



REVIEW ARTICLE

# Bibliometric analysis of millet technology adoption: Exploring the research innovation for sustenance

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## ARTICLE HISTORY

Received: 26 January 2025

Accepted: 12 March 2025

Available online

Version 1.0 : 19 March 2025



## Additional information

**Peer review:** Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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## CITE THIS ARTICLE

Vennila MA, Harini S, Srividhya S, Sivakumar K, Deivamani M. Bibliometric analysis of millet technology adoption: Exploring the research innovation for sustenance. Plant Science Today (Early Access). <https://doi.org/10.14719/pst.7435>

## Abstract

As per The United Nations General Assembly, the international year of millets was declared to be 2023 with the motto of achieving sustainable production of millets and raising awareness about their nutritional and health benefits. This study aims to identify and analyze scientific literature on millet varieties and technologies using Bibliometric analysis. The primary objective is to uncover the main topics, authors, sources, most-cited articles and contributing countries in this field. For this purpose, articles indexed in the Main Collections of ScienceDirect and Scopus between 2018 and 2024 were examined. The findings are presented in two parts. The first part includes a quantitative analysis, providing an overview of millet varieties and technologies through tables, graphs and maps. Key performance indicators such as article production and citation metrics are highlighted. A total of 55 articles were identified and analyzed in this study, offering valuable insights into the literature landscape. The analysis reveals that millet varieties and technologies have broad applications across various domains, ranging from adoption and livelihoods to emerging trends. The most cited papers primarily focus on millet's role in climate resilience, food security and health benefits. Additionally, recent trends indicate a growing interest in value-added millet products and sustainable farming practices. These findings underline the increasing importance of millet in addressing contemporary agricultural challenges. The study also highlights its significance in promoting food security and sustainable development, as millet technologies are adaptable to diverse environments and play a vital role in enhancing resilience to climate change. In conclusion, it emphasizes their multifaceted role and provides a robust foundation for future research and policy-making, aiming to leverage millet's potential for sustainable agricultural development and improved livelihoods worldwide.

## Keywords

adoption; bibliometrics; emerging trends; millet; systematic literature review

## Introduction

Millets, small-seeded cereals belonging to the Poaceae family, are widely cultivated in dry and tropical regions of Asia and Africa. Evidence of millet consumption dates back to the Indus Valley Civilization around 3000 BC, making them among the earliest domesticated crops. Globally, millets are significant cereal grains, ranking just behind wheat, rice, maize and barley (1). Known for their sustainability, millets require minimal inputs and can

withstand harsh biotic and abiotic conditions (2). Major millets include sorghum, pearl and finger millet, while minor millets comprise foxtail, proso, kodo, barnyard and little millet (3). Due to their resilience and high nutritional value, millets are considered essential future crops for overcoming agricultural challenges. With decreasing arable land, food shortages and nutritional deficiencies, it is essential to incorporate millets into the staple diet alongside wheat and rice. Recognizing this, various organizations and researchers have highlighted the importance of millets. The Food and Agriculture Organization (FAO) of the United Nations has underscored millet's potential to improve food and nutrition security, particularly in regions with high malnutrition and poverty (4). Consequently, the FAO declared 2023 the "International Year of Millets. Consumer awareness of the nutritional, economic and ecological benefits of millet has been growing, leading to increased acceptance of millet-based products in India and a rise in entrepreneurs within the organized sector (5). However, food entrepreneurs encounter several challenges, resulting in slower-than-expected growth and indicating a need for further research. The COVID-19 pandemic also heightened global uncertainty and anxiety (6). Millets are nutritionally superior to widely promoted grains like rice and wheat, offering three to five times more proteins, minerals and vitamins. They provide nutritious grain and fodder quickly and can be stored for long periods under ordinary conditions, earning them the title of "famine reserves." The government has rebranded millets such as jowar, bajra and ragi as "Nutri Cereals," moving away from the term "coarse cereals" (7). India is the leading producer of sorghum and millets, contributing to more than 80 % of Asia's total production. India leads in millet research citations because it is the largest producer and has a strong focus on millet farming. Many universities and research institutes study millets, leading to more scientific publications. Government policies, funding and promotion of millets also boost research. This helps global millet research by sharing knowledge, improving cultivation methods and supporting food security worldwide (8). Millets have been a staple food in India for centuries, especially in arid regions where other crops struggle. India cultivates millets on approximately 12.7 million acres, producing 16.9 million tonnes, which constitutes about 6 % of the nation's total food grain output (9). For millet cultivation to thrive, farmers need access to modern techniques, best practices and relevant information. Existing millet adoption studies often lack detailed insights into key factors influencing farmers' decisions. Many studies focus on production but do not explore barriers like market access, policy support, or awareness of millet benefits. There is also limited research on how socio-economic factors impact adoption rates. Additionally, few studies analyze emerging trends using data-driven methods like bibliometric analysis. This study addresses these gaps by identifying research trends, highlighting influential studies and uncovering areas needing further exploration to improve millet adoption strategies. Unfortunately, many farmers are unaware of millets' nutritional benefits, climate resilience and market potential, limiting widespread adoption and their impact on

