ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue V May 2025

Status and Prospects of Research on Millets as a Sustainable Crop in India: Reflections through a Bibliometric Analysis

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DOI: https://doi.org/10.51244/IJRSI.2025.120500013

Received: 18 April 2025; Accepted: 24 April 2025; Published: 26 May 2025

ABSTRACT

The paper aims to examine the status and prospects of research on Millets as a sustainable crop in India by performing a bibliometric analysis. Scopus data after applying necessary filters yielded 328 research papers in the data set. Our study revealed that research work has gone up significantly in the period 2021-2025 demonstrating the renewed interest in Millets as an important crop. Co-author analysis indicated high level of inter-country as well as intra-country collaborations. Co-occurrence analysis identified 'Millets,' 'India' and 'Sustainability' as prominent words. Clusters indicate a focus on increasing the yield and productivity of millets as it is a sustainable crop which can be used for nutrition. Most of the research work in the field is trying to address the issue from a supply point of view. There is evident research gap as there are very few studies to examine factors affecting consumer behavior, perceptions, and attitudes towards millet. Further research may also be undertaken to look at historical and socio-cultural aspects of millets acceptability covering and comparing the different geographical patterns of consumption. The study is very useful for future researchers as it identifies the research gaps in the existing work done in the area and gives directions for future research.

Keywords: Millets, India, Sustainability, Nutrition, Bibliometric analysis

INTRODUCTION

Historically speaking, millets have had a strong presence in the agricultural sectors of Asia and Africa. They are a small group of cereal crops that are considered to be highly resilient requiring low fertile soils, less water as compared to rice and wheat, and low inputs in terms of fertilizers and pesticides. Millets have been regarded as nutritious and because of their characteristics of being able to adapt to changing environmental conditions are also regarded as a sustainable crop providing food security during times of adversity. They are gluten free, contain magnesium, niacin, and are a rich source of vitamin – B3 (Prathyusha et al 2021). The most commonly grown millets are Pearl Millet (Bajra), Sorghum (Jowar), Finger Millet (Ragi/Mandua), Foxtail Millet (Kangni), Brown top Millet (Korale), Barnyard Millet (Sawan/Jhangora), Little Millet (Kutki), Proso Millet (Cheena/Common Millet) and Kodo Millet (Bhat et.al 2018). It is generally believed that before the development of proper irrigation systems, millets were the staple food of Africa and Asia. Most of these varieties originated in these regions. While Sorghum and Finger millet owe their origin to north-eastern Africa, Little millet and Brown millet seem to have been domesticated in India. With the passage of time, millets travelled to different parts of the globe and were significant up until the advent of rice, wheat, and barley as dominant cereal crops for consumption by humans. It is ironical to note that though they are one of the oldest crops known to human kind, have been beneficial both as food and fodder, have great nutritional value and yet are considered to be insignificant crops. They are neglected and are normally not part of our food basket.

Several reasons have contributed to the decline of millets both in terms of production and consumption. It began with the green revolution in the 1960s when high yielding varieties of rice and wheat became plentily available. Government schemes promoted their use by providing rice and wheat at subsidized prices (Kane-Potaka and Kumar 2019; Eliazer Nelson et al 2019). Millets fell out of favour owing to their cooking methods and taste too (FAO 2023). It is tougher to make 'rotis' from millets as it is gluten free just as it is tastier to consume white rice as most millets have a slightly bitter taste. Gradually after the 1980s, the crop soybean

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came to be prioritized over millets production in drylands as it was more profitable leading to its further decline in terms of area used under cultivation. With better irrigation facilities, cotton and maize too began to occupy spaces designated for millets cultivation (Bhat et.al 2018). Studies also indicated that both pearl millet and sorghum per capita consumption show declining trends. While pearl millet per capita consumption has declined from 11.4 to 4.7 and from 4.1 to 1.4 kg per year between the years 1973-2005 (Basavaraj et. al 2010), per capita consumption of sorghum has declined from 19.1 to 5.2 and from 8.5 to 2.7 kg per year (Rao et.al, 2010). Though India was regarded as a leading producer and consumer of a wide variety of millets, even then, what became a cause for concern was that both its production and consumption were declining steadily. More importantly, its yield per hectare was lower than other countries.

In an era of increasing environmental uncertainty due to climate change millets have come to be recognized as both a sustainable and nutritious crop the world over and India is no exception. Small wonder therefore, the government of India declared 2018 as a National Year of Millets to be followed by the year 2023 being declared as the 'International year of the Millets' by the United Nations General Assembly (Ministry of Agriculture and Farmers Welfare, 2024). Many governmental initiatives in the form of millets mission, targets, fund allocation to the cause etc. followed. This in turn led to an intensification of research on millets both at the global and at the national level. Given this kind of a context, this study using a bibliometric analysis of the research articles done in the field in the Indian context, attempts to understand the status and prospects of research on millets as a sustainable crop in India.

This study broadly looks the following research questions: 1. How much research has been published on millets in millets in social sciences, business, and other related fields. 2. What are the major collaborative studies both national and international? 3. Does the existing body of research focus on the health and nutritional aspect of millets? 4. Does the existing body of research reflect upon sustainability and climate change issues related to millets? 5. What is the acceptability of millet as a prominent item in India's cereal basket? 6. What factors operate as hindrances in its acceptance?

In so doing it hopes to identify the current strengths and gaps in the literature. The findings may then be used to indicate the future directions in which research may proceed. Closer inspection of the article topics also reveals the specific fields that have received significant attention and those that haven't leading to a set of consequences that are conducive to or operate as hindrances for reinstating millets as the sustainable and health crop of India.

The paper is divided into 5 sections including the current one. The next section takes an overview of millets in India. The third section details the data and methodology used in the paper. The results are discussed in the subsequent section. The final section gives conclusions, identifies the research gaps and gives directions for future research.

Millets as A Sustainable Crop: Overview

The International Crops Resistant Institute for the Semi-Arid Tropics (ICRISAT) designate millets as a 'smart food.' A smart food is explained as one that is 'good for you, good for the farmer and good for the planet.' While 'Good for you' implies a food that is primarily nutritious, healthy and easily accessible, 'Good for the farmer' implies a crop that is sustainable, can adapt itself to adverse climatic conditions, has a shorter harvesting period in order to be able to feed the population and can also be used as fodder. 'Good for the planet' implies a crop that has lesser carbon footprints, using limited resources of the earth such as water, doesn't alter the ecosystem balance due to its specific requirements and doesn't generate much waste. Considering these characteristics that make millets a unique crop vis a vis other cereal. In this section we elaborate the current status of Millets in India and how have policies impacted millet production, cultivation and consumption.

Current Status of Millets Production: Global and National and Policy Implications

According to the Indian Council of Agricultural Research (ICAR) - Indian Institute of Millets Research Division Report 2018, globally speaking, millets are grown in 76 million hectares of land contributing to the

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production of 95 million tons of food grains that is part of the 300 million cereal grains basket. According to the FAO, in 2023, India with a share of 38.4 percent of the world's millet production is acknowledged as the world's largest producer of millets. Table 1 provides an insight into the area under cultivation and production of millets in the year 2024:

Table 1: India's Millet Production and Export Statistics for FY 2024

Production	15.38 mil MT
Area under Cultivation	12.19 Mil ha
Volume of Export	1.46 lakh MT
Exported in FY 24	70.89 USD Mil

Source: APEDA and Ministry of Commerce and Industry, GOI 2025

India happens to be one of the leading producers of most of the millets such as sorghum, pearl millet and finger millet but its yield levels are low in comparison to others. For instance, China produces more than 2 million tons each of sorghum and pearl millets with yield levels of about 4500 kg and 2600 kg per hectare (Bhat et.al 2018). Table 2 shows the top 10 producer states of millets in India during 2022-23. Rajasthan happens to be the largest producer of millets in the country, followed by Uttar Pradesh, Karnataka and Maharashtra. The prominent varieties of millets grown are Jowar, Bajra and Ragi. Smaller millets received scant attention. The all-India level production was estimated around 17321.23 thousand tonnes.

