



### RESEARCH ARTICLE

## "VISUALISING TRENDS AND PATTERNS OF THREE DECADES OF RESEARCH ON MILLET PRODUCTION IN INDIA: A SCIENTOMETRICS ANALYSIS"

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### Abstract

This study analyses three decades of Millet Production research in India (1989–2023) with a Scientometrics approach, visualizing trends and patterns in scholarly output. India is the world's largest producer of millet, with significant regional variations in millet cultivation. Major contributing states include Rajasthan, Karnataka, Maharashtra, and Madhya Pradesh. Scientometrics analysis, carried out on the Web of Science database using VOSviewer software, produced 600 publications with 12,028 citations. Development of millet research was found to be consistent with specific growth beginning after 2012, peaking during the International Year of Millets, 2023. Visualization of collaborative networks indicated the core institutions to be ICRISAT and ICAR. Prominent authors including Kumar A and Kumar S, and journals such as the Indian Journal of Agricultural Sciences are also featured in the Table. Keyword analysis showed that the research focus was on "pearl millet," which primarily connects to agriculture and nourishment. Co-authorship and co-citation analyses underscore a robust collaborative environment in terms of research spanning several disciplines, concerning agronomy, biotechnology, and sustainable agriculture. This research focuses on the millet production research arena concerning food security, sustainable agricultural practices, and environmental challenges.

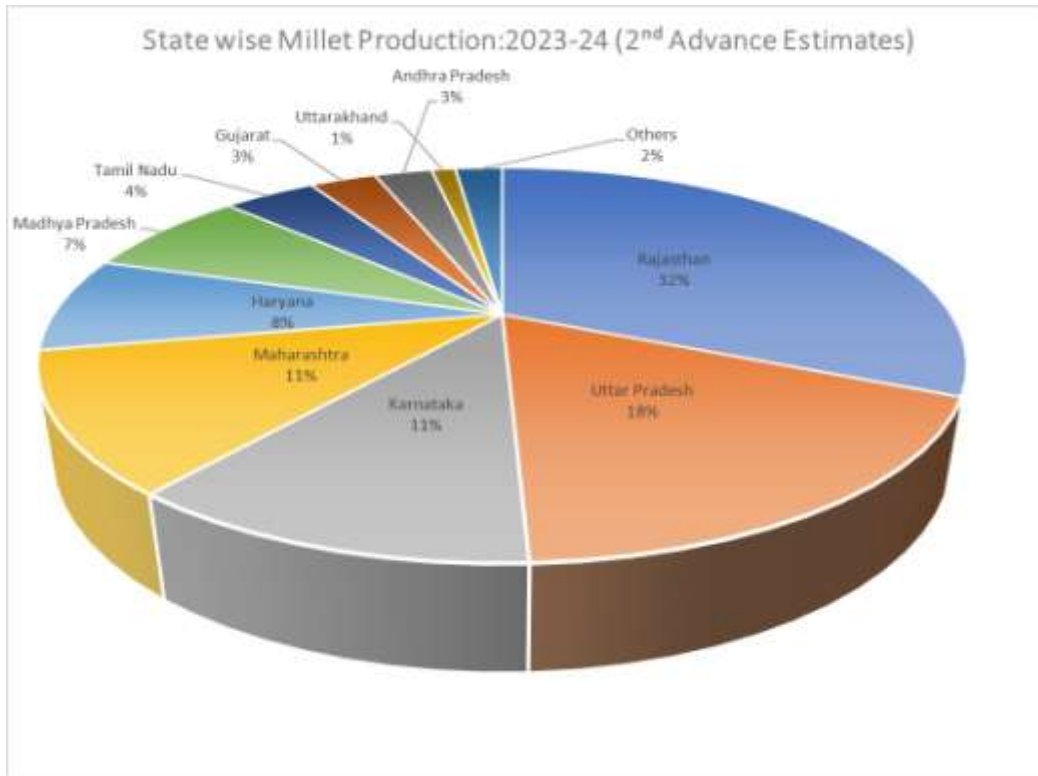
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### Introduction:-

The nutritional advantages, resistance to harsh weather, and potential to improve food security of millet have drawn much attention to its cultivation. Small-seeded grasses with a wide range of varieties known as millets are widely grown as cereal crops, or grains, for global human and animal feeding. The majority of the plants that are referred to be millets belong to the Paniceae tribe. Similar to rice and wheat, millets are cereals, however, they are higher in vitamins, minerals, and proteins. India's three most popular millets are ragi, pearl millet, and sorghum, often called Jowar, Bajra, and Finger millet, respectively. Millet Production in India plays a vital role in the country's agricultural landscape, contributing significantly to food security and rural livelihoods. Millets, which include varieties like pearl millet, finger millet, sorghum, and minor millets such as foxtail and little millet, are known for their resilience to harsh climates and poor soil conditions, making them an essential crop for sustainable agriculture in arid and semi-arid regions. These cereals are also rich in nutrients, offering substantial health benefits, which has led to a resurgence in their popularity as a superfood.