food security and sustainable agriculture (10). Recognizing millets' significant potential in addressing global challenges like food security, nutrition and climate change, the United Nations declared 2023 the International Year of Millets (11). Bibliometric analysis helps track research trends in millet studies using data and statistics. It identifies key authors, top institutions and frequently cited papers. Unlike traditional reviews, it provides objective insights through citation analysis and keyword mapping. This method helps find research gaps, emerging trends and global contributions. It supports better policy-making and guides future millet research. The study analyses the previous studies on millet varieties and examines the following research questions: a) which authors and affiliations lead the literature on millet varieties and technologies? b) What are the words that contribute most to the scientific production used in the literature on millet varieties and technologies? c) "What are the current and emerging trends in the adoption of millet varieties at both global and regional levels?"

## Materials and Methods

The SLR methodology is adopted in line with the protocols suggested by the prior literature (12, 13). Since it encourages the analysis of existing research on a particular topic and delivers an analytical understanding of the underpinning Practice (14). We conducted a systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The PRISMA diagram should clearly define screening criteria and exclusions at each stage to enhance transparency and reproducibility. To ensure a systematic review follows PRISMA guidelines, a well-structured keyword selection strategy is essential. First, key terms relevant to the research, such as "millet adoption" and "emerging trends," should be identified. Boolean operators (AND, OR, NOT) refine search queries, while synonyms and related terms expand the search scope. Keywords must be tailored for different databases like Scopus and Web of Science. Pilot searches help refine the strategy and detailed documentation ensures transparency. A well-defined PRISMA diagram and a robust keyword selection process strengthen the review's credibility and replicability (15). We used the Scopus database to search. Scopus-indexed data may have biases as it mainly includes well-established journals, sometimes overlooking research from smaller or regional publications. It has strong coverage in fields like health sciences but may underrepresent social sciences and agriculture studies. Web of Science was not included because it has fewer agricultural journals and limited research from developing countries. Other databases like CAB Abstracts may have more agricultural studies but lack strong citation analysis tools. Scopus was chosen because it provides a broad collection of agricultural research, useful bibliometric tools and easy accessibility through university libraries and institutional subscriptions. Many combinations of algorithms related to millet varieties and technologies were applied in the search for research publications. The algorithms used keyword combinations from each of the

following categories. a) Millet varieties and technologies b) future and farmer or millet c) livelihood or enhancement and millet.

Inclusion and exclusion criteria were set for the first screening of the publications (Table 1). The studies that a) include predetermined keywords in the title, abstract, or keywords section of the paper b) take millet varieties and technologies into consideration as an outcome c) have millet varieties as the sample should be used to further extract articles from the screening of titles and abstracts. d) Highly cited authors and institutions in millet research focus on adoption, emerging trends and livelihood impact. Studies on how farmers adopt millet varieties, climate-smart farming and millet's role in improving income and nutrition receive more citations, increasing their influence. Contains a minimum of three millets-related determinants: adoption, trends and livelihood (Table 1).