Table 2: Top 10 State/UTs: Production of Millets (in 000's tonnes) for 2022-23

State/ UT	**Jowar**	**Bajra**	**Ragi**	**Small Millets**	**Total Millets**
Rajasthan	567.18	5,105.02*	-	1.41	5,673.61
Uttar Pradesh	315.41	2,045.52	-	7.64	2,368.57
Karnataka	681.68	177.40	1,148.17*	25.35	2,032.60
Maharashtra	1,312.25*	467.93	91.03	27.37	1,898.58
Gujarat	46.12	1,293.68	8.30	15.99	1,364.09
Madhya Pradesh	169.46	943.44	-	140.65*	1,253.55
Haryana	14.12	1,199.85	-	-	1,213.97
Tamil Nadu	292.81	113.38	206.50	17.52	630.21
Andhra Pradesh	283.78	50.68	32.00	9.46	375.92
Uttarakhand	-	-	114.23	61.54	175.77
All India	3,814.18	11,431.42	1,691.37	384.26	17,321.23

Source: PIB https://static.pib.gov.in/WriteReadData/specificdocs/documents/2023/dec/doc2023125278801.pdf

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*Largest producer

Foxtail, Little, Kodo, Barnyard and Proso are grown in the central and eastern regions of India, in the states of Madhya Pradesh, Uttar Pradesh and Bihar. Finger Millet is grown in Tamil Nadu, Karnataka, Andhra Pradesh, Odisha and Maharashtra. Sorghum, in Maharashtra, Karnataka and Andhra Pradesh and Proso is grown in regions of Maharashtra, Madhya Pradesh and Tamil Nadu.

Global consumption of millets is around 30 million tones with sub–Saharan Africa and South Asia as its major consumers using around 85 percent (FAO 2023). Following is a graph depicting world consumption of millets indicating that the consumption aspect needs further exploration because millets consumption is way behind consumption of other cereals such as rice, maize, wheat etc. Scholars attribute it to a lack of awareness regarding millets as a crop having nutritional, economic and environmental benefits in some cases (Shah et al 2023) and in certain others, people are unaware of its contribution to healthy diets (Orr et al 2023).

Figure 1 shows five countries that are the major exporters of millets. They are India, the Russian Federation, Ukraine, the United States of America and France. These countries account for 70 percent of the total recorded shipments. The European Union followed by Saudi Arabia, Indonesia and Canada happen to be the World's major importers. However, according to the FAO Report 2023, only 1 percent of total millet production is traded in the international market in comparison to other staples such as wheat (24%), maize (15%), barley (20%), and rice (8%) indicating that millets are mostly sold in local markets and are still considered to be inferior crops despite their unique properties. Considering the fact that we live in a world governed by environmental risks and uncertainties with majority of the world's population being poor, the United Nations declared 2023 as the international year of the millets recognizing it as a better alternative to the already existing staples.

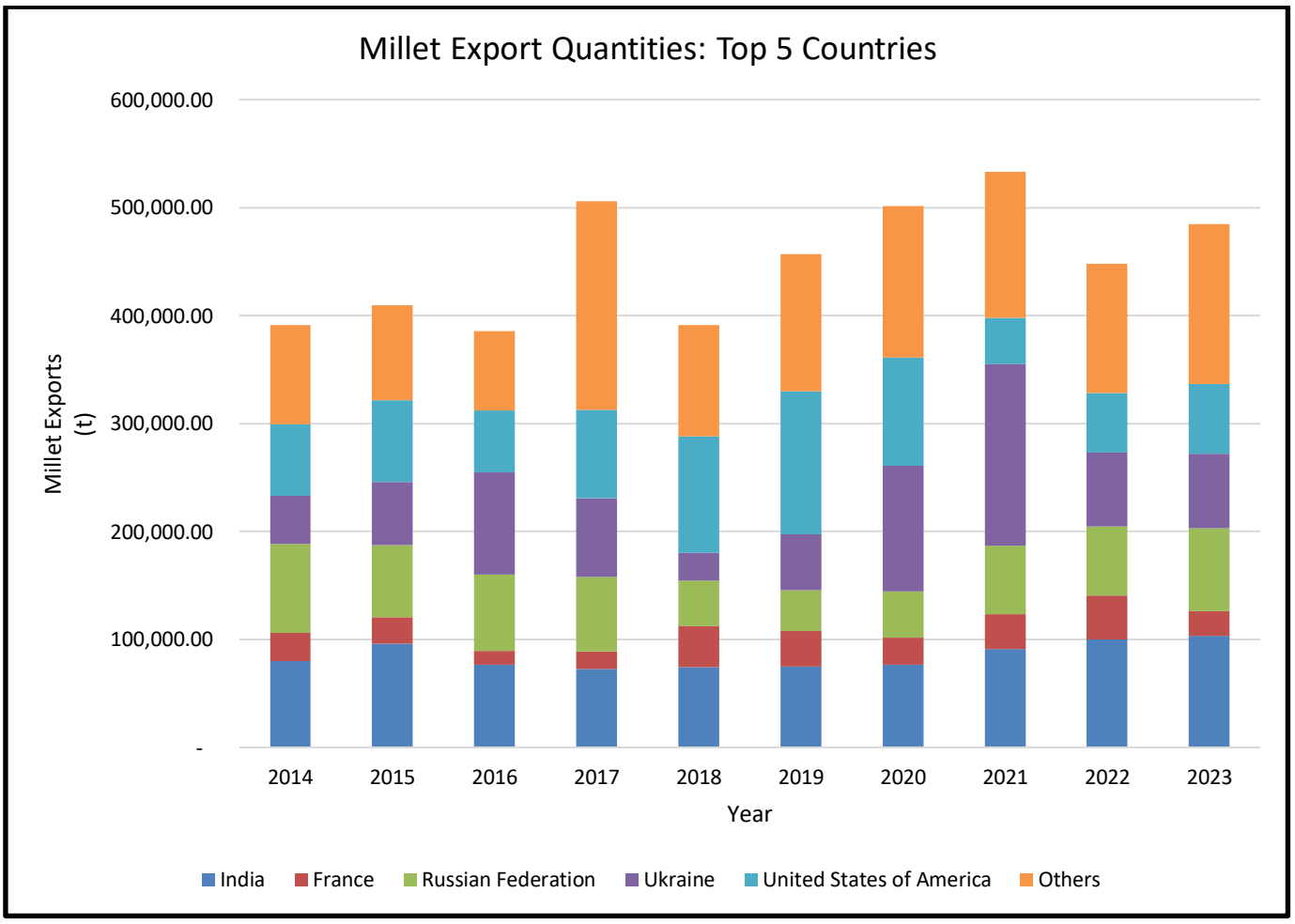

Figure1: World Export of Millets 2022-2023 (Source: Data extracted from FAO website https://www.fao.org/faostat/en/#home)

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Several initiatives have been undertaken by the government of India to boost millet production and promotion through several central and state governmental programs. Prominent among such initiatives are the submission on 'Nutri Cereals under National Food Security Mission' (NFSM), 'Production Linked Incentive (PLI) for Food Processing Industry', 'Promotion of millet by Ministry of Women and Child Development (MWCD) in supplementary nutrition program (SNP)', and the 'Promotion of millets in Public Distribution System (PDS)'. While the sub-mission on Nutri-Cereals from 2018 to 2019 worked towards developing a market strategy for dealing with the production, demand and research-related concerns, towards enhancing millet productivity through area expansion, the PLI scheme with a budget of INR 10,900 crores emphasizes on the development of global leaders in the food manufacturing industry. Its focus is to innovate ready-to-eat and ready-to-cook millet based products. Similarly, under the PDS, the Government is trying to make millets more widely available by including it in the system and also by revising rules for transporting millets when produced in excess to other states. The MWCD on the other hand has mandated states and UTs to include millets as part of their Anganwadi services SNP (Jadhav and Londhe 2023). Apart from these direct interventions, other steps for millets promotion include the observance of the National Year of Millets 2018, The International Year of Millets sponsored by the GoI and accepted by the UN assembly, the Rahtriya Krishi Vigyan Yojana (RKVY), Paramparagat Krishi Vigyan Yojana (PKVY) and Mission Organic Value Chain Development for North Eastern Region (MOVCDNER). More recently, the World Food Programme (WFP) and NITI Aayog under the 'Mapping and Exchange of Good Practices' program for millets production in Asia and Africa have identified several effective methods for increasing millet's production and consumption both in India and abroad. All these policy interventions at both the national and state level indicate how the government of India is aggressively pursuing the cause of millets. Success of these interventions however will largely depend upon research and evidence on the subject.

