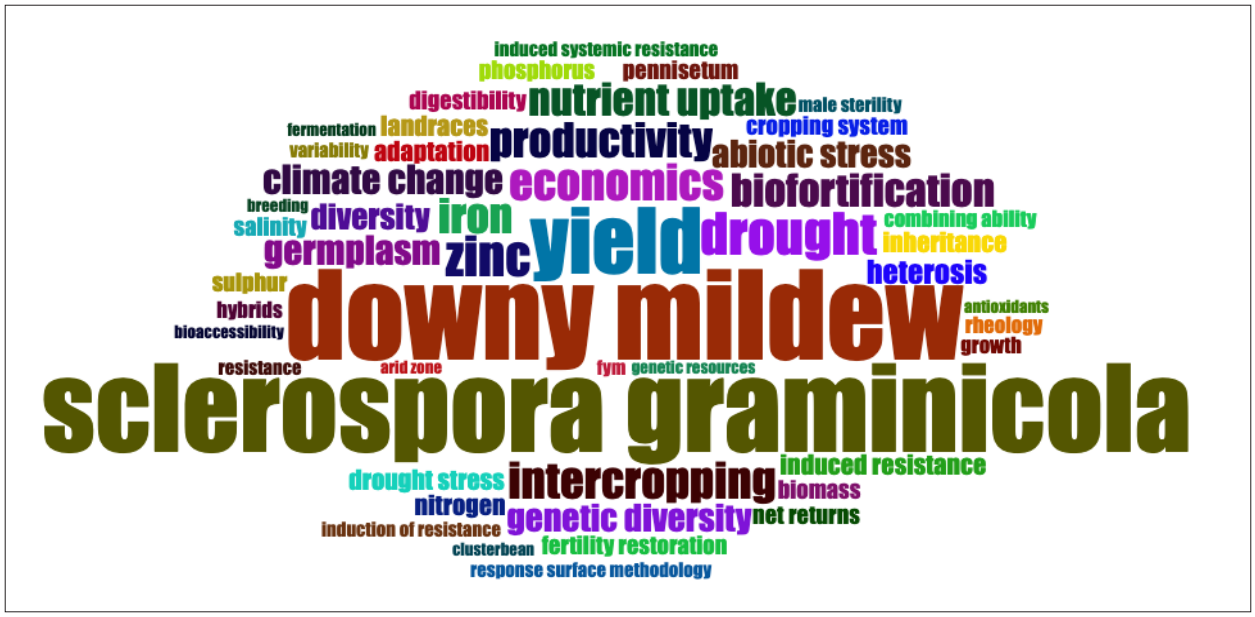

Fig. 10. Word cloud representing the most frequent keywords used in articles related to pearl millet research in India during 2000-2022. The size of these words represents their frequency of occurrences.