## Results and Discussion

We employed the Scopus database, which was compatible with the Biblioshiny data analysis program. Only articles with the term "millet varieties" in the headline were included in the search. This is provided in quotation marks so that you can find all the documents with that word combination in the title as well as all the potential combinations with the keywords millets. We also obtained articles with titles containing words linked to production, adoption and livelihood.

It displayed the total number of studies that were found in the database using the previously mentioned search terms. There were 4177 articles found in all from the database search. 4052 articles were purged from the records after being reported as exempt using the inclusion and exclusion criteria decided upon for initial identification (e.g., non-English, restricted access, review papers, etc.) based on the automated filters provided by the databases. This demonstrates that while numerous research measure in millet varieties and technologies. Following the removal of duplicates, 55 articles out of the 73 that remained were excluded. Based on factors such as applicability, relevance and clarity in addressing millet varieties, 55 papers in total were selected for quantitative analysis (Table 2).

**Table 2.** Documents obtained through database searches

DATABASE SCOPUS	SEARCH TERMS	NO OF ARTICLES
1.	"MILLET" AND "PRODUCTION"	1,878
2.	"MILLETS" AND "ADOPTION"	301
3.	"EXTENSION SERVICES" AND "MILLETS"	21
4.	"MILLET" AND "FARMER" AND "NUTRITIONAL" AND "YIELDING"	15
5.	"VALUE" AND "CHAINS" AND "MILLET"	7
6.	"MILLET" AND "VARIETIES"	47
7.	"MILLET" AND "VARIETIES" OR "TECHNOLOGIES"	1,823
8.	"FUTURE" AND "FARMER" OR "MILLET"	65
9.	"LIVELIHOOD" OR "ENHANCEMENT" AND "MILLET"	2
10.	"FOOD" OR "SECURITY" AND "MILLET" AND "FARMER"	4
11.	"MILLET" AND "FARMER" OR "PROMOTION"	14

## Data analysis

The Bibliometrix package is an open-source tool programmed in the R language. This package is capable of performing a comprehensive scientific mapping. It also has several graphical and statistical features with good flexibility and frequent updates (16). We used Bibliometrix features like collaborative network analysis and Strategic mapping. When two or more authors collaborated on an article, the software created a collaborative network. In this way, we were able to understand the dynamics of the production of the studies. Bibliometric trends help identify key research areas, influential authors and emerging topics in millet studies, guiding future policy and technological interventions. Data analysis of citation patterns, keyword trends and research collaborations highlights gaps in adoption, market accessibility and technological advancements. Policymakers can use this data to prioritize funding for under-researched areas, such as value addition and climate-resilient millet varieties. Similarly, technological interventions, like improved seed varieties and mechanization, can be developed based on frequently cited innovations. By tracking bibliometric trends, stakeholders can align research efforts with real-world challenges, ensuring more effective policies and advancements in millet cultivation and processing.

The data covers six years, showing recent trends up to now 31 different sources were used. This means a variety of publications contributed to the research. There are 55 documents in total. This small number suggests the research is focused on a specialized topic. Publications are

**Table 1.** Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Timespan	2018-2023	<2018
Subject area	Social Sciences	Energy, Economics, Econometrics and Finance, Arts and Humanities, Engineering, Medicine, Decision Sciences, Earth and Planetary Sciences, Pharmacology, Toxicology and Pharmaceuticals, Genetics and Molecular Biology, Neuroscience, Nursing, Materials Science, Chemistry and Chemical Engineering.
Document Type	Article	Conference papers, Book chapters, erratum, Conference review, Notes, Book.
Language	English	Chinese, French, German, Portuguese, Korean, Spanish, Russian, Persian, Undefined, Japanese, Hungarian, Ukrainian, Polish, Italian, Czech
Source type	Journal	Book, Conference Proceeding, Book Series, Undefined, Trade Journal
Publication stage	Final	Article in Press
Open access	Open access	Restricted access
<b>Screening</b>		
Title and abstract	Related to millet varieties and technologies	Irrelevant to the millet varieties and their emerging trends