DATA AND METHODOLOGY

The paper employs bibliometric analysis for performing the literature review. This is a quantitative technique based on statistical analysis of the research done in a field (Pritchard, 1969; Broadus, 1987). Under bibliometric analysis data is collected from one or more central databases. The same is used for performance analysis and science mapping (Donthu et al 2021). The results then help in understanding the focal areas of past research, contributions, collaboration opportunities, relationships, and trends in the discipline. This can also help in identifying the research gaps in the field.

The data was collected from Scopus which is the largest database for multidisciplinary scientific works of literature (Chadegani et al., 2013). The PRISMA framework was used for collecting the relevant data records. The Scopus database was searched for the keyword "Millets" which yielded 19,635 results. The search was then limited to final article and review papers published in Journals. Only papers published in English were considered. The search was limited to India as per the scope of the research questions. This narrowed the search results to 5,544 records.

Further, since the research is being done from the perspective of Social Sciences, business and related fields, 20 unrelated subject areas were excluded from the search leaving a sample of 435 papers which satisfied the criteria. For this data set, the abstract of the papers was carefully analysed for relevance to the research questions and duplicates and a further 107 papers were excluded because they were not relevant for the study. These were removed from the list. The details of the process for selecting the records are illustrated in Figure 2. Finally for the remaining 328 papers the bibliometric details were downloaded from Scopus in a .CSV format. This data was used for analysis.

The data obtained was analysed using VOSviewer software which enables creating Network maps (Van Eck & Waltman, 2010). In this paper performance analysis is done for examining the contributions of research through publication related metrics in the area of millets research. This part of the analysis is mainly descriptive (Donthu, et al, 2020). Science mapping is also done to examine the underlying relationships through techniques such as co-authorship analysis, and keyword co-occurrence analysis.

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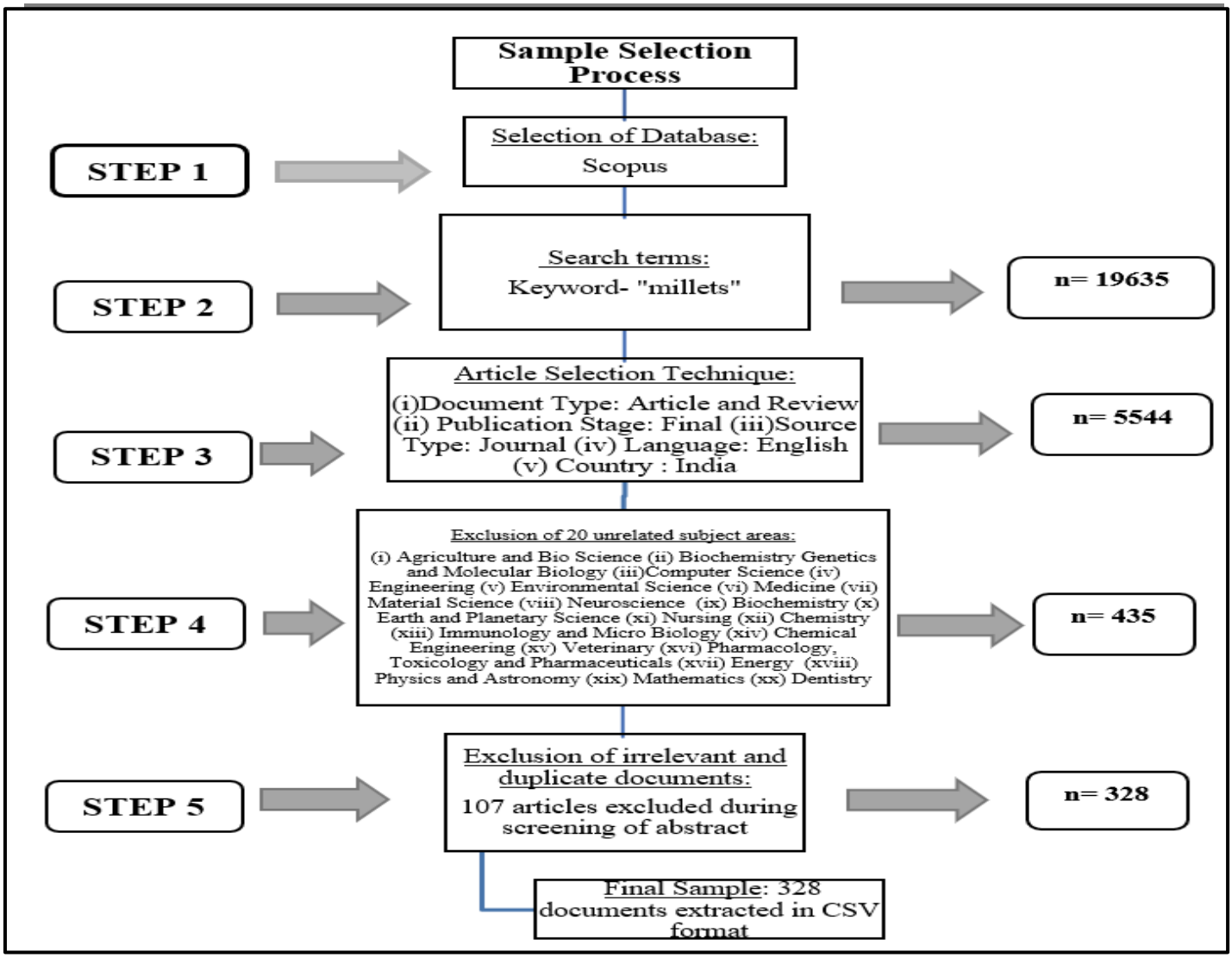

Figure 2: Step-wise Sample Selection Process for Bibliometric Analysis

RESULTS AND DISCUSSION

The results obtained are discussed in this section. The discussion includes performance analysis through examination of publication pattern over the years. Thereafter science mapping is done through co-author analysis and keyword co-occurrence.

Publication Pattern and Research Interest

The data collected for bibliometric analysis was initially scrutinized for publication pattern. This involved summarizing the number of publications over the years. Since the study is not limited by time; analysis is done for intervals of 5 years with the first interval being open ended including publications up to the year 1990. All other intervals have a 5-year time period except the last one where the current year is included and covers only the publications till the date of data retrieval i.e. till February, 2025. The data is represented graphically in Figure 3. An observation of this graph shows an increasing trend in publications. While the total number of publications remains very low, being 42, till 2010; the same number of publications is seen in the subsequent block of 5 years indicating an increased research focus on the subject area. After 2010 the numbers increase exponentially almost doubling every 5 years. This can be explained by a renewed interest in millets as a sustainable crop with health benefits. Between 2021 and 2025 we see the highest number of publications at 151. The year 2023 was celebrated as the International Year of Millets. So, around this period the focus of government policy was also on millets which may explain the high volume of publications.