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Source:<https://apeda.gov.in/milletportal/Production.html>

India is one of the largest producers of millets globally, with production primarily concentrated in states like Rajasthan, Karnataka, Maharashtra, Uttar Pradesh, and Madhya Pradesh. Rajasthan leads the country in pearl millet production, leveraging its hot and dry climate. Karnataka is the top producer of finger millet, benefiting from its favorable growing conditions in the southern plateau. Maharashtra and Uttar Pradesh are also significant producers of sorghum, while Madhya Pradesh contributes largely to the production of minor millets. These regional differences in millet production reflect the adaptation of specific millet varieties to local environmental conditions, highlighting the crop's importance to India's diverse agricultural economy. Currently, the combined output of millet in India's 10 states is expected to be around 98% between 2023 and 2024 (2<sup>nd</sup> Advance Estimates). Thirteen percent of India's total millet output comes from Rajasthan. Many types of millets include canary seeds, Jowar (sorghum), ragi (finger millet), buckwheat, and Bajra (pearl millets). Pearl millet (Bajra) and sorghum (jowar) make up most of India's overall production.

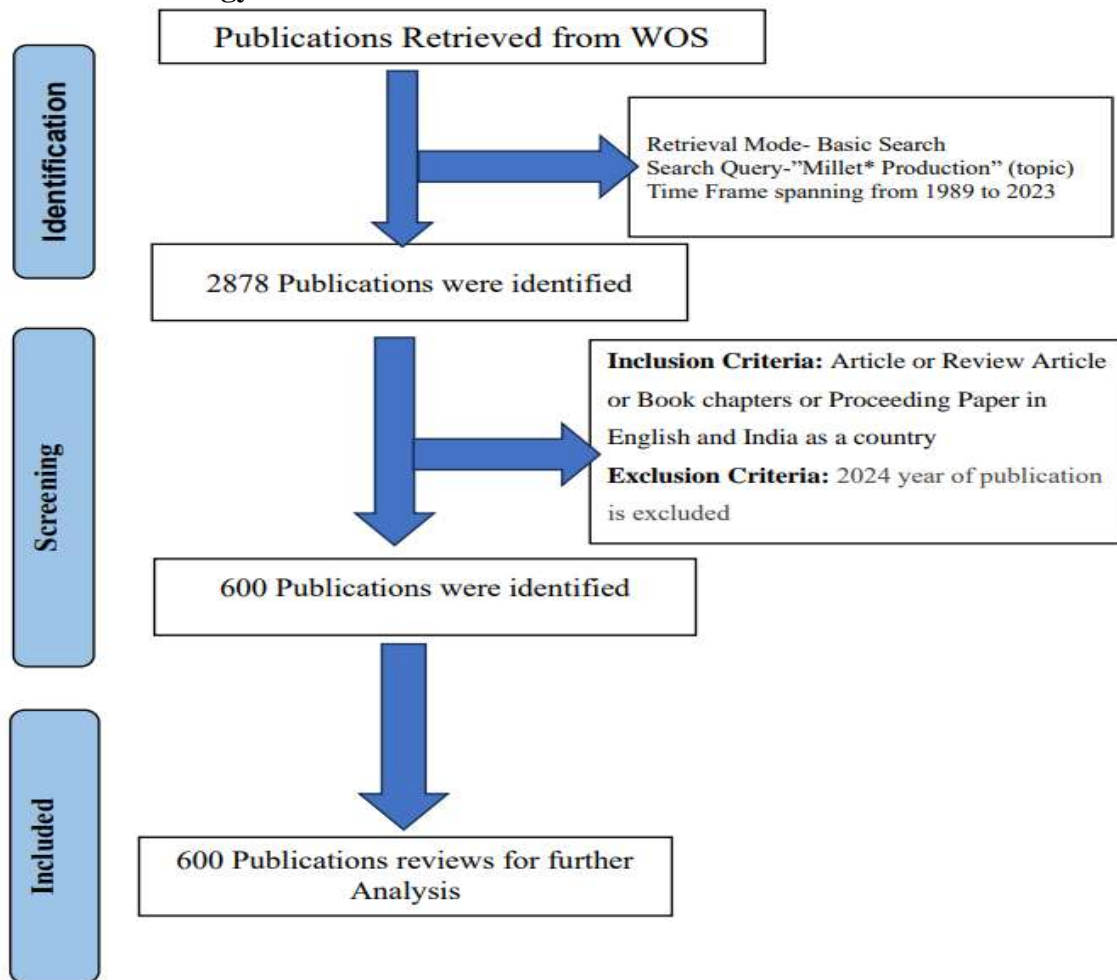
A useful method for evaluating the state of the field, seeing patterns, and delving into the dynamics of millet production research is Scientometric analysis. Scientometrics is a sub-field of bibliometrics. Scientometrics refers to the application of quantitative science methods. The term was coined with the establishment of the journal's name 'Scientometrics' by T. Braunin in 1977. Scientometrics is the measurement and analysis of scientific literature to understand the direction, scope, and magnitude of scientific research. Quantitative techniques in output and impact comparison and evaluation of an individual academic, journal, or organization include publication counts and citation analysis. Scientometrics provide insight into the development processes of science and collaboration between the disciplines due to trends in academic publishing and citations. Vijesh P.V., Joseph M. K., and Anupama A. (2023) conducted a study by using the WOS database to do a Scientometrics analysis for the years 2005–2023 to analyze and study the present status of millets research in India. The authors examined the millet research and publishing output of the WOS database from 2005 to 2023 using the biblioshiny program. For analysis, from the WOS database, a total of 432 papers were selected. Various analysis was done based on average citations per year, most relevant sources, annual scientific publications most prolific authors, most prolific affiliations, most occurrences words, Research trend topics, top Productive institutions, etc., the paper examined the broad characteristics of millet research output. K.C. Anandraj et al. (2023) examine research papers on millet that were obtained from the WOS database and from 1989 to 2022, the period was taken. By looking at 3,373 papers out of 11,585 worldwide, the paper seeks to conduct a Scientometrics study of Millet research productivity in India. The