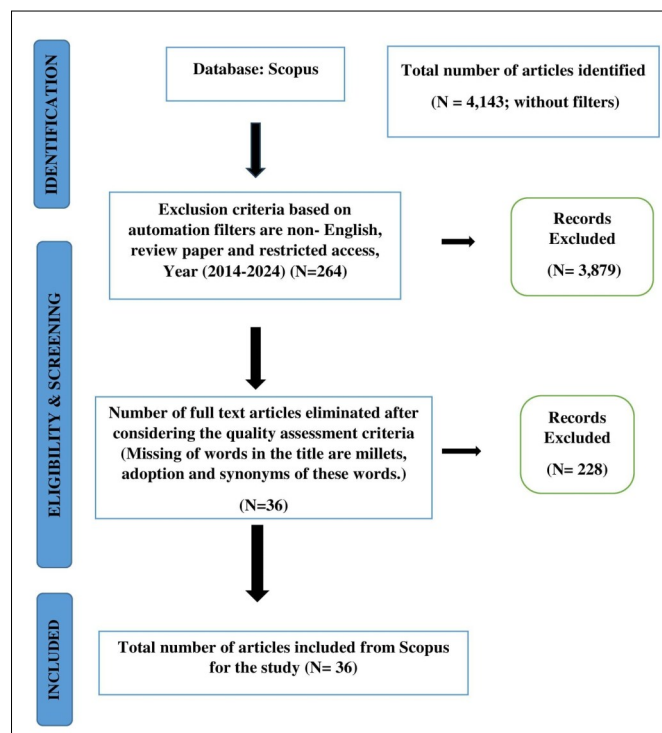
decreasing each year by 25.82 % and it indicate shifting research priorities. This decline could be due to reduced funding, a growing focus on other crops, or the belief that millet research has reached a limit. It may also reflect changing global interests in areas like biotechnology and climate-smart farming. Additionally, fewer studies might result from challenges in research collaboration or limited policy support. Understanding this trend is important to ensure continued research on millets, as they play a key role in food security, nutrition and climate resilience. This might be due to changes in research interests, funding, or the topic becoming less active. The documents are on average almost 3 years old, indicating they are fairly recent. Each document is cited about 13.45 times, showing they are important and often referenced. There are 2510 references across all documents, showing extensive research and thorough reviews. There are 295 Keywords Plus and 262 Author's Keywords. This shows a wide range of specific terms being studied, indicating detailed and complex research topics. 281 authors contributed to the 55 documents, showing high collaboration (Table 3; Fig. 1).

Only 2 authors wrote documents by themselves, highlighting the collaborative nature of this research. There are only 2 single-authored documents, reinforcing that most research is done in teams. On average, each document has about 5.35 co-authors, indicating strong teamwork, possibly across different fields. About half of the documents involve international collaboration, showing the global interest and cooperation in this research area. All 55 documents are articles, emphasizing formal and peer-reviewed research publications. The field of research is specialized and highly collaborative.

Despite a decline in the number of new publications, the documents are recent and widely cited, showing their impact. The research involves significant international cooperation, indicating its global importance. The diverse use of keywords shows the detailed and varied nature of the topics studied.