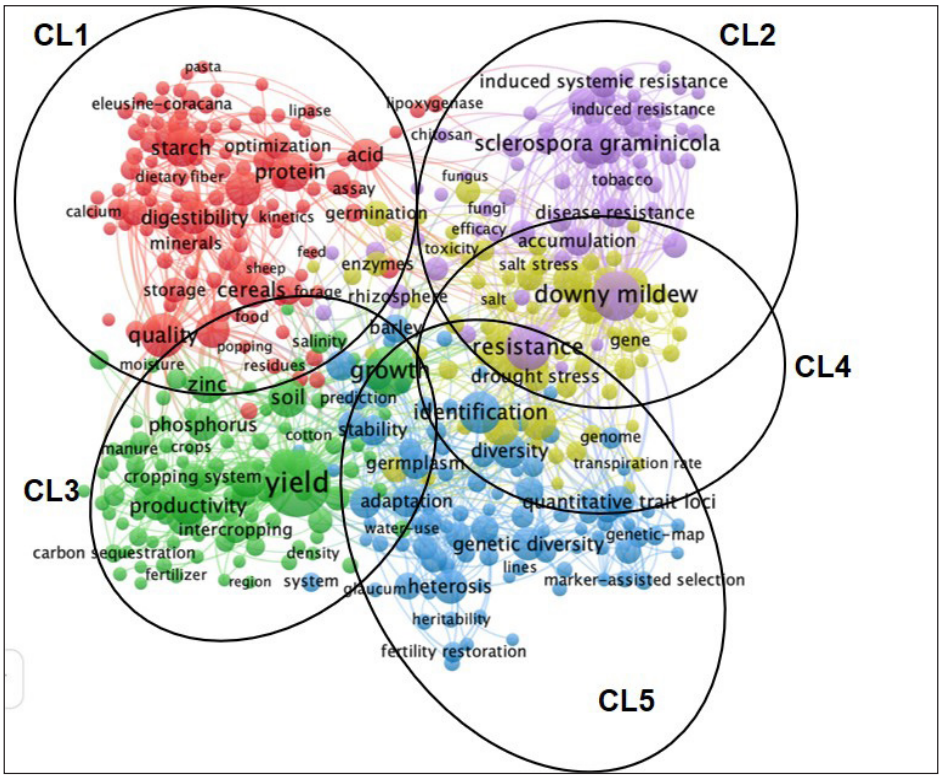

Fig. 11. Network analysis depicting the most common keywords used in articles related to pearl millet research in India during 2000-2022. The size of these words represents their frequency of occurrences.

economic considerations are also being taken into account.

Clustering of keywords

Based on the authors' keywords, we could identify five clusters that could highlight different aspects of pearl millet research in India (Fig. 11). The first cluster (CL1) represents the nutrition aspect of pearl millet research in which keywords such as protein, starch, digestibility, minerals, storage, quality etc. were frequently used (Fig. 11). Pearl millet has a distinct nutritional advantage over other cereals (Sharma and Choudhary, 2012) as it has higher protein content with a remarkable combination of amino acids and relatively elevated levels of vitamin A (Gopalan *et al*., 2003; Rai *et al*., 2008). Additionally, pearl millet is recognized as a "high-energy" cereal due to its relatively greater oil content compared to maize.

The second cluster (CL2) highlights the plant protection aspect of pearl millet research that includes induced systemic resistance, *Sclerospora graminicola*, fungus, induced resistance etc. were shown as most used keywords (Fig. 11). In comparison to wheat, rice, maize and sorghum, pearl millet is relatively less susceptible to pests and diseases. Pearl millet possesses unique anatomy and cell wall structure that make it more tolerant to biotic stress compared to rice and wheat. In India, only five diseases have significant economic impact, including downy mildew caused by *Sclerospora graminicola* (Sacc.) Schroet, blast caused by *Pyricularia grisea* (Cke.) Sacc, smut caused by *Moesziomyces penicillariae* (Bref.) Vanky, ergot caused by *Claviceps fusiformis* (Loveless), and rust caused by *Puccinia substriata* Ellis & Barth. These diseases directly affect grain yield, with downy mildew being the most devastating on susceptible and genetically uniform hybrids. Understanding the biology, epidemiology, and management of downy mildew has been particularly challenging due to its complexity compared to other major pathogens (Shetty *et al*., 2016). However, efforts have been made in recent decades to address these issues and develop resistant cultivars to manage the diseases.

The third cluster (CL3) refers to the agronomic and soil management section of pearl millet with higher frequency of words such as yield, productivity, zinc, phosphorus, intercropping etc. (Fig. 11). This cluster reflects the studies related to increasing the yield of

pearl millet, soil fertilization with essential nutrients, standardisation of fertilizer quantity in pearl millet-based cropping systems, carbon sequestration in these systems. Pearl millet is a robust crop that can thrive in regions with high temperatures and arid conditions, as well as on soils that are unsuitable for cultivating crops such as maize and sorghum. Pearl millet is recognized for its superior ability to use soil moisture and its greater tolerance to heat in comparison to sorghum and maize (Khairwal *et al*., 2007).

Pearl millet faces a daunting task of coping with both drought and heat stress in different agricultural settings of South Asia and Sub-Saharan Africa. While drought is a regular phenomenon, heat stress poses a significant threat in certain areas. The subject of how to enhance drought tolerance in pearl millet has been an important research challenge, and consequently, a considerable amount of work has been carried out to understand and improve its response to drought (Yadav *et al*., 2021). Moreover, the increasing climate change has resulted to high degree of land degradation, salinization and prolonged drought. The fourth cluster (CL4) shows the studies related to the effects of abiotic stress and its management in pearl millet cultivation (Fig. 11).