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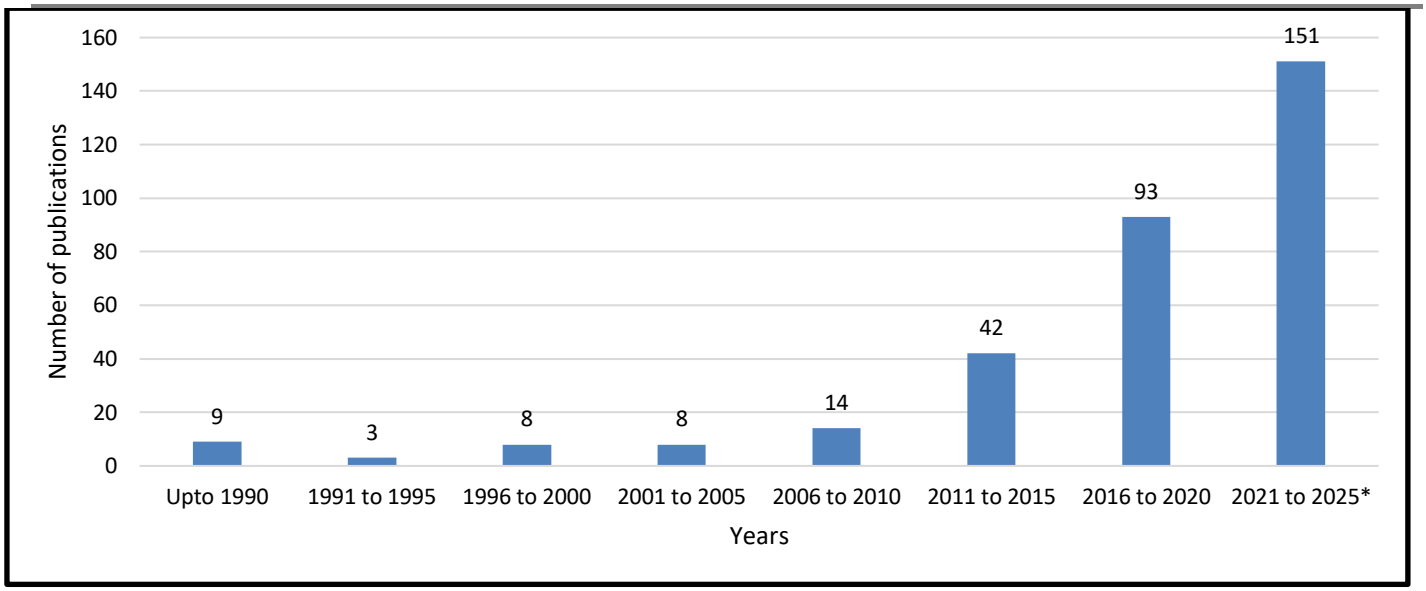

Figure 3: Publication pattern in the field in India over the years. (*For the ongoing year 2025 only the Months of January and February are included)

It is also observed that "Current Science," a journal published by Indian Academy of Sciences has produced the largest number of papers i.e. 33 (about 10 percent of the total publications) in the data set (Refer to Table 3). This is closely followed by "Scientific Reports" published by Springer nature; where 32 papers are published respectively. This journal also has the highest CiteScore of 7.5 for 2023 amongst the listed journals making it the most impactful one in the field. Taken together the top 10 journals listed in Table 3 account for more than 50 percent of publications in the area (as included in the dataset).

Table 3: Top 10 Productive Journals based on the Number of publications on Millets

	Name of the Journal	**Publisher***	**Number of publications in the field of Millets**	**Scopus CiteScore of the Journal (2023)***
1	Current Science	Indian Academy of Sciences	33	1.5
2	Scientific Reports	Springer Nature	32	7.5
3	PLoS ONE	Public Library of Science	25	6.2
4	Indian Journal of Traditional Knowledge	National Institute of Science Communication and Policy Research	22	1.8
5	Indian Journal of Agricultural Economics	Indian Society of Agricultural Economics	13	0.6
6	Sustainability (Switzerland)	Multidisciplinary Digital Publishing Institute (MDPI)	12	6.8
7	Heliyon	Elsevier	11	4.5
8	Journal of the Indian Society of Remote Sensing	Springer Nature	9	4.8

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9	Foods	Multidisciplinary Digital Publishing Institute (MDPI)	8	7.4
10	Journal of Scientific and Industrial Research	National Institute of Science Communication and Information Resources (NISCAIR)	8	1.7

*Source: https://www.scopus.com/sources.uri

Co-author Analysis

In this section we do co-authorship analysis as a tool of science mapping. Co-author analysis is used to explore the collaboration among researchers. Inter-country collaborations by research scholars are also examined for the field of study. The analysis highlights the importance of collaborations to enrich the result output by providing deeper insights (Tahamtan et al., 2016).

Figure 4 shows the network visualization map of the authors based on citations. Of the 1242 authors in total, 60 have produced 3 or more papers with 10 or more citations. Of these 60 authors; 35 were seen to have collaborations with at least one other researcher. Upadhyaya, H. D. of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Telangana, India has the highest number of collaborations as indicated by 11 links in Figure 4. However, Ignacimuthu, S. from Loyola College, Chennai; India has the highest total link strength.

Table 4 summarizes the number of documents published, citations, total link strength and affiliations of the most prominent authors in the field. Prasad, M., affiliated to National Institute of Plant Genome Research, New Delhi, India has the highest number of citations (740) for his work as also indicated by the size of the node in Figure 4 He has produced 10 papers which is the second highest number of publications. He has also collaborated with others as indicated by the total link strength of 14. Kumar, A. has published 11 documents which is the largest number of papers in the group. This author who is associated with G.B. Pant University of Agriculture and Technology Uttarakhand, India; has 251 citations and total link strength of 5.