**Table 3.** Main Information

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2018:2024
Sources (Journals, Books, etc.)	31
Documents	55
Annual Growth Rate %	-25.82
Document Average Age	2.95
Average citations per doc	13.45
References	2510
DOCUMENT CONTENTS	
Keywords Plus (ID)	295
Author's Keywords (DE)	262
AUTHORS	
Authors	281
Authors of single-authored docs	2
AUTHORS COLLABORATION	
Single-authored docs	2
Co-Authors per Doc	5.35
International co-authorships %	50.91
DOCUMENT TYPES	
articles	55



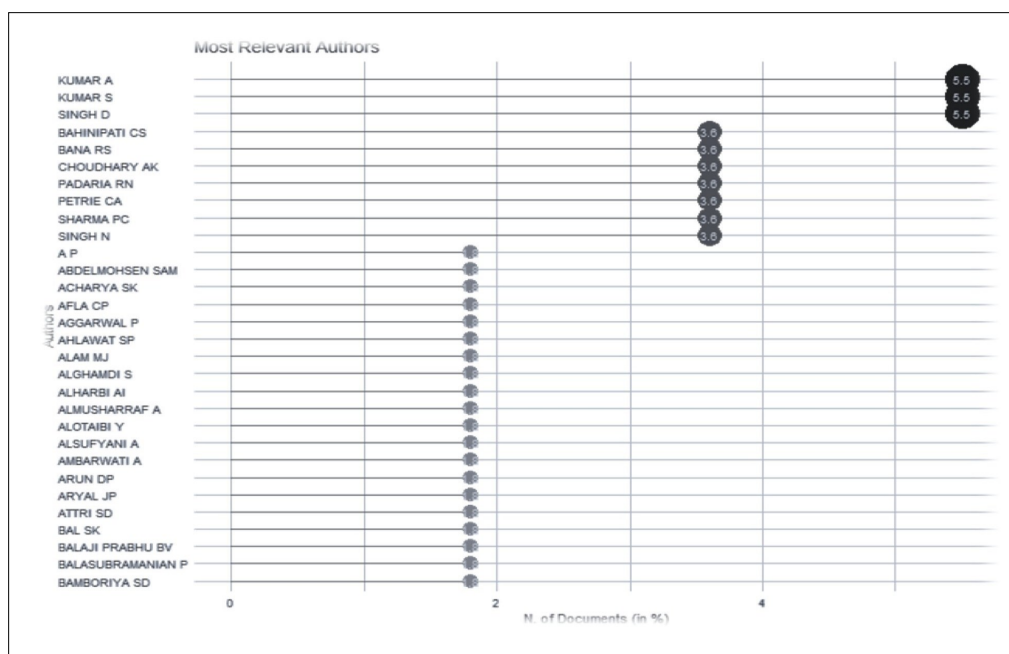
**Fig. 1.** PRISMA flowchart depicting the search literature for a systematic review of social media marketing. (Source adapted from Amitha et al., 2023)

Based on their contributions, the chart shows which writers are most relevant in a certain field of study. The quantity of documents written is shown on the x-axis and the writers' names are shown on the y-axis. For the authors who have published the greatest number of documents, the chart displays certain data points. With 5.5% of documents individually, three authors-Dunn AG, Liang H and Smith M stand out as the most significant writers, according to the chart. Hosking S, Rodriguez AM and Nguyen TQ are among the other groups of authors that have contributed to 3.6 % of documents apiece. Several additional writers, including Anderson P, Brown GS and Wilson K, have each contributed to 1.8 % of papers. With a larger base of writers who have made immense but fewer contributions, this distribution shows a few prominent contributors who are leading in terms of publications. The existence of several writers with massive publication counts points to an engaged and cooperative research community. The field of study is collaborative and these insights aid in identifying the top researchers (Fig. 2).

**[Institution A-** Tamil Nadu Agricultural University; **Institution B-** ICAR- Central Soil Salinity Research Institute; **Institution C, D-** ICAR- Indian Agricultural Research Institute; **Institution E-** International Maize And Wheat Improvement Center (CIMMYT); **Institution F-** ICAR- Central Research Institute For Dryland Agriculture; **Institution G-** Campbell Collaboration; **Institution H-** Centre For Study Of Social Change; **Institution I-** University of Kwazulu-Natal; **Institution J-** World Vegetable Center; **Institution K-** Department of Humanities and Social Sciences.]