study assesses citation trends, collaborative research, and prolific writers among other elements of millet research. To advance knowledge, solve issues, and encourage sustainable growth in the agriculture sector, this Scientometrics study is essential.

### Objectives:-

- To examine the trends in research output on Millet Production in India from 1989 to 2023.
- To identify the most prolific Authors and their research contribution towards Millet production research.
- To find out the prominent journals and publication counts on Millet production research.
- To identify the top Funding Agencies supporting Millet production research.
- To visualize the Co-authorship, Co-occurrence, and Co-citation patterns and their significance on Millet Production research.

### Research Methodology:-



**Fig-1 Research Design and Scheme of Analysis**

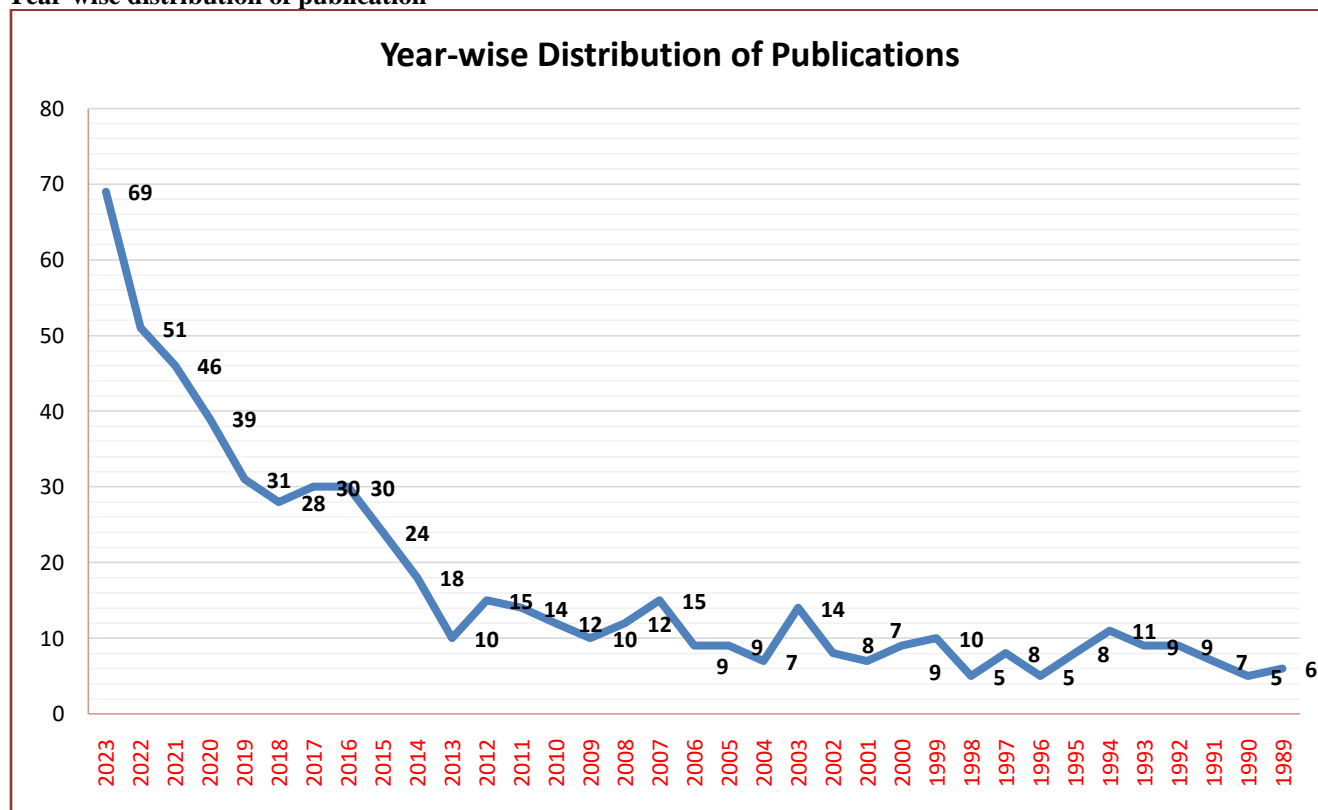
Web of Science is a massive source that discloses much information in depth on articles issued in about 12,000 prestigious journals in the world, making it the best bibliographic source used in Scientometrics research for developing the scientific space for the production of millets and outlining its development stage. We accessed the Web of Science Search Engine, which is a comprehensive database of scholarly literature, and obtained 2878 results with the search query as "Millet\* Production" (topic). Initially, a time frame spanning from 1989 to 2023 and India as a country was selected, and by applying the Exclusion and Inclusion criteria as shown above in fig-1, resulting a total of 600 number of documents. In the present Research Paper, we generated several visualizations using VOSviewer software.