During the past six decades, significant advancement has been made in India to enhance productivity by creating high-yielding cultivars and enhancing their agronomic management (Jukanti *et al*., 2016). The success of pearl millet breeding is often considered as one of the remarkable achievements in Indian agriculture (Yadav *et al*., 2019), which is highlighted in the fifth cluster (CL5). In this cluster, the frequent keywords are genetic diversity, heterosis, marker-assisted selection etc. (Fig. 11).

Trend topics

The analysis shows that research on legumes, stability, and host-pathogen interaction was prevalent between 2000 and 2008. Later, nitrogen, resistance, phosphorus, induced systemic resistance, biofertilizer, rainfed, and heterosis were in focus between 2004 and 2013. Moreover, downy mildew and *Sclerospora graminicola* gained more attention than any other topics between 2004 and 2013. Starting from 2010, drought, abiotic stress, and zinc became major concerns among researchers, while genetic diversity, economics, intercropping, and productivity remained important topics over the years. Additionally, climate change gained importance from 2016 onwards, and cropping systems, drought

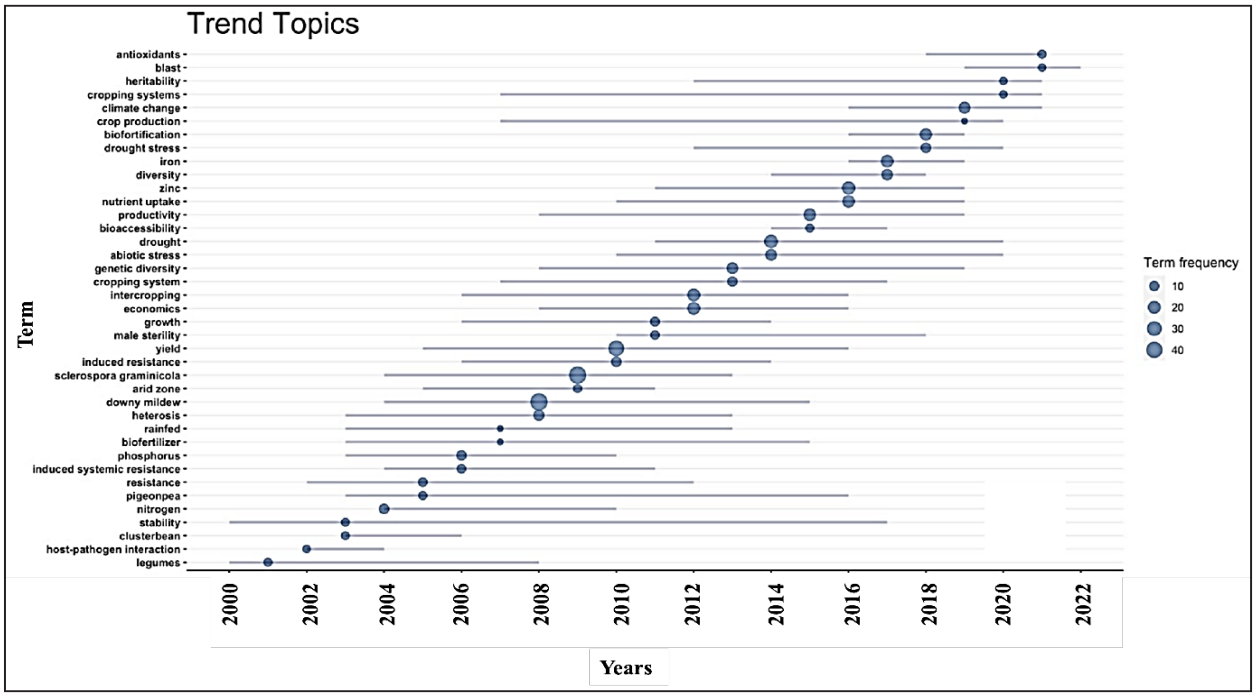

Fig. 12. Evolution of trending topics related to pearl millet research in India during 2000-2022. The size of these words represents their frequency of occurrences.