Based on the number of papers each institution has generated, the graph shows which researchers within a certain topic have the most relevant affiliations. The quantity of documents is shown on the x-axis and the names of the institutions are listed on the y-axis. "Institution A," which has

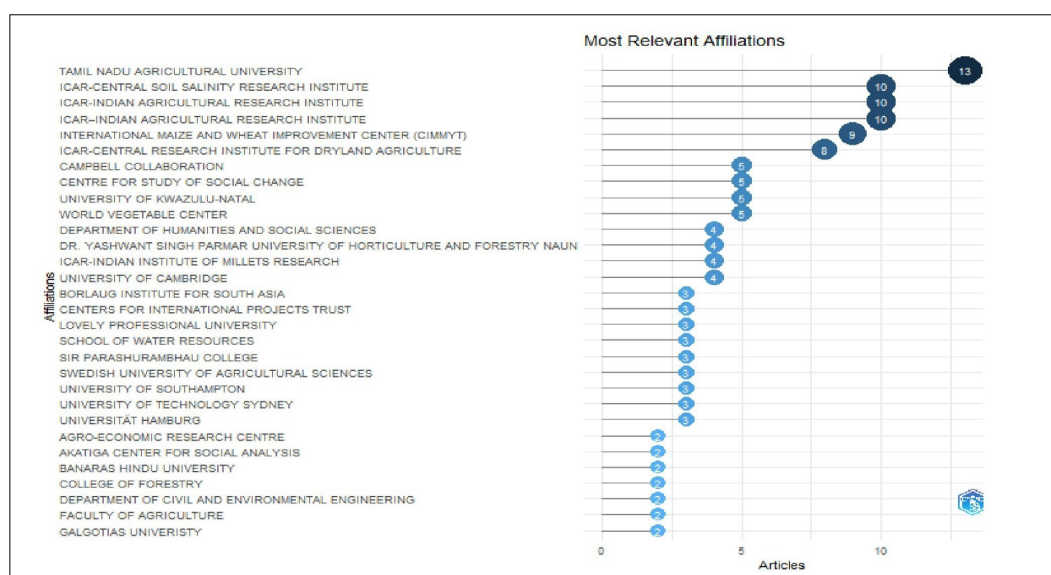




**Fig. 2.** Most relevant authors - Highlighting the leading researchers with the highest number of publications.

13 documents, is the most productive institution and the obvious leader in this field of study, according to the chart. Three institutions, "Institution B", "Institution C" and "Institution D" which each contributed ten documents, are next in line. Nine documents have been created by "Institution E," another institution that has demonstrated a high level of activity. Several establishments, including "Institution F", "Institution G" and "Institution H" have each authored eight publications, indicating their active involvement in this field of study. Several institutions further down, "Institution I", "Institution J" and "Institution K" have each donated five documents. While a wider range of universities actively contributes, although, to a reduced extent, this distribution emphasizes a concentrated contribution from a few significant leading institutions in the research. The data indicates a joint effort across numerous universities and research institutes and highlights the dominance of specific institutions in advancing the study. The research output is probably more dependable and diverse as a result of this collaboration (Fig. 3).

The data presented in the chart illustrates the number of citations for various countries, indicating the most cited countries in a given context. With 351 citations, India is the most cited country by a significant margin. This suggests a high level of academic or research activity, or perhaps a particular focus on subjects related to India. The second most cited country, Thailand has 162 citations. While significantly lower than India, Thailand still stands out compared to other countries. Ranked third, Ethiopia has 64 citations. This indicates a notable amount of research or references, but still far behind India and Thailand. With 27 citations, Germany is the fourth most cited country. This shows a moderate level of citations relative to the top three countries. Switzerland has 22 citations, closely following Germany, indicating a similar level of academic attention. With 19 citations, the Netherlands occupies the sixth position, suggesting some significant research contributions. South Africa and the United Kingdom both countries have 12 citations each, indicating a shared seventh position and suggesting equal academic or research focus. Each country