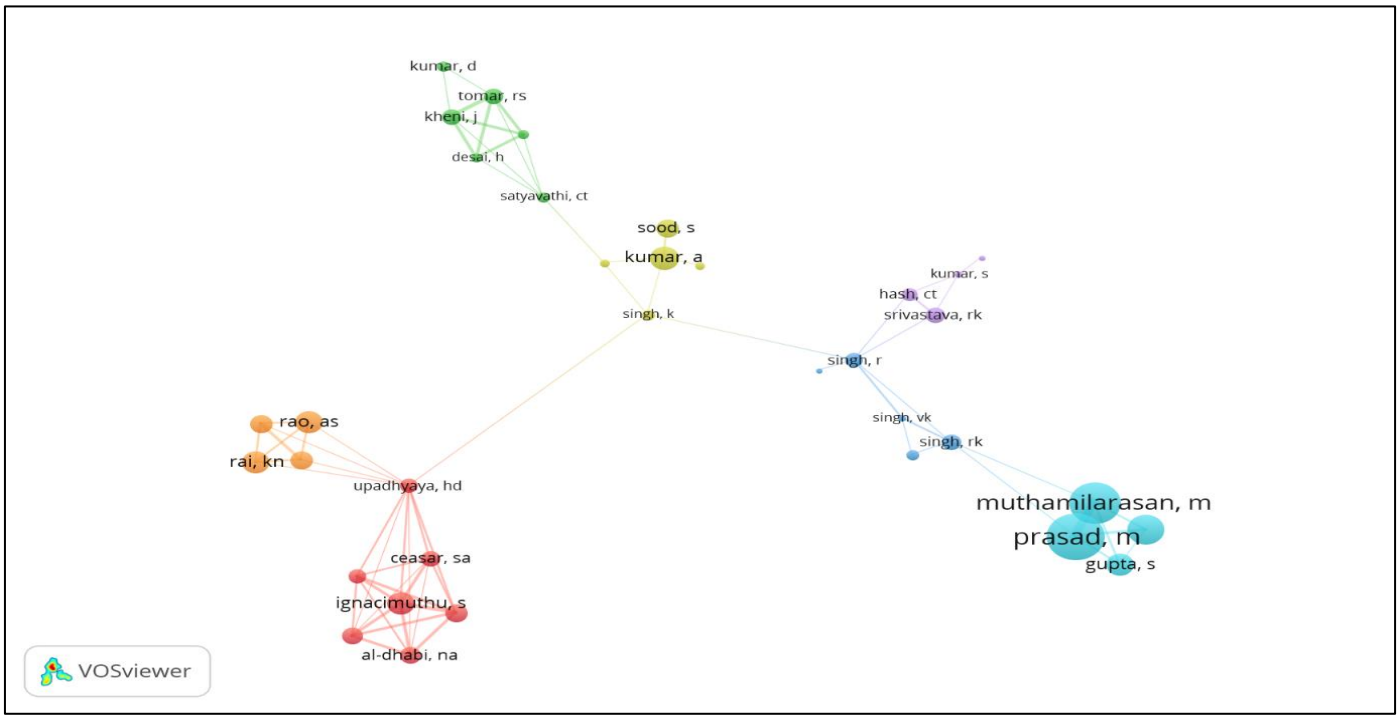

Figure 4: Co-authorship Analysis

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Table 4: 20 Most influential authors in the area (based on number of citations and documents published)

Author	No. of documents	Citations	total link strength	Institute/ Affiliation
Prasad, M	10	740	14	National Institute of Plant Genome Research, New Delhi, India
Muthamilarasan, M	9	606	13	National Institute of Plant Genome Research, New Delhi, India
Parida, S.K.	3	359	6	National Institute of Plant Genome Research, New Delhi, India
Udayakumar, M	3	304	2	University of Agricultural Sciences, Bangalore, Karnataka, India
Singh, D	3	266	3	School of the Environment, Washington State University United States
Defries, R	3	266	3	Columbia University, New York, USA
Kumar, A	11	251	5	G.B. Pant University of Agriculture and Technology Uttarakhand, India
Gupta, S	4	231	5	Jawaharlal Nehru University New Delhi, India
Nataraja, K.N.	3	229	2	University of Agricultural Sciences, Bangalore, Karnataka, India
Rao, A.S.	3	228	7	International Crops Research Institute for Semi-Arid Tropics (ICRISAT) Hyderabad, Telangana, India
Ignacimuthu, S	5	225	18	Entomology Research Institute, Loyola College, Chennai, India
Srinivasarao, C	3	221	5	Central Research Institute for Dryland Agriculture Hyderabad, India
Kundu, S	3	221	5	Central Research Institute for Dryland Agriculture Hyderabad, India
Rai, K.N.	3	217	7	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Telangana, India

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Singh, Ak	3	195	4	Indian Council of Agricultural Research, Krishi Anusandhan Bhawan (KAB-II), New Delhi, India
Kanatti, A	3	165	8	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Telangana, India
Govindaraj, M	3	165	8	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Telangana, India
Ramakrishnan, M	4	161	17	Entomology Research Institute, Loyola College, Chennai, India
Sood, S	4	155	2	Vivekanand Parvatiya Krishi Anusandhan Sansthan (Indian Council of Agricultural Research), Uttarakhand, India
Duraipandiyan, V	3	142	13	Entomology Research Institute, Loyola College, Chennai, India

Figure 5 shows the co-authorship network map of India with other countries. India has 65 inter-country collaborations. The size of the nodes indicating the number of publications while the thickness of the curved lines linking the countries indicates the strength of link between the countries (Van Eck., and Waltman, 2019). As indicated by the figures 5 and 6, Indian authors have the largest number collaborations with United States of America and United Kingdom and has also produced the highest number of documents with the countries. One can also observe that average year of publication for these 3 countries lies between 2016 and 2018. However, based on the average year of publication, the collaboration with Sweden, Azerbaijan, Greece, New Zealand, Turkey and Tunisia is fairly recent (average year of publication 2024)