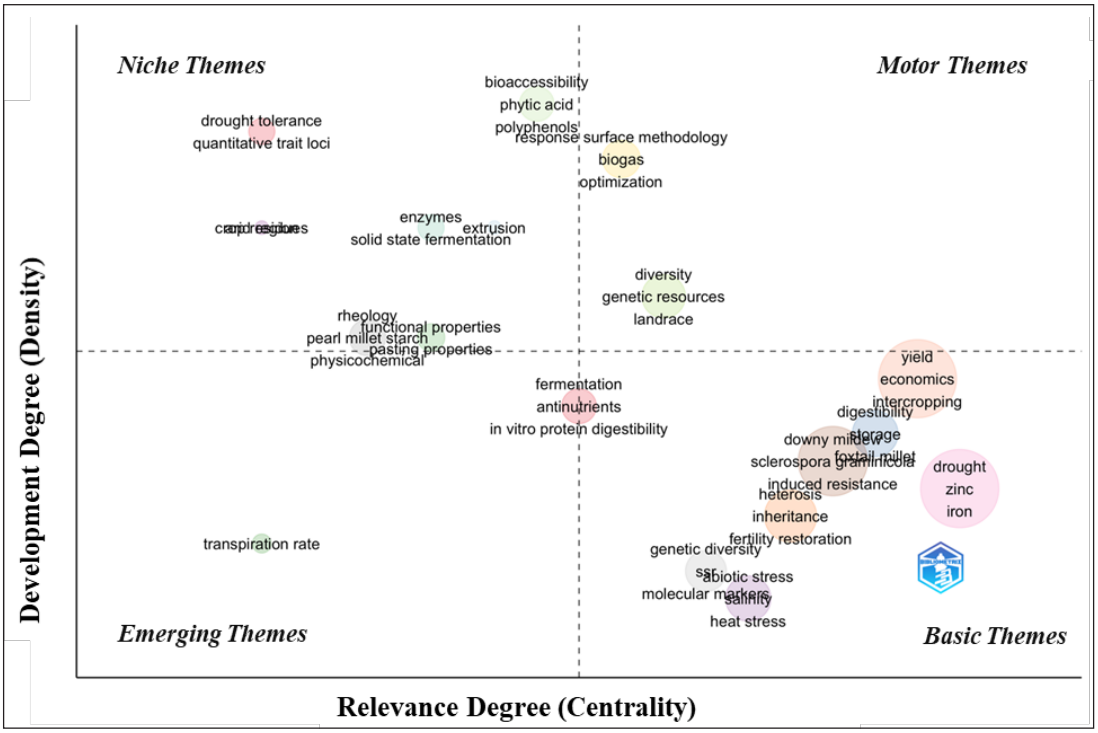

Fig. 13. Thematic map related to pearl millet research in India during 2000-2022. The size of these bubbles represents their importance in their respective themes.

stress, biofortification, diversity, and iron were among the hot topics in recent years. Overall, the analysis suggests that research interests in different agricultural areas are changing over the years, and new challenges like climate change and biofortification have become research priorities (Fig. 12).

Sclerospora graminicola (Sacc.) Schroet. causes downy mildew or 'green ear' disease, which was initially reported in India as a disease of poorly drained lands where it turned into severe epidemics (Butler, 1907). Before 1970, downy mildew was considered a minor issue as it was only sporadic on local cultivars. However, the first epidemic of downy mildew occurred in 1971 on the popular pearl millet hybrid, HB 3, resulting in severe grain loss of around 4.6 million metric tonnes (Singh *et al.*, 1993; Singh, 1995). In some Indian states, the re-occurrence of downy mildew in farmers' fields over the past several years led to the withdrawal of even promising cultivars that were vulnerable to the disease (Singh, 1994; Singh *et al.*, 1997).

Pearl millet is a crucial component of ensuring food and nutrition security for the impoverished communities residing in arid and semi-arid regions across the globe. Although it was once considered a neglected and underutilized crop, pearl millet is abundant in nutrients and exhibits exceptional resilience towards extreme environmental conditions such as salinity, drought, and high temperatures. Furthermore, pearl millet can produce a high yield using limited resources. Micronutrient deficiency, also known as "hidden hunger," is still prevalent in developing nations, especially in areas with poor soil quality, where the populace cannot afford nutrient supplements. Therefore, improving the nutritional value of indigenous, climate-resilient staple crops such as pearl millet can effectively tackle the issue of micronutrient malnutrition.