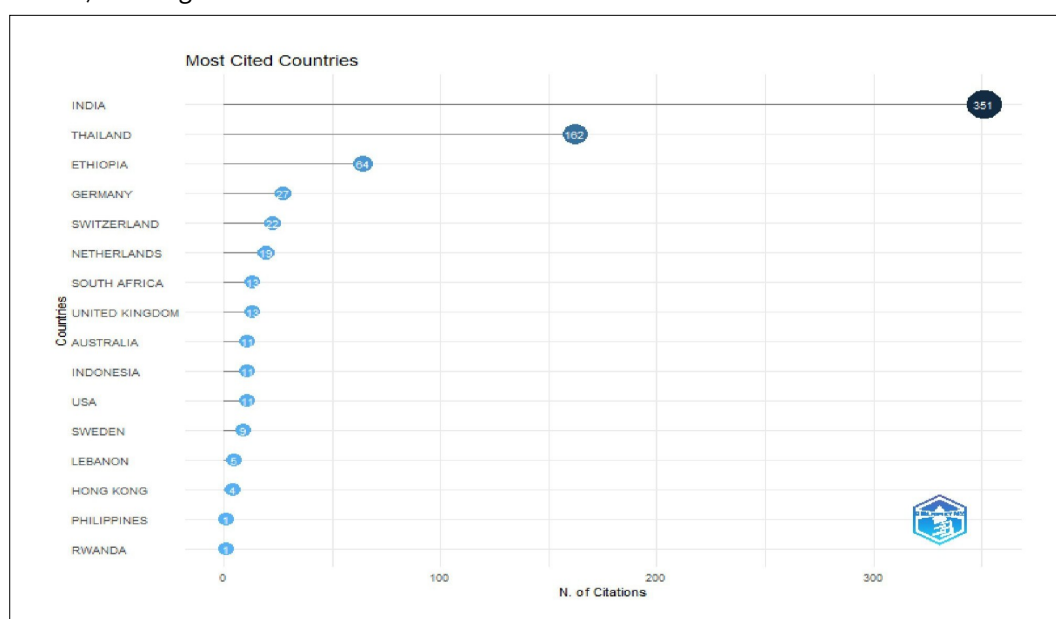


**Fig. 3.** Most relevant affiliations - Emphasizing the institutions with the highest research output.

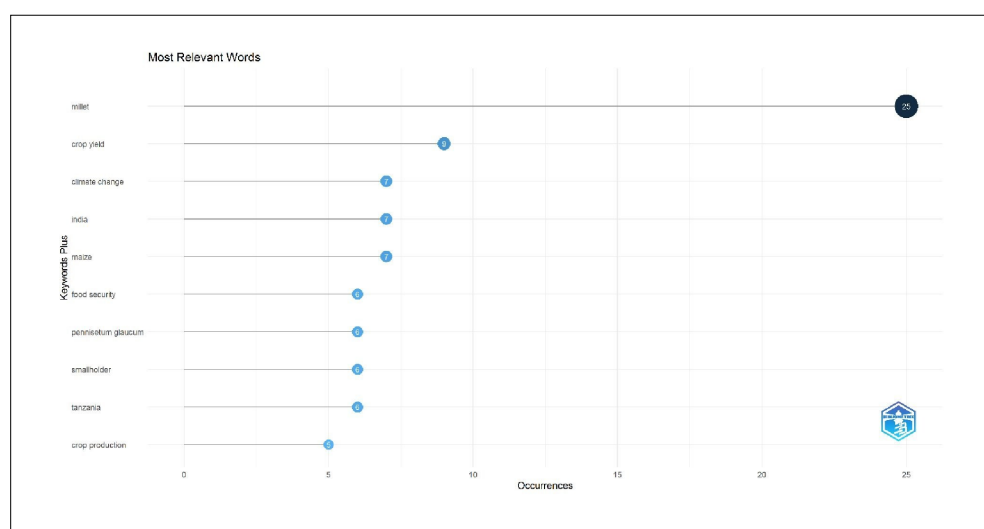
has 11 citations, reflecting a similar level of citation frequency as South Africa and the United Kingdom. With 10 citations, the USA is somewhat surprisingly lower on the list, which could imply a narrower scope of research focus or fewer relevant studies in this specific context. Sweden has 9 citations, showing a modest level of citations. With 5 citations, Lebanon appears towards the lower end of the list, indicating fewer references compared to the others. Hong Kong has 4 citations, suggesting limited academic attention in this context. The Philippines and Rwanda Both have only 1 citation each, indicating very minimal citation frequency. The significant disparity in citation counts highlights the varying levels of academic or research activity and impact across these nations (Fig. 4).

