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Research Article

A Scientometric Exploration of Multidisciplinary Food Security Research in India: Trends and Patterns

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ABSTRACT

Food security is a multidisciplinary field with evolving definitions, causes, consequences and solutions. In this paper, using tools of scientometrics and bibliometrics-publication performance analysis and science/network mapping, we try to gain an aggregated macro view of food security literature conducted in or closely related to India. We use VOSviewer and bibliometrix/biblioshiny in the R programme to generate network maps and publication trends. We find that the quantum of publications in the field of food security has increased over the last 30 years (1980-2021). India collaborates most with the USA and more recently with Belgium, Israel, Japan and Hungary. 'Field Crops Research' and 'Food Security' are the most impactful journals. The authors and publications exploring the mitigation of climate change, genetic trait improvement of crops and sustainable agricultural practices are of much relevance and influence. Climate change, agriculture, rice, wheat, yield and productivity are the most prominently used keywords for food security research in India. Research on food security now focuses on nutrition, gender, climate change and diet structure rather than yield and supply. For further research, building climate resilient food consumption patterns, exploring indigenous food diversity and links between gender and food/nutrition security and other micro-level intra-household dynamics can be explored. Evidence-based decision-making, intellectual collaboration and the creation of successful policies and interventions will all be made possible by scientometrics' insightful understanding of the dynamics and structure of food security research

Keywords: Scientometric, Bibliometric, Food Security, India, VoS viewer, Bibliometrix.

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INTRODUCTION

Food security is a major enabling factor for overall human development and economic growth. Although the status of food security has improved slightly in recent years, there are countries still suffering from acute hunger and malnutrition, especially after the COVID breakout. However, the synthesis of research trends on food security is mostly confined to the developed world. A macro review of the literature of developing and less developed countries is limited, where food security is a serious issue. To comprehend the state of research, a scientometric analysis of Indian food security literature is essential. This study tries to gain a bird's-eye view of the food security research conducted in or closely related to India. Using the study area, author affiliation location, publication name and other criteria, we examine the corpus of research on food security that is relevant to India in our investigation.

Globally, we are not yet on track to end world hunger and malnutrition. The prevalence of undernourishment has increased from 8.4% (2019) to 9.9% (2020) (Food and Agriculture Organization (FAO), 2021).[1] The National Family Health Survey-5 (2019-20) for India shows that child stunting and other nutrition indicators have not changed much. India has also been performing poorly in the Global Hunger Index rankings.[2]

Food insecurity is defined by the FAO as a situation in which people lack secure access to a sufficient amount of safe and nutritious food for normal growth, development and an active healthy lifestyle. Over time, the conceptual understanding of food security has expanded, evolved and deepened. Food security was mostly about the availability of adequate food at all times (FAO 1974). Soon, it was realized that food security is not just about food supply but is an amalgamation of various socio-economic, political and regional factors. The definition of food security has evolved from '*access to adequate food and eradication of hunger'* to "*food safety-hygiene*" and "*food sustainability*". The latest definition of food security by FAO focused on four pillars-*availability, access, utilization and stability*.

Concerns about food security came into existence a few years after World War Two (1939-1945). In fact, Malthus's (1798)

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research is considered the starting point of food security research by some scholars.[3] It depicts the current challenge of feeding the world's ever-increasing population while having a limited ability to produce food. Food security is a complex issue affected by a plethora of factors spanning across many disciplines, like climate change, agricultural productivity, poverty, political tensions, topography, demography, urbanization and consumption patterns. Food insecurity is exacerbated by poverty since it results in unequal resource distribution and economic imbalances. Through technological innovation and sustainable methods, agricultural productivity guarantees sufficient food production. Conversely, the food system-which includes production, processing, distribution and consumption-is adversely affected by climate change, jeopardizing every aspect of food security. In a similar vein, urbanization can increase population purchasing power while also lowering agricultural product output. Therefore, a range of eradication strategies are proposed, ranging from reducing poverty, increasing crop yield and adapting sustainable food habits to social security schemes

Extant studies have discussed the definition, causes, consequences and solutions of food security or food insecurity. But there is a general lack of articles examining the temporal and content evolution of the body of food security research in less developed or developing countries. In recent years, a few studies have explored global trends in food security research and analyzed the research status of food security in the context of food price instability, climate change, agricultural supply and COVID-19.[4-6] Most of these studies have used scientometric/bibliometric tools to quantitatively analyze the research status, intellectual structure, content and collaboration networks in the concerned field of study. These studies have helped summarize the dispersed field of study on a global level.