Thematic map

The analysis revealed four themes (Fig. 13):

(a) Emerging themes are those that are gaining attention and interest among researchers and are beginning to establish themselves as important areas of study. Topics such as plant transpiration, soil physico-chemical properties, fermentation, presence of anti-nutrients, *in-vitro* protein digestibility fell in the emerging theme section.

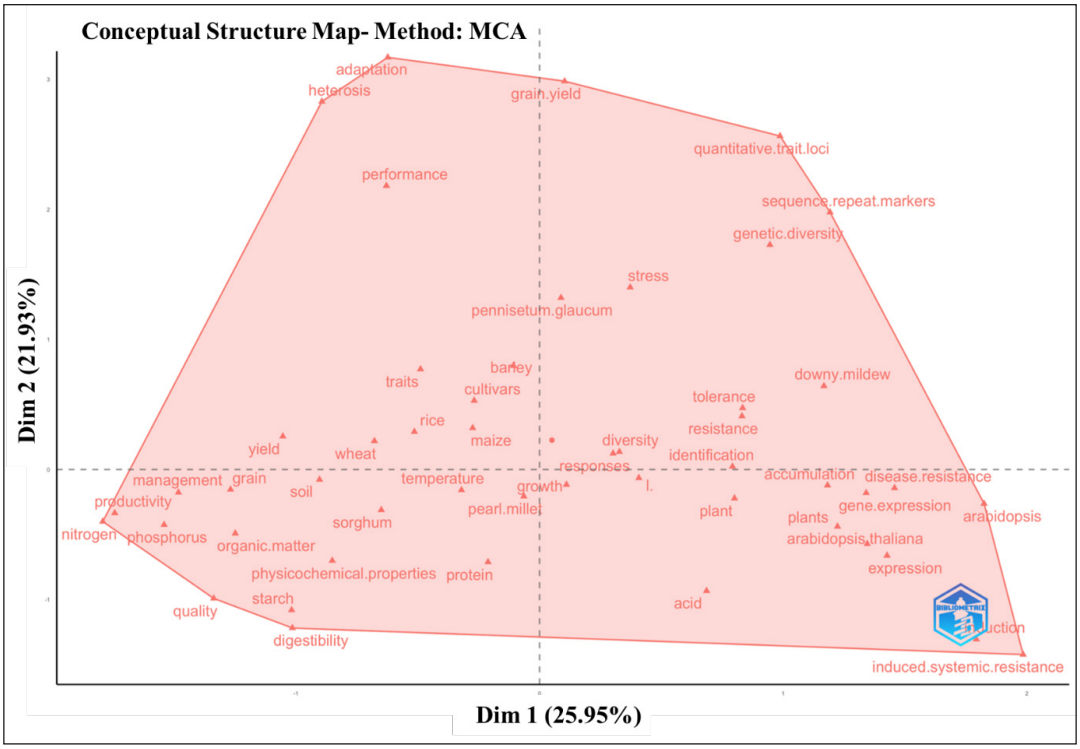

Fig. 14. Factorial map related to pearl millet research in India during 2000-2022.

(b) Motor themes are themes that have a large number of publications and citations and are frequently researched, indicating their importance and influence in the field. In our case, biogas, genetic resources, diversity and landrace were under motor themes.

(c) Basic themes, on the other hand, are those that have been studied for a long time and are considered to be foundational to the field such as drought, downy mildew, heat stress, heterosis. These themes often form the basis for emerging and niche themes as researchers build upon existing knowledge and expand the boundaries of the field.

(d) In scientometrics, niche themes are those that are less frequently researched but have potential for growth and development. These themes often involve narrow topics and may be specific to a certain field or regions, such as enzymes, solid state fermentation, extrusion etc.