The data presents key terms along with their frequency focused on agricultural research. Millet (35 mentions). This term appears the most frequently, indicating that the article primarily discusses millet, a diverse group of small-seeded grasses widely grown as grains or cereal crops globally. Crop Yield (9 mentions). The frequent occurrence of this term suggests that the review extensively covers crop yield or output, particularly concerning millet. Climate Change (7 mentions). The significant number of mentions

highlights the focus on the impact of climate change on millet cultivation and crop productivity. India (7 mentions) the frequent mention of India implies a substantial part of the study or discussion revolves around India's role as a major millet producer. Corn (7 mentions). The term corn appears frequently, indicating comparisons or connections between millet and corn in terms of yield, farming practices and climate resilience. Food Security (6 mentions). The relevance of this term suggests discussions on how millet contributes to food security, particularly in regions where it is a staple crop. *Pennisetum glaucum* (6 mentions) Also known as pearl millet, this term's frequent use emphasizes a particular focus on this millet variety, highlighting its importance in the review. Smallholder (6 mentions). The repeated mention of smallholder farmers indicates a focus on their roles, challenges and farming practices related to millet production. Tanzania (6 mentions) Similar to India, Tanzania is frequently cited, suggesting the review includes significant case studies or data from this key millet-producing region. Crop Production (5 mentions). This term's usage suggests the review covers broader agricultural production topics, likely discussing methods, innovations and outcomes related to millet (Fig. 5).



**Fig. 4.** Most cited countries - Identifying the nations with the highest citation counts.



**Fig. 5.** Most relevant words - Understanding how specific terms influence research visibility.

## Conclusion

In conclusion, several important areas should be the focus of future studies on the adoption of millet varieties and improving livelihood. To increase food security and prepare for changing climatic conditions, the development and promotion of high-yield, climate-resilient millet cultivars should be prioritized. Furthermore, an extended study is required to determine the socioeconomic effects of millet farming on smallholder farmers, especially in places like Tanzania and India. To improve millet adoption and farmer livelihoods, researchers and policymakers should take key actions. Researchers should focus on developing high-yield and climate-resilient millet varieties, studying how millet farming impacts small farmers and exploring better processing and storage methods. They should also look into modern farming techniques like precision agriculture and promote research collaborations. Policymakers should support millet farmers by providing subsidies, better market access and strong extension services for training. They should also include millet in nutrition programs and encourage public-private partnerships to boost production and value addition. These actions will help increase millet adoption, improve livelihoods and strengthen food security. It will also be essential to investigate highly advanced agricultural techniques and technology that can increase crop yields and sustainability. To ensure that the benefits of research reach those who need them most, policies and support systems that aid in the adoption of enhanced millet varieties and improve farmers' livelihoods should be given priority.

## Acknowledgements

The authors acknowledge and are grateful to the Indian Council of Agricultural Research (ICAR), Government of India, New Delhi for funding this research study.

## Authors' contributions

VMA carried out the Idea and concept framework and drafted the manuscript. HS carried out the statistical design and performed the software analysis. SS participated in the experimental planning and layout of design for the study. SK conceived of the study and participated in its design and coordination. DM participated in the sequence alignment. All authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interests to declare.

**Ethical issues:** None

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