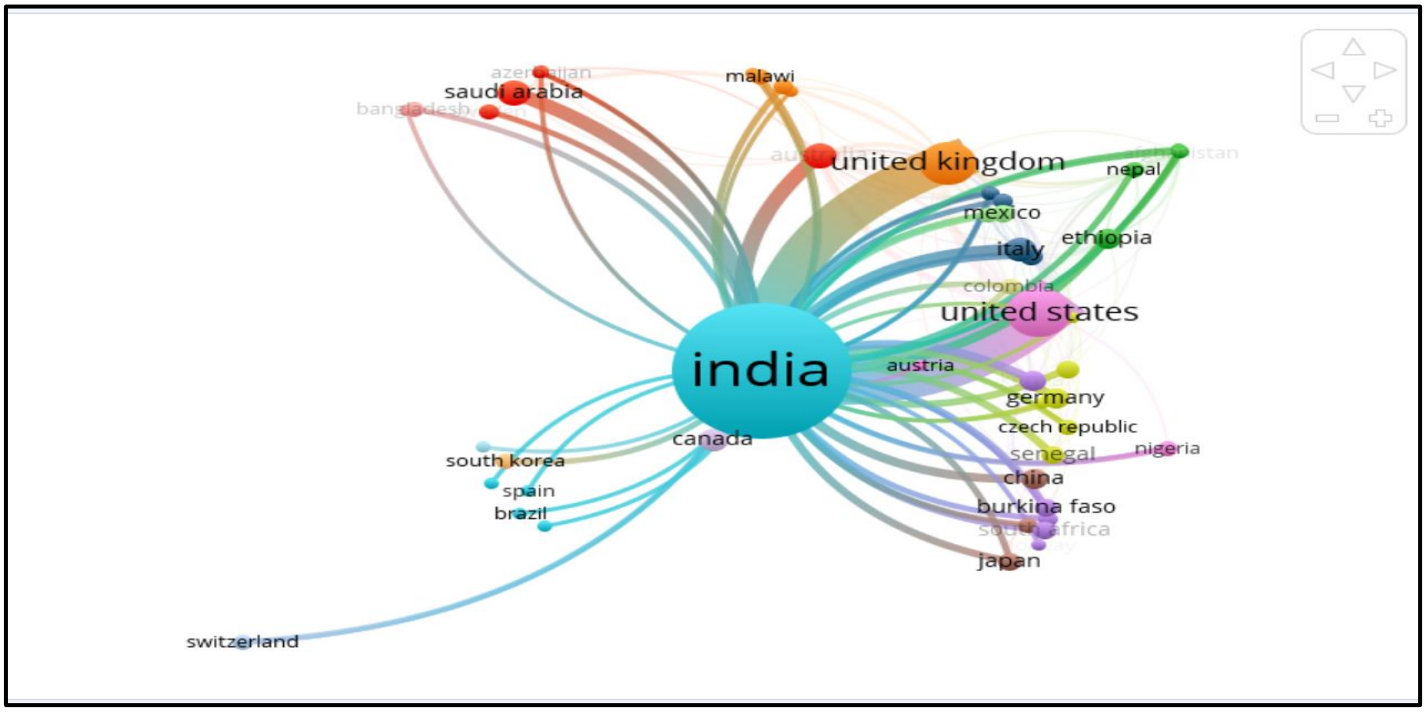

Figure 5. Co-authorship Network between India and other countries

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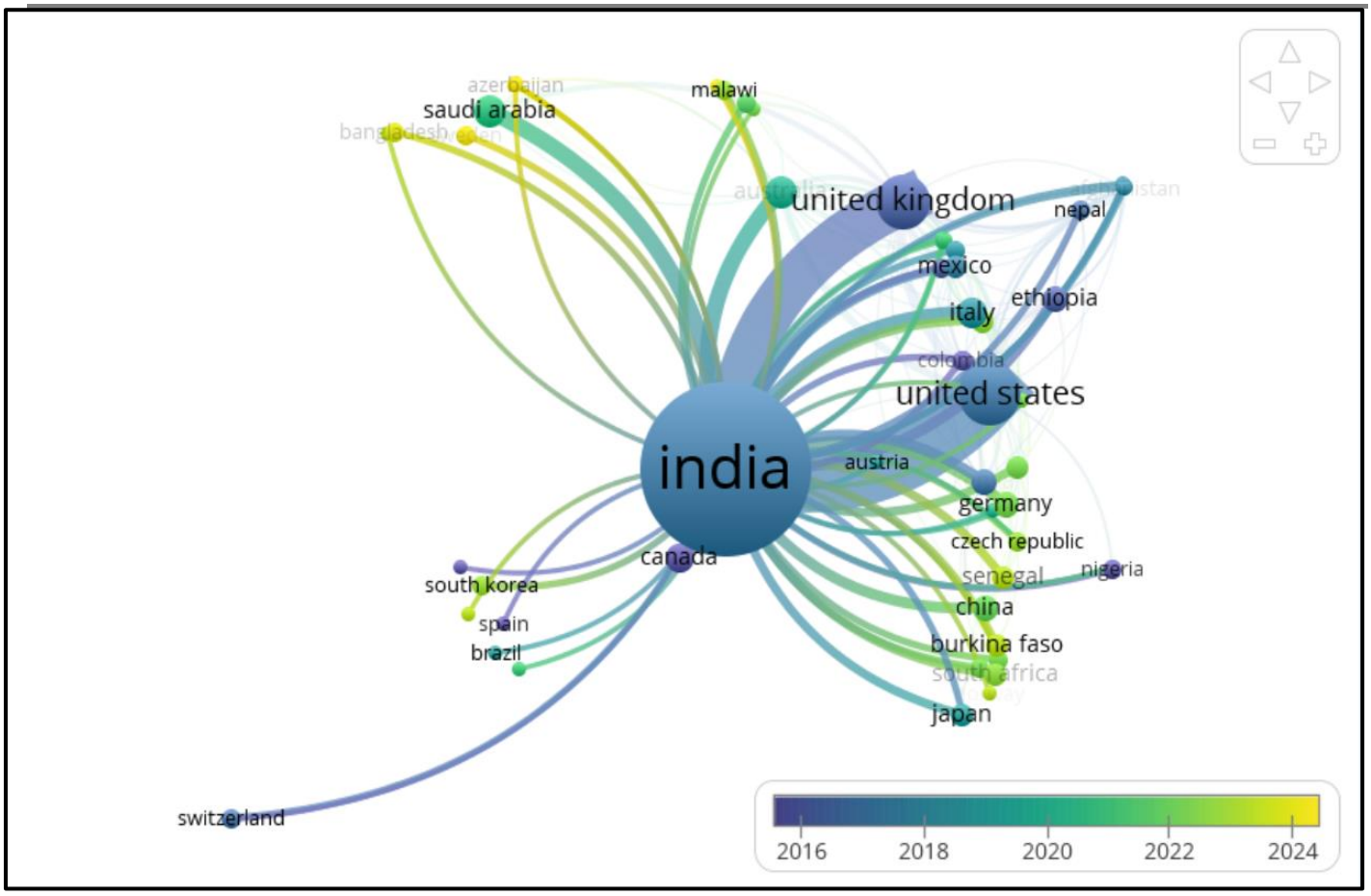

Figure 6: Overlay visualization of country collaborations of Indian authors with other countries

Co-occurrence Analysis

Co-occurrence analysis is a technique which helps in identifying the most frequently used keywords in literature indicating the area of interest in the field. It is expected that words which are commonly used together have the same underlying theme. This helps in exploring the existing and possible links between themes of research (Emich et al., 2020).

For performing the keyword co-occurrence, a thesaurus file in VOSviewer for author keywords was prepared. This was scrutinized to club the variations of the same words as well as remove any general terms. Only those keywords which occurred 3 or more times were included for network visualization. Only 38 words out of 930 fulfilled the criteria and had 1 or more linkages. These were included for final visualization where a minimum cluster size of 5 items was defined. This resulted in obtaining 5 clusters which can be seen in Figure 7. The keyword with maximum occurrences is "Millets." This is followed by "India"; "Sustainabilty", "Climate Change" and "Nutrition".

An observation of the overlay visualization map (Figure 8) also impresses the keywords which are used in the recent years. The 4 most recent areas are "Odisha", "Nutri-cereals", "glycemic index" and "Nutritional security". Odisha had launched the Odisha Millets Mission 2017 to bring millets to mainstream and had also hosted the International Convention on Millets in 2023. The world focus is also shifting to the nutritional and health benefits of Millets which also explains these results.

Analysis of the Clusters based on Keyword Co-occurrence Analysis

This sub-section discusses the thematic clusters formed in co-occurrence analysis. Figure 7 shows 5 clusters - cluster 1 in red, cluster 2 is seen in green, cluster 3 in blue, cluster 4 yellow and cluster 5 is purple.

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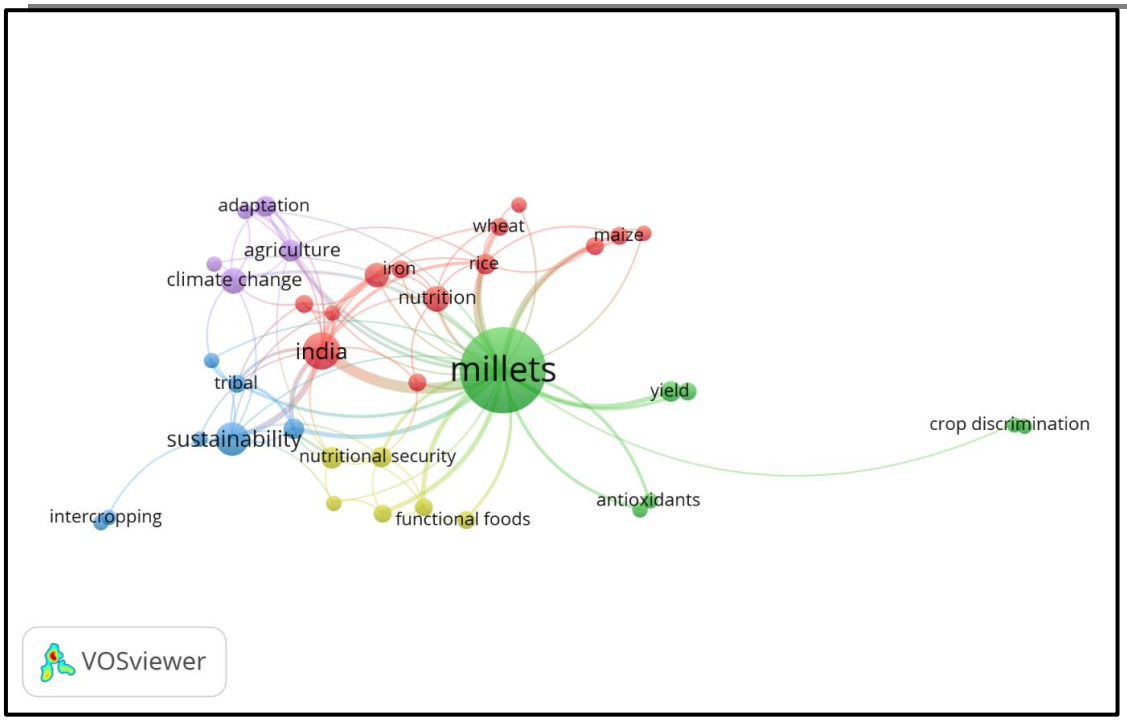