In this paper, we conduct a scientometric/bibliometric study of food security research specifically originated in or closely related to India. The Web of Science database is used and mapped using the VOS viewer and Bibliometrix/Biblioshiny (R package). Both publication performance analysis and scientific/network mapping are carried out to have an aggregated macro view of the research field and evoke the multidisciplinary nature of the same. In the following sections, we first review the existing literature on the concerned topic, followed by a brief on the data and methodology used. Further results for both publication performance analysis and network mapping are presented, followed by discussion and conclusion.

Literature Review and Research Gap

Over the years, bibliometric/scientometric analysis has been widely used to quantitatively analyze the scientific research fields of social sciences, economics, business management, education, medicine and others. Recently, this technique has also been inculcated to study the research profile for specific crops, terms, authors, institutions, or journals.[7,8] A study attempted to analyze the research productivity for India in the fields of social sciences and humanities during 2005-2014.[9] These studies have helped in giving a sense of evolutionary direction to a much scattered field of research. Bibliometric/Scientometric studies have helped in pinpointing the gap between the research output quality of developed versus developing countries.

In the context of food security literature, a global study analyzed 3169 papers from the Web of Science database for 46 years.[10] The authors found that the first paper in the field of food security was published in 1974 and that since then the publication temporal trend has been on a consistent rise. They observed that the developed nations of the USA, UK and Canada have more publications in comparison to sub Saharan African or Asian countries. In line with the propelling problem of increased food demand and deteriorating climatic conditions, they pointed out that the broad spectrum of research in food security has moved from socio-economic analysis towards climate specific analysis of the problem.[10]

Another study noted that food security research has shifted from socio-economics to environmental aspects.[11] This study too found the USA as one of the nations with a major share of publications, along with 'Food Security' as one of the most prominent journals in the field. They concluded that the share of undernourished people in the world is on the decline. At the same time, the literature on food security is consistently rising, but the developing and developed nations need more intellectual interaction.[11] Further, a study analyzing the global trends in food security research, found that the research shows an increasing trend for the past 30 years, with 2013-2019 being the most active phase of all.[12] They highlighted the multidisciplinary nature of food security research and discussed the agricultural, ecological, environmental, food science and technological aspects of food security research at length. They concurred that food security research is getting more mature day by day and newer facets of the same, like climate change, poverty, gender, nutrition and diet structure, are being explored.[12]

Bibliometric studies also try to gain a bird's-eye view of food security research on single or multiple dimensions. Bibliometric analysis for the journal Global Food Security observed that globalization of trade and ethical issues in social decisions on nutrition security need special emphasis in the context of eradicating food insecurity.[13] A bibliometric analysis of peer-reviewed literature on food security in the context of climate change from 1980 to 2019 found that the USA ranked first in terms of the number of publications, whereas India ranked first in terms of research productivity per GDP per capita.[6] The author concluded that food security as one of the dimensions of climate change challenges is an emerging topic.[6] Therefore, research on new technologies to mitigate the impact of climate change on food security is a top priority. Another study explored the research that

has been published with food security, price volatility and price transmission as keywords. The authors concluded that the shift in food security research trends is associated with changes in health and food nutrition status.[4]

In the most recent times, the COVID pandemic exposed the true picture of food security status globally. A comprehensive study of literature about the effects of COVID-19 on agricultural production and food security, using both the Web of Science and the Scopus database explored the dynamics of a pandemic and food security research. The authors note that the effects of the pandemic on the agricultural food supply negatively affect all four pillars of food security.[5]

The research on food security is slowly diversifying.[27-32] The food security research is transitioning towards themes of climate change, livelihood, health and sustainability.[31] The research is becoming interdisciplinary with growing importance of nutrition sciences. A study of literature on urban food security could witness prominent links between urban food security and sustainable urban development.[29] Another study focusing on the literature related to food science and technology found that the spatial distribution of research is very skewed, concentrated only in a few countries.[28] Further, a study of food security literature found far less association between where food security research is prevalent and the regions plagued with food security issues.[31] Extant bibliometric studies on food security are mainly in the global context of trends, themes, citations, collaborations and impact. It is observed that the USA has the highest share of publications, followed by the UK, Canada and other European countries.