Millet Production research from WoS	Results
Timespan	1989-2023
Sources	600
Times Cited	12028
Keywords	3426
Authors	2174
Documents with single Author	23
Documents with multiple Authors	2151
Institutions	768

**Table 1:-**Main information on Millet Production in WoS.

## Analysis and Discussion:-

### Year-wise distribution of publication



**Fig. 2:-** Year-wise Distribution of Publication.

Fig-2 shows a snapshot of India's millet production over the years 1989–2023. In this case, the amount of publications output in a year gives excellent information into the research output and what was 'in vogue' during this period. The average number of published papers during the period from 1989 to 2023 is 17.142 papers/year, amounting to a total of 600 publications for 35 years. By 2012, articles increased apparently because of the increasing trend. Since 2014, the total output of research also has been increasing which means that the scientific world has just commenced recognizing the importance of millets as a study problem. 2023 is the most productive year with 69 publications, which is an outcome of various Promotional activities. United Nations General Assembly declared 2023 as the international year of Millets (IYM 2023). The review of the table indicates a consistently increasing volume of scientific publications on millet generated within India from 1989 to 2023. The perceived upward trend suggests that there is an increased acknowledgment of the importance of millet production as a field of research and, hence, serves to underscore the intensified efforts toward understanding the challenges associated with millet cultivation and consumption for better recognition of their significant contribution to food security and nutritional well-being in India.

**Top 10 Authors in Millet Production Research**

Sl No	Authors	Affiliation	Publication	H-Index
1	Kumar A	CCS Haryana Agricultural University	25	7
2	Kumar S	Bihar Agricultural University	18	5
3	Upadhyaya HD	International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT)	16	57
4	Hash CT	International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT)	14	35
5	Vadez V	International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT)	14	62
6	Yadav OP	Indian Council of Agricultural Research (ICAR)	14	21
7	Sharma R	International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT)	11	14
8	Singh S	Indian Council of Agricultural Research (ICAR)	11	9
9	Singh A	Govind Ballabh Pant University of Agriculture Technology	10	10
10	Thakur RP	International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT)	10	19

**Table2:-** Top 10 Authors in Millet Production.

The analysis identified the top ten prolific authors who published their works in reputable publications. The analysis shows that Kumar A has the highest number of publications, 25, with an h-index of 7. Kumar S follows with 18 published papers and an h-index of 5. Upadhyay HD has 16 publications with an h-index of 57, while Vadez V was from ICAR with the highest value of the h-index-62 among the top 10 authors. Singh A has the fewest publications with 10 and an h-index of 10. The analysis revealed that 5 out of the top 10 authors are affiliated to International Crops Research Institute for Semi-Arid-Tropics whereas 3 is with the Indian Council of Agricultural Research. These two institutions have promoted more research output in the area of millet production research in India.