Factorial analysis

The factorial analysis of the keywords in pearl millet research in India resulted in a list of words and their corresponding coordinates in a two-dimensional space. The first dimension (Dim.1) explains the majority of the variation and is positively associated with traits related to yield, economics, iron, zinc, biomass, phosphorus, sulphur, growth, and net returns. On the other hand, it is negatively associated with traits related to downy mildew, *Sclerospora graminicola*, heterosis, fertility restoration, inheritance, induced systemic resistance, and male sterility. The second dimension (Dim.2) is positively associated with genetic diversity, induced resistance, and response surface methodology. These results suggest that research on pearl millet in India has focused on increasing yield and improving the economic returns of cultivation through improved nutrient uptake and better crop management practices (Fig. 14). Furthermore, the negative association of certain traits with Dim.1 highlights the importance of addressing biotic and abiotic stresses in pearl millet cultivation. The importance of these data lies in providing insights into the research trends and priorities in pearl millet cultivation in India, which can guide future research and development efforts in this area.

Limitations of the study

1. Limited to published literature: Scientometric analysis is limited to published literature, and it may not include the latest

research findings or unpublished data. This limitation may cause bias in the analysis, and it may not give a complete picture of the research landscape. Therefore, in order to avoid such biasness in this study, we accessed Web of Science which offers a comprehensive coverage and indexes a large number of high-quality scientific journals, books, and conference proceedings from different subject areas. As a result, it provides an extensive coverage of the research output, making it an ideal source for scientometric analysis. Web of Science uses a rigorous selection process to ensure that only high-quality, peer-reviewed publications are included in the database. This ensures that the data is reliable and valid, making it a useful resource for scientometric analysis.

2. Quality of data: Scientometric analysis relies on the quality of data provided in bibliographic databases. Errors in data entry, incomplete or inaccurate citation information, and inconsistencies in author name and affiliation can limit the accuracy and reliability of scientometric analysis. Despite these limitations, bibliographic databases provide a valuable source of data for scientometric analysis, and many efforts through the filtering process of this study have been made to improve the quality of data in these databases.

3. Biases in citation behaviour: The citation behaviour of researchers can be influenced by factors such as language, geography, and disciplinary norms, which can result in biases in scientometric analysis. Despite these biases, scientometric analysis can provide valuable insights into patterns of citation behaviour and the impact of research on the broader scientific community. Moreover, by identifying biases in citation behaviour, scientometric analysis can help to inform strategies for promoting greater diversity and inclusivity in research.

4. Limited scope of analysis: Scientometric analysis is limited to the analysis of quantitative data, such as citation counts and author affiliations, and it may not capture qualitative aspects of research, such as the quality or impact of individual studies. However, scientometric analysis can provide valuable insights into patterns of research output, and impact, which can inform research policy and practice. Moreover, by complementing qualitative analysis with quantitative data, scientometric analysis can help to provide a more comprehensive understanding of research activity and impact. There is a risk of exclusion of certain papers since these articles are selected through Web of Science subject categories related to agriculture. However, all disciplines related directly or indirectly to agriculture were selected during the filtering of the meta-data.

Conclusions

The scientometric analysis examined 1,186 documents from a range of sources, including books, journals, and other documents. The findings revealed that pearl millet research in India has experienced a consistent increase in scientific output over the past twenty years, with a significant rise in recent times. Indian journals were highlighted as prominent sources of several articles, with a particular focus on downy mildew. Research areas in pearl millet in India were grouped into different categories such as breeding, genetics, soil, agronomic management, and plant protection. Future researchers should pay close attention to the pearl millet research in India, as it is a crucial drought-tolerant crop that needs to be thoroughly studied in the face of changing climate conditions. There are several ways to address this issue, such as supporting the scientists currently working on pearl millet or enhancing research facilities to improve the quality of research. There are several potential areas for future pearl millet research in India. One such area could be the development of new cultivars with improved resistance to biotic and abiotic stresses, as well as better yields. Another area of research could focus on optimizing agronomic management practices, such as crop rotation and fertilization, to improve crop productivity and sustainability. Additionally, there is scope for exploring the nutritional benefits of pearl millet and developing value-added products. Finally, research on the use of modern biotechnological tools could help accelerate the pace of pearl millet improvement in India. Overall, this scientometric study highlighted the growth of pearl millet research in India and identified certain themes where most of the experiments are being conducted during these two decades.

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