There is limited studies analyzing the research of third world countries who are vulnerable in dealing with changing climatic conditions, have lesser resources at their disposal and more prone to suffer from food insecurity, undernourishment, hunger and deaths by starvation. In order to address issues related to food security in India, it is imperative to identify important themes, gaps and developing areas. This information shall help with resource allocation, decision-making and focused interventions. Understanding the structure of food security research in India will promote evidence-based tactics to draw solutions for the situation.

In this paper we have refined our bibliographic database to specifically study the food security research conducted in or closely related to India. To draw upon an aggregate macro view of food security research in India we defer from specifically analyzing any particular dimension of food security research. In this paper while observing an overall picture of this field, we try to highlight the multidisciplinary nature of food security research and bring in the collaborative and intellectual structure along with thematic evolution of the field. In line with our objectives, we try to work around the following research questions:

What has the publication trend in food security research in India been like? How impactful are various authors, publications, or journals in the field of food security research in India? Which are the most influential publications and what are their broad themes? How collaborative is the structure of this research field in terms of organizations and countries? Which themes are the most popular and evolving recently? What areas involving food security research need further attention?

Analytical Framework

Data

The bibliographic data for this study was taken from the Web of Science (WoS) Core Collection, which includes the Science Citation Index (SCI) expanded 1965-present, the Social Science Citation Index (SSCI) and the Arts and Humanities Citation Index (AHCI). The WoS, initially known as the Web of Knowledge, was developed and released by Eugene Garfield around 1963 and later commercialized by Clarivate Analytics.[14] WoS enables sound scientometric /bibliometric analysis at aggregate macro level and has a reputation for better indexing of publications due to long established practices.[15]

We searched for the keywords “Food Security in India” or “Food Insecurity in India” in “All Fields” for the time span of 1965-2022. We obtained 3759 publications. Excluding 2022 from publication years, as it was the ongoing year, we obtained 3551 publications. We restricted our study to only India in “countries/regions”, "articles" as “document type” in English “language”. Adhering to these restrictions, we excluded another 1485 publications and materialized a comprehensive dataset of 2066 articles 1 We are aware that these studies don't particularly address India, based on the criteria we applied when materializing the collection of 2066 publications. Nonetheless, the study area, author affiliation, publication name, funding agency and other factors that come under "All Fields" all relate to India in these works. in accordance with our objectives.

Methodology

Over the years, scientometric has evolved as an effective field to study, assess, evaluate and gauge the impact of any body of research in any discipline.[16] It is helpful in analyzing vast amounts of data and capturing the multidisciplinary nature of a field. The techniques of scientometric/bibliometric are helpful in highlighting the quality and quantity of published research in terms of the number of authors, number of publications over the years, author productivity, citations and references, language and prominent journals. It allows the generation of maps based on network/text data and helps identify core research areas, frequently cited authors and publications, collaborating countries or institutions and emerging research areas.

Software

We use VOSviewer version 1.6.18 and Bibliometrix package/ biblioshiny library in R programme. VOSviewer, which was developed by Van Eck and Waltman (2010),[17] is a free-to-use software used to generate and visualize bibliometric networks.[18] It can be used to draw network maps based of citation, co-citation (co-citation is the frequency with which two papers are cited together by other papers.), bibliographic coupling (Bibliographic coupling occurs when two publications cite a common third publication in their bibliographies) , co-authorship (Co-authorship is when two or more authors work in collaboration) and keyword co-occurrence (Keyword co-occurrence is a technique to analyse the co-occurrences of key words and understand their pattern of occurrence and interaction)[17] Bibliometrix package, developed by Aria, M. and Cuccurullo, C. (2017) is used to generate a thematic evolution of research area along with a temporal analysis of author's productivity, publications, research impact and prominent journals.[25]

Metrics

We have carried out scientometric analysis in two segments-performance analysis and science mapping. Performance analysis is used to account for the contribution of research constituents. Here quantity of publication and citations are used as a proxy for productivity and impact of research respectively. Science mapping is helpful to analyze the relationship between research constituents. Here the intellectual structure and social collaboration within the research field is visualized (Figure 1).

RESULTS AND DISCUSSION

Publication Performance Analysis

The first paper on food security related to India was written in the years 1980 by M S Swaminathan, where he talks about the role of botanists in building a national food security system.