**Top 10 prolific Journals in the Millets Production Research field**

Sl No.	Journals	Publications	% of 600
1	INDIAN JOURNAL OF AGRICULTURAL SCIENCES	32	5.333
2	FIELD CROPS RESEARCH	20	3.333
3	BIORESOURCE TECHNOLOGY	10	1.667
4	FRONTIERS IN PLANT SCIENCE	10	1.667
5	ANIMAL FEED SCIENCE AND TECHNOLOGY	9	1.500
6	CURRENT SCIENCE	9	1.500
7	INDIAN JOURNAL OF AGRONOMY	9	1.500
8	JOURNAL OF FOOD SCIENCE AND TECHNOLOGY MYSORE	9	1.500
9	RANGE MANAGEMENT AND AGROFORESTRY	9	1.500
10	ANIMAL NUTRITION AND FEED TECHNOLOGY	8	1.333

**Table3:-** Top 10 Journals for Millets Research.

The Indian Journal of Agricultural Sciences emerges as the most prominent journal, with 32 publications, accounting for 5.333% of the total dataset. This indicates a significant emphasis on agricultural research within this collection of records. Field Crops Research is the second most prominent journal, with 20 Publications, which make up 3.333% of the total. This substantial number suggests a strong interest in crop science research. Following this, Bioresource Technology, Frontiers in Plant Science has 10 Publications, representing 1.667% of the total dataset, highlighting its importance in plant science research. Several journals share an equal number of records, each with 9 Publications: Animal Feed Science and Technology, Current Science, Indian Journal of Agronomy, Journal of Food

Science and Technology, Mysore and Range Management and Agroforestry. Each of these journals accounts for 1.500% of the total records. The least Publications out of the Top 10 Journal is the Journal of Animal Nutrition and Feed Technology with 8 Publications. This diverse representation signifies a broad range of research activities, spanning biotechnology, general science, food science, and agroforestry.

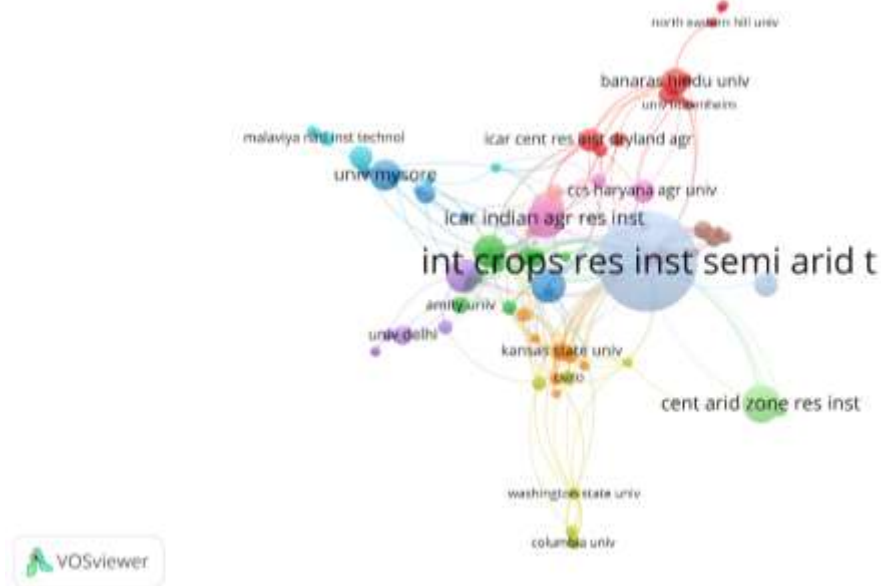
**Top 10 Funding Agencies in Millets Production Research**

Sl No.	Funding Agencies	Publications	% of 600
1	INDIAN COUNCIL OF AGRICULTURAL RESEARCH ICAR	26	4.333
2	DEPARTMENT OF BIOTECHNOLOGY DBT INDIA	25	4.167
3	DEPARTMENT OF SCIENCE TECHNOLOGY INDIA	17	2.833
4	UNIVERSITY GRANTS COMMISSION INDIA	17	2.833
5	CGIAR	15	2.500
6	COUNCIL OF SCIENTIFIC INDUSTRIAL RESEARCH CSIR INDIA	10	1.667
7	BILL MELINDA GATES FOUNDATION	7	1.167
8	MINISTRY OF SCIENCE AND TECHNOLOGY GOVERNMENT OF INDIA	6	1.000
9	EUROPEAN RESEARCH COUNCIL ERC	5	0.833
10	KING SAUD UNIVERSITY	5	0.833

**Table4:-** Top 10 Funding Agencies in Millet Production Research.

It is seen that funding by different agencies is concentrated to a large extent; ICAR at the top funded 26 Publications, accounting for 4.333 percent of the total 600 Publications. This makes for a huge contribution and justifies the council's prime objective of boosting agricultural research in India. At a close level is DBT, India, which funded 25 Publications, accounting for 4.167 percent of the total. Thus, DBT's strong support for biotechnological research from time to time has instilled a commitment toward the advancement of scientific developments. DST India and University Grant Commission, India have contributed 17 publications each and make up 2.833 percent of the dataset. This indicates DST and UGC have a crucial role in fostering a broad spectrum of scientific research across various disciplines in India. Both European Research Council and King Saud University have each 5 Publications which is the least one in the Top 10 Funding Agencies. This analysis highlights the diverse contributions of these Funding Agencies to advancing scientific knowledge and emphasizes the importance of their roles in facilitating research dissemination across various fields.