Figure 7: Keyword Co-occurrence Analysis

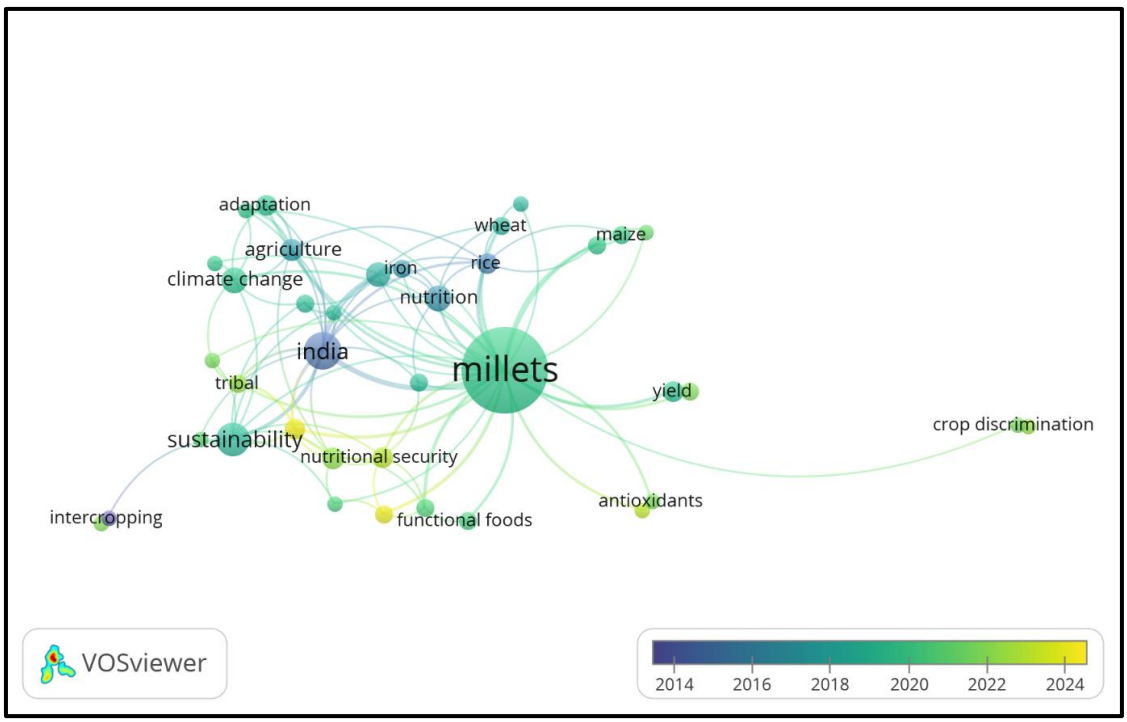

Figure 8: Keyword Co-occurrence Analysis: Overlay visualization

Cluster 1: Improving nutrition through the use of millets.

Table 5 indicates that Cluster 1 consists of 13 keywords. Based on the number of occurrences, the most prominent term in this cluster is India. The term "India" has second highest number of occurrences amongst the keywords (which is visible from the table 5 as well as size of node in Figure 7). It occurs 17 times and has 17 links with a total link strength of 32. This is expected given that study focuses on millet research in Indian context. The cluster explores the theme of improving nutrition through the use of millets. 2 terms which find frequent occurrences are

"Nutrition" (Occurrences 8; Total Link strength 8) and "Biofortification" (Occurrences 7; Total Link strength 6). A close observation of links reveals that 'nutrition' and 'biofortification' are linked with each other and

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with the terms ‘iron’, ‘India’ and ‘millets’. Most of these studies explore how nutritional needs can be fulfilled through biofortification of minerals like iron to millets and other cereals (Bouis et al. 2011; Banerji et al 2016; Neeraja et al 2017; Gannon et al 2019; Meier 2020; Foley 2021; Neeraja et al 2022). Other terms in the cluster include “rice” (5 occurrences), “cereals”, “wheat”, “maize”, “sorghum” and “value chain” with 4 occurrences each and green revolution with 3 occurrences. These papers focus on agricultural practices to improve the production and value chain of millets and other cereals like rice, wheat , maize and sorghum (Jeeva 2019; Shaloo et al 2022; Thakur et al 2022; Downs et al 2022). Lastly, some studies also elaborate the role of millets in improving the nutritive value of food through use of “composite flour”, “rheology” or different culinary practices (Khetarpaul and Goyal 2009; Thirumangaimannan and Gurumurthy 2013; Kumar et al 2023; Meherunnahar et al 2023; Manchanda et a; 2024)

Table 5: Keywords used for Co-occurrence Analysis

Keyword	**Occurrences**	**Total Link Strength**	**Avg Pub Yr**	**Cluster**
India	17	32	2015.12	1
Nutrition	8	8	2016.5	1
Biofortification	7	6	2018.14	1
Rice	5	12	2015.8	1
Maize	4	6	2020	1
Sorghum	4	6	2019.75	1
Cereals	4	6	2019	1
Value Chain	4	4	2019	1
Wheat	4	7	2018.5	1
Iron	4	6	2016.75	1
Rheology	3	2	2021	1
Green Revolution	3	7	2019	1
Composite Flour	3	2	2018.67	1
Millets	92	63	2019.75	2
Yield	5	4	2019.4	2
Nutrient Use Efficiency	4	3	2021.5	2
Glycemic Index	3	3	2022.67	2
Sentinel-1a	3	2	2022	2
Antioxidants	3	3	2021.33	2

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Crop Discrimination	3	3	2021.33	2
Sustainability	14	15	2018.86	3
Odisha	5	11	2023.6	3
Tribal	4	8	2022	3
Productivity	3	1	2021.67	3
Shifting Cultivation	3	5	2021.33	3
Soil Organic Carbon	3	2	2020.67	3
Intercropping	3	2	2013.67	3
Food Security	6	7	2021.83	4
Nutritional Security	5	8	2022.6	4
Nutri-Cereals	4	6	2023.5	4
Value Addition	4	7	2020.5	4
Functional Foods	4	3	2020.25	4
Climate Resilience	3	4	2020.33	4
Climate Change	8	9	2019.5	5
Agriculture	6	10	2017	5
Adaptation	5	9	2019.4	5
Vulnerability	3	8	2020.67	5
Marketing	3	2	2019.67	5

Cluster 2: Use of Science and Technology to improve yield and sensory acceptability of millets

Cluster 2 consists of 7 keywords (Refer to Table 5). “Millets” is the most prominent term (92 occurrences) of the entire set of keywords (as seen in the table 5 as well as size of node in Figure 7). It is linked to 31 other terms across clusters with total link strength of 63. This is expected given that study focuses on millet research in Indian context. The cluster explores use of science and technology for improving yield and sensory acceptability of millets. Additionally, the health aspects of Millets are also covered in the cluster. In this cluster; “yield” and “nutrient use efficiency” are 2 terms which are linked to each other and to millets. Some papers which study the ways to increase nutrient use efficiency and yield of millets include Srinivasarao et al 2016; Pramanick et al 2024; Rangaiah et al 2024. The terms “Crop discrimination” and “sentinel 1a” also find place in the cluster. Shanmugapriya et al (2020) and Milesi. and Kukunuri. (2022) discuss the use of advanced technology like crop discrimination using remote sensing through Sentinel satellite for monitoring the yield.

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A secondary theme of the cluster is related health aspects of millets and use of scientific techniques to improve its acceptance (while preserving the beneficial aspect of such food). This is specifically demonstrated by the inclusion of terms "glycemic index" and "anti-oxidants" both of which occur 3 times with total link strength of 3 and are connected to each other (Refer to Figure 7 and Table 5). The studies dwell on health benefits and sensory response of millet-based products which could increase its acceptability (Saraswat et al 2020; Santhoshkumar 2024; Shrestha et al 2024). While these studies have focused on health benefits and how its acceptability could be increased, there are other studies that have analyzed the market potential for Ready to Eat (RTE) and Ready to Cook (RTC) millet-based products. In one such study by Udaiyar (2018) on women in Mumbai, it was found that popularity of these RTE items among women was due to double income, lack of time, convenience and taste. Studies such as these indicate that along with scientific techniques highlighting the health benefits, taste and convenience also influence millet acceptability. These studies are however fewer in number.