The publications starting from 1980 to 1996 are few and sparsely distributed (Figure 2). It is only after 1996, the number of publication in this field increased. There is a sudden spike in publications in 2008, post which the publications have raised consistently over the years. Majority of papers published in 2008, were agro climatic studies that dealt with the theme of improving agricultural adaptability in context of changing climate, so as to ensure food security. The theme of climate change and food security, had its beginning point around 2007-2008 in India, plausibly drawing motivation from the extreme climatic events like the millennium drought of Australia (Bureau of Meteorology, April 2015)[26] heat wave in California, unseasonal rains in kerala, cyclone Nargis in Burma and other such events, along with the third and fourth assessment reports of IPCC.[19,20] The share of publication originating or connected to India in total publications of this field has been consistent over the years. To better understand the publication trend, we conducted a

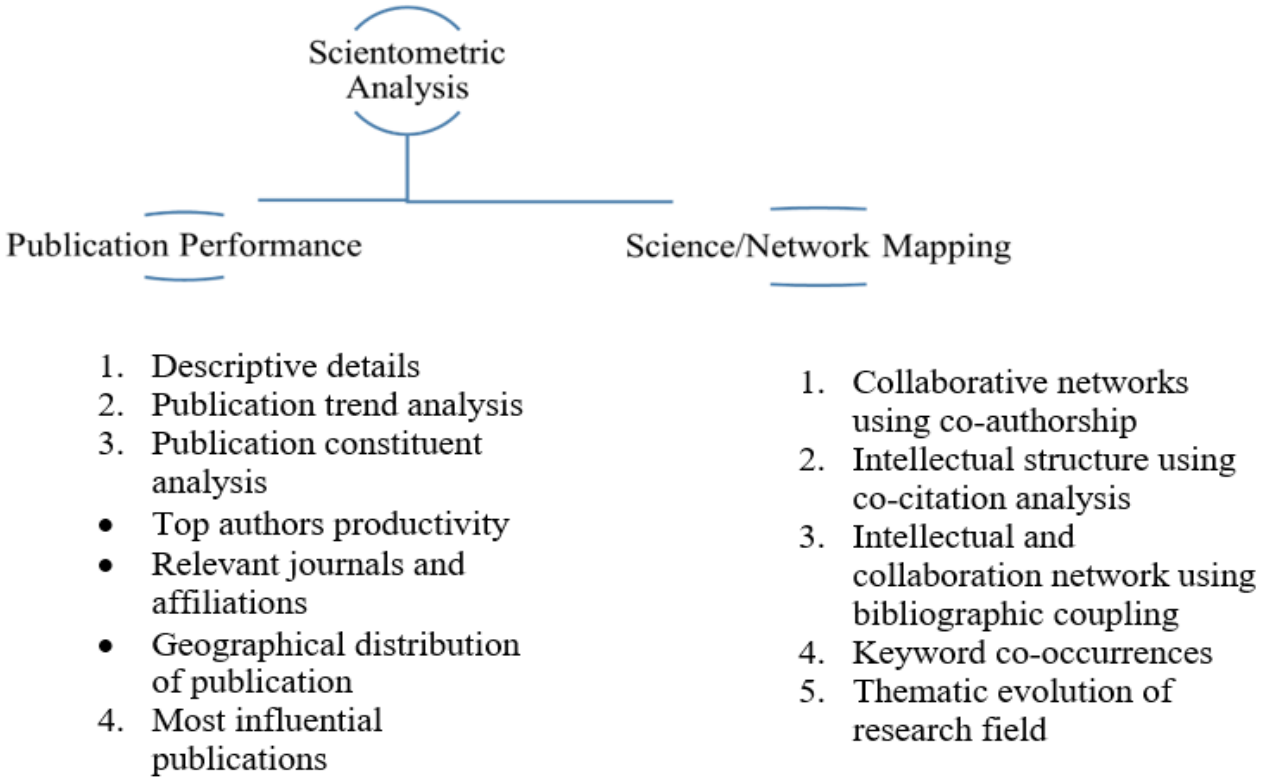

Figure 1: Author's representation of methodology.

Table 1: Description of Bibliographic Database.