**Co-Authorship visualization trends of Organisation**



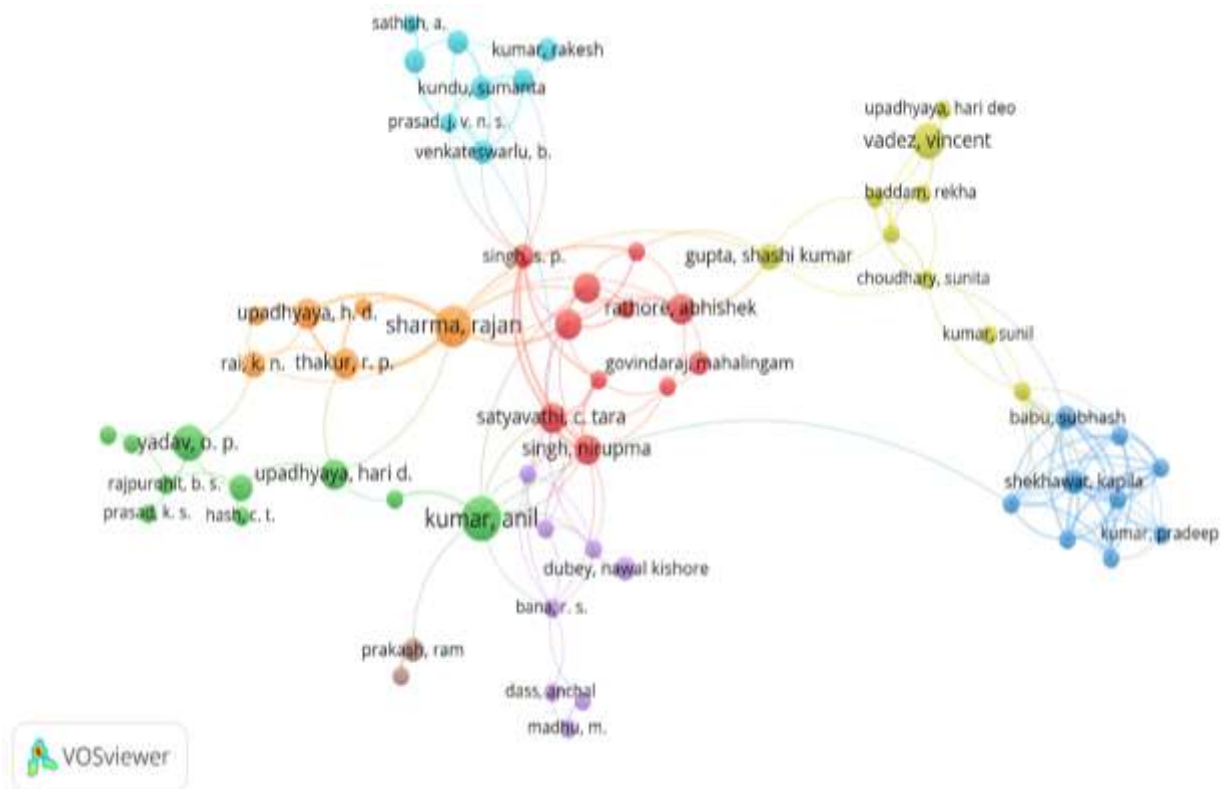
**Fig.3:-** Co-Authorship between Organisation.

The visualization is a co-authorship map generated using VOSviewer, displaying the collaborative relationships between different organizations based on their co-authorship in published research. Links: The connections between

nodes represent co-authorships, meaning the number of times organizations have collaborated on research papers. Thicker lines indicate stronger or more frequent collaborative relationships.

The placement of nodes shows how central or peripheral an organization is within the collaborative network. Central nodes indicate organizations with broad and diverse collaborative ties, while peripheral nodes may be involved in more specialized or regional collaborations. Notable organizations like the "International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)" with 99 documents, 2508 citations, and with a total link strength of 95 Followed by "Indian Agricultural Research Institute (ICAR)" with 23 documents, 265 citations, and with the 37 total link Strength. Both these Organisations have larger nodes, highlighting their significant contributions and central roles in research collaborations.