Cluster 3: Millet as a sustainable crop

Cluster 3 focuses on Sustainability of Millets. The term "Sustainability" has the third highest (14) occurrences in the set of keywords and has a total link strength of 15. Andreotti et al 2022 discuss the renewed interest in millets and compare the same to quinoa and teff. Many of the sustainability studies are from Odisha which is a major producer of millets (Shah 2023 and Pani et al 2023). The term "Odisha" occurs 5 times and has a total link strength of 11. Odisha had launched The Odisha Millets Mission in 2017 to focus on millets as a sustainable crop. So, a number of papers cover the initiatives to promote the use of millet and their impact including a focus on tribal communities in the state (Kumar 2023; Samal and Mishra 2023; Mathur et al 2024; Padhee, 2024). Techniques like shifting cultivation, intercropping and enhancing soil organic carbon, are examined as methods for improving productivity or maintaining sustainability by researchers (Srinivasarao et al 2014; Sati and Wei 2018; Pandey et al 2019; Mummidi 2024; Sheoran et al 2024; Sukanya et al 2024.

Cluster 4: Providing Food and Nutritional Security through the Millets

Ministry of Agriculture and Farmers Welfare recognized Millets as "Nutri-cereals" owing to their rich nutritive value (FSSAI Guidance Note No. 12/2019). The second Sustainable Development Goal (SDG 2) goal is Zero Hunger (United Nations SDG Report, 2016). Food Security and Nutrition Security are the most common terms in this cluster (Refer to Table 5) indicating that the cluster focuses on Food and Nutritional security through the use of the nutri-cereal millets (Notaro et al 2017; Samal and Mishra 2023). Sangappa et al 2023 and Shah 2023 also talks about providing food and nutritional security by focusing on the supply chain of this nutri-cereal while Manohar & Rehman (2018) examine the factors influencing consumer preference for these functional foods. Some studies examine methods of value addition to make millets better functional foods (Khulbe et al 2014; Kumar et al 2021; Dwivedi et al 2024; Neeharika and Suneetha 2024). The climate resilience of this nutri-cereal is also examined by some scholars (DeFries et al 2016; Choudhary et al 2023). Many attempts have also been made to promote millets by adding value to the product through food processing technologies branding them as healthy and convenient foods. Some such recently available products in the markets include Jowar idli mix', 'flakes', 'khichdi powder', 'pasta', 'upma mix', 'vermicelli' etc. Some of these products are being sold by a commercial brand known as 'Eatrite' owned and promoted by the Indian Institute of Millet Research (IIMR) led consortium. There are several other such startup companies which are also involved in the promotion and development of millet products under the patronage of Nutrihub – a technology business incubator funded by DST, GoI (Pravallika et al 2020).

Cluster 5: Impact of Climate change on Millet cultivation

"Climate change" and "agriculture" are the most commonly occurring terms in cluster 5 (Refer to table 5). Most papers in this cluster explore the impact of climate change on millet production and the agricultural practices suitable in the changing environment scenario (Gupta et al 2014; Fischer et al 2016; Reynolds et al 2016; Janarthanan 2024). Singh et al 2020 and Nannewar et al (2023) investigate the factors which make agriculture vulnerable to climate change and the farmer awareness and adaptations required to overcome the environmental challenges. Paragbhai and Singh 2019 discussed the shift towards millets owing to climate

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change and suggest the marketing strategies for the same. Some other papers which focus on the marketing strategies of millets are Gruère (2009); Dani and Dasgupta (2021)

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

Considered to be a neglected crop up until 2010, Millets have been receiving steady attention post 2021 in India. Our study revealed that research work has gone up significantly in the period 2021-2025 demonstrating the renewed interest in Millets as an important crop. Co-author analysis indicated high level of inter-country as well as intra-country collaborations indicating the seriousness with which research on millets is being pursued to enhance the overall result output. Similarly, the co-occurrence analysis identified 'Millets', 'India', 'Sustainability', 'Climate Change' and 'Nutrition' as prominent cluster themes on the subject. As is evident, most of the research work in the field is trying to address the issue from a supply point of view. Broadly speaking, they highlight that millets are an important crop because they are sustainable, climate change resilient and have great nutritional value.

Some studies also highlight the ways in which yield and productivity of millets can be enhanced. Their emphasis is mostly on farming and agricultural techniques that can increase production. The linkages of biofortification and nutrition with other minerals and cereals as found in cluster 1 also indicates efforts by means of which the nutritive value of millets can be further augmented. Just as studies on the use of science and technology to improve yield and sensory acceptability of millets through the use of terms like 'glycemic index', 'anti-oxidants' etc. further elucidate health related benefits and sensory responses of millets-based products that would improve their acceptability. However, missing from these studies are an emphasis on the demand point of view. For instance, there are very few studies on how to make millets consumption an attractive proposition from the consumers' point of view. Just conveying that it is a nutritious crop having health benefits may not encourage the consumers to make it a part of their cereal basket. More so, when it is a well-accepted fact that millets have a slightly bitter taste and owing to some of their characteristics are not easy to knead like wheat flour.

Similarly, there are few studies on the consumers' attitude and perception towards millet consumption or on the factors affecting their consumption behaviour. Not always consumer's preferences and tastes are scientifically or rationally determined. The consumer does not always make informed choices as autonomous individuals to reach a desired end. Consumer choices are subject to a series of restrictions based upon the categories that they belong to. Categories such as caste, class, tribe, gender etc. have an impact on food habits. Historically speaking millets were earlier regarded as the 'poor man's crop' and were mostly relegated as being inferior crops (FAO 2023). It was Thorstein Veblen (1899) who in his work on 'The Theory of the Leisure Class' had introduced the concept of 'conspicuous consumption' highlighting how people often consumed specific products to display their status and wealth. Hence the middle class and the upper middle class living in the urban areas of India may not consider millets consumption as worthy of their status. This study promotes the idea that more research should be undertaken to look at historical and socio-cultural aspects of millets acceptability from the consumer point of view.

Cluster 3 focuses on Millets as a sustainable crop. The term sustainability has 14 occurrences in the set of keywords and has a total link strength of 15. Again, most of the studies are technique centric related to techniques like shifting cultivation, intercropping etc. to improve productivity or they are studies highlighting specific regions such as Odisha promoting the use of millets with a focus on tribal communities. The studies on sustainability are limited in scope. For instance, there are few studies which are geographically spread-out all over India highlighting the strengths, weaknesses and challenges related to millets cultivation. Though Rajasthan and Maharashtra are major producers of millets, there are very few studies from these areas. Similarly, cluster 4 recognizes millets as 'nutri-cereals' providing food and nutritional security but these are again value chain centric. The current study suggests that probably making millets a part of the public distribution system would also go a long way in ensuring millets consumption. Research should therefore be directed along the viability of millets as an important item of the public distribution system like wheat and rice.

Finally, though the study through a bibliometric lens demonstrates that the status and prospects of reinstating millets as a sustainable crop in India look bright, but much needs to be done. Future research should also

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue V May 2025

explore millet consumption patterns and policy outcomes that lead to its acceptance as an important cereal. Use of other diverse data sets beyond Scopus could further enrich our understandings of millets providing insights into unexplored dimensions on the subject. To establish millets as a smart crop, along with studies on consumer preferences, tastes, marketing, socio-cultural and historical factors, studies on adaptive potentials of both the crop as well as the community in addressing climate change should also be encouraged. Moreover, recognizing that India is a diverse country with a diverse population, category-based studies through an intersectional lens such as gender and class dimensions related to millets should also be encouraged. That would shed light on the acceptability rate of millets by specific communities and then these could be targeted.

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