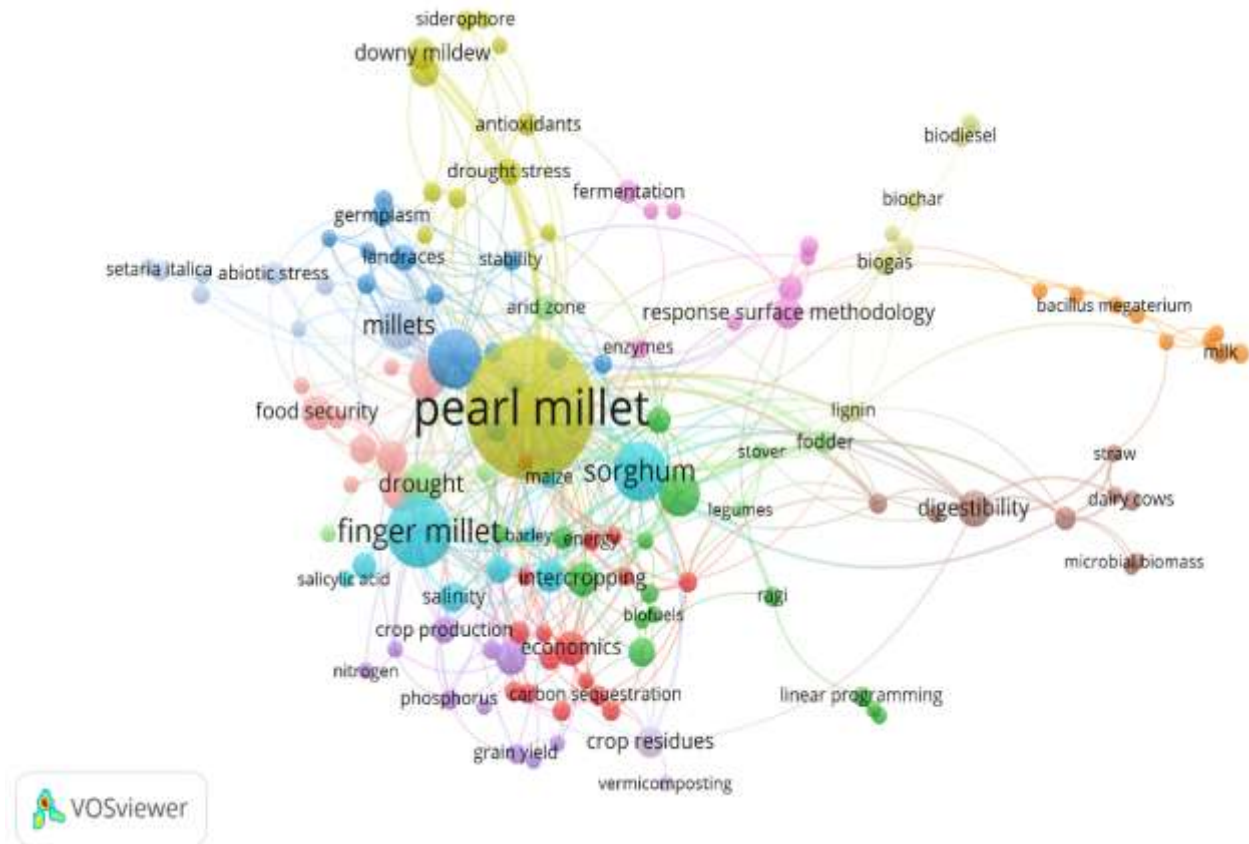
### Co-Authorship Pattern among Authors



**Fig. 4:-Co-Authorship Pattern among Authors.**

A prominent form of co-authorship analysis within the realm of Scientometrics research is the examination of co-authorship dynamics among the Authors. Figure 4 illustrates the methodology employed to construct a network utilizing the VOS viewer, which visualizes the co-authorship patterns among the authors, highlighting the most prominent individuals and their collaborative efforts. The collaborative relationships among the Authors are depicted through the connections established between the nodes. The network has 8 clusters, 173 links, 64 nodes, and 273 total link strength. The different colors of the map (yellow, green, dark blue, red, light blue, orange, violet, and brown) express that the research directions of the authors are different. The biggest cluster is made of 11 authors (red color). The next 10 authors contributed to the cluster (green color). 8 authors participated in the third cluster (dark blue). The leading central nodes in Figure 4 reveal numerous publications and many collaborative efforts. The fact of its multi-clustering proves that there is a strong and collaborative research environment with the multidisciplinary team working on multiple facets of millet production research.

### Co-Occurrence Visualization of Authors' Keywords



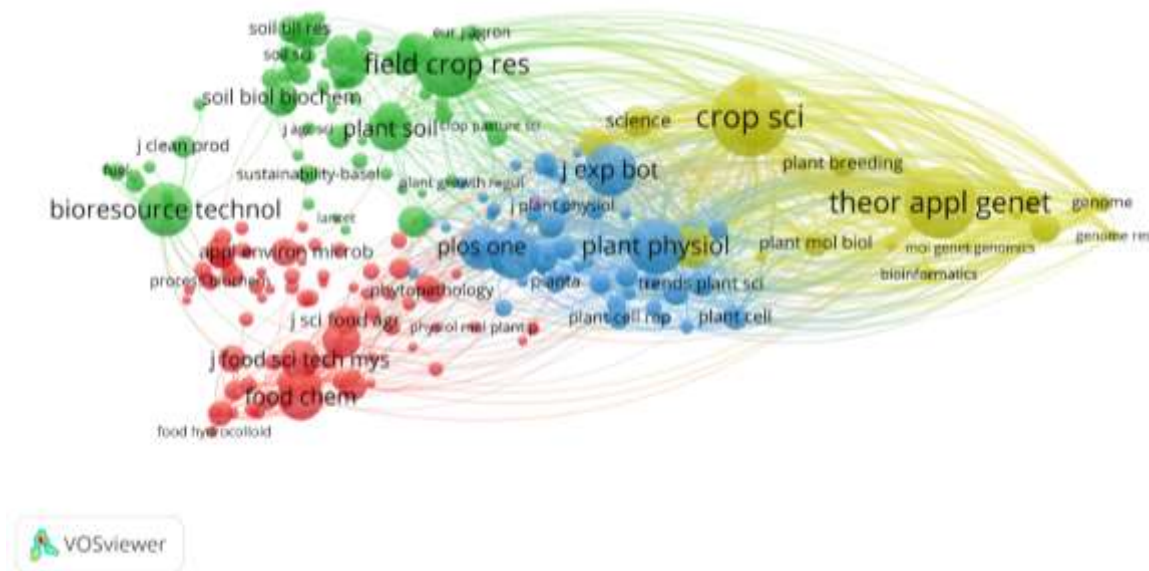
**Fig. 5:-Co-occurrence visualization of Authors Keywords.**

From the citation data, a total of 1942 Author keywords were taken out and analyzed to determine their distribution and co-occurrence over time. Nonetheless, the most common terms were the focus of the investigation since they are crucial for identifying trends. The connections between nodes represent co-occurrences, meaning the number of times keywords appear together in the same research documents. Thicker lines indicate stronger or more frequent co-occurrence relationships. Pearl millet with 82 occurrences and with a total link strength of 133 tops the list followed by sorghum with 21 occurrences and a total link strength of 50 and Pennisetum glaucum with 21 occurrences and with a total link strength of 43, all these were found to be the most commonly recurring terms. Based on relationships and frequency, it is evident that there is a convergence of the major terms. Keywords related to agricultural practices, such as "Inter-cropping," "grain yield," and "salinity," show the focus on improving millet cultivation and productivity. The presence of keywords like pearl millet with the highest percentage of occurrence indicates that among all types of millet, there is more demand, and research trends incline towards it which shows there is better future scope for it in the Millet Production in India.

The Fig-6 visualization is a co-citation map generated using VOSviewer, which shows the relationship between cited sources based on how frequently they are cited together in the literature. The connections between nodes represent co-citations, meaning the number of times two sources are cited together in other works. Thicker lines denote stronger co-citation relationships. Notable sources like "Field Crop Research," "Crop Science," "Plant Soil," and "Bioresource Technology" have larger nodes, highlighting their significance and influence in the research domain. Node placement within the map is a guideline on how central or peripheral a source will be within the research field. Central nodes provide sources that are very broadly relevant. Peripheral nodes, on the other hand, can be very specialized. The map visualizes how different fields are connected. For instance, sources within "Agricultural Sciences" are green, while those linking to "Plant Physiology" and "Biotechnology" are yellow and red respectively; hence, interdisciplinary.



### Co-Citation Visualisation Of Cited Sources



**Fig. 6:-** Co-citation visualization between Different Sources.

### Conclusion:-

Over the period 1989-2023, several findings in Millet's Production research formed some very important trends and characteristics. There has been a constant rise in publication output, hence showing interest and realization of the prime need for sustainable and environment-friendly approaches in this sphere of science. One prime characteristic of millet production, therefore, is collaboration among researchers and institutions. The degree of collaboration, as observed, is high and on an increasing trend of multi-author publications.

Leading journals and publishers strongly shape the discourse, with many publications having high impacts with wide citations. Substantial contributions from prolific authors and key institutions underline dedicated efforts to advancing knowledge and innovation output related to millet production. Most funding sources, especially from national agencies, reflect the priority that agricultural research holds in its ability to answer pressing concerns in food security and sustainable farm practices. Among the publications in this area are some on application and innovation, in particular, biofortification and mitigation of drought stress, thus clearly giving weight and relevance to such research in agriculture worldwide. In general, Millet production research informs the advancement of sustainable practices and the development of environmentally friendly technologies to address global environmental challenges. Further steps in promoting sustainable development and a greener future for coming generations can be executed by embracing and implementing emerging technologies and strategies suggested. The findings from this study may assist interested stakeholders, particularly researchers, in understanding more clearly the research trend and efficacy of Indian Millet Production studies for better decision-making.

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