Description	Results
Main information about data.	
Timespan	1980:2022
Sources (Journals, Books, etc.,).	691
Documents	2066
Average years from publication.	5.4
Average citations per documents.	22.23
Average citations per year per doc.	3.658
References	95885
Document types	
Article	1941
article; book chapter.	4
article; data paper.	2
article; early access.	30
article; proceedings paper.	89
Document contents	
Keywords Plus (ID)	4766
Author's Keywords (DE)	5994
Authors	
Authors	9156
Author Appearances.	14353
Authors of single-authored documents.	92
Authors of multi-authored documents.	9064
Authors collaboration.	
Single-authored documents.	105
Documents per Author.	0.226
Authors per Document.	4.43
Co-Authors per Documents.	6.95
Collaboration Index.	4.62

Source-WoS Core Collection; Note-As mentioned in section 3.1, we searched the WoS database for the years 1965 to 2022; nevertheless, the earliest work, which dates from 1980, is found in the bibliographic database. This may be the result of the fact that articles published before 1980 aren't indexed and therefore aren't included in the dataset that this study examines.

Bai-Perron multiple structural break test[21] and found that there was significant increase in publications in the years of 2008 and 2018 Bai-Perron multiple structural break test gave us two break dates as 2008 and 2018. The f-statistics obtained were 78.75826 and 21.61888. The Bair-Perron critical values obtained are 8.58 and 10.13. The results obtained are significant at the 0.05 level. The research theme was initially on the climate change mitigation and adaptation. The realms of research have slowly expanded to other areas such as undernourishment, gender dynamics, food governance etc.,

Food security has been evolving as a multidisciplinary research area (Figure 3). Expertise from multiple disciplines is combined to comprehend the interrelated aspects influencing food production, distribution and accessibility. This includes dietitians looking at food habits, economists assessing trade policies and agronomists researching sustainable farming methods. Aspects such as farming, economy, health and the environment are all facets of food security. Agronomists investigate how to increase agricultural productivity; economics study how commerce and money affect food availability; and nutritionists research the sorts of foods that people need to eat to stay healthy. Publications are in the themes of environmental sciences, agronomy, food science and technology, agriculture, water resources, economics and nutrition. The diversity and multidisciplinary nature of food security research helps authors from various facets of sciences contribute to the research. For our study we have considered top authors, affiliations and journals in terms of their research productivity. Assessing the work of top authors, affiliations and journals would enhance the understanding of seminal themes and topics being researched in the field. It will help exploring the dynamics of the particular research field and facilitate a direction for future scope of research. We use number of publications and h-index as proxies for research productivity and influence of authors, respectively (Table 2).[22]

It is found that Jat M. L is the most cited author of all with an h-index of 24 and publication count of 59 and is followed by Sapkota T.B with an h-index of 20. Both these authors work in the area of climate smart agriculture and have contributed towards exploring various cost-effective agricultural practices relevant with climate change mitigation. Along with them Jat H.S and Aggarwal P.K also work in the area of climate change and food security. Kumar V with 27 publications broadly works in the field, connecting crop yield and climatic condition in context of food security. Kumar A carries out more of socio-economic studies and recently explored household level food and nutrition insecurity and its determinants. Kumar S recently analyzed the cognitive impact of food insecurity in the elderly. Singh A with 34 publications and an h-index of 13, brings in a very micro-level perspective of food consumption patterns. The author has highlighted the cultural significance of diverse ethnic food and brought to notice indigenous food consumption pattern as means to securing nutrition and livelihood. The top productive authors are mostly seen to be exploring the links of food security with climate change, nutrition level, Crop yield, agricultural techniques and intra-household dynamics. They published their articles in a number of journals. To assess out most relevant journals we list out top 20 journals in the field of food security research in India (Supplementary Table 1). We measure their relevance via count of publications and their influence by *h*-index. *H*-index for a journal is defined as a journal having index h, if h of its Np papers have at least h citations each and the other (Np – h) papers have ≤h citations each. Most of these journals started only around 1995, post which we also see a rise in overall publications as discussed earlier. 'Field Crops Research' and 'Food Security'

are most impactful journals followed by 'Current Science' and 'Scientific Reports'. Similarly, most relevant affiliations are the ones with higher number of publications. International Crops Research Institute for the Semi-Arid Tropics, situated in Andhra Pradesh is the most active affiliation in terms of publication count followed by International maize and wheat improvement institute in New Delhi, ICAR-Indian Agricultural Research Institute, International Food Policy Research Institute (IFPRI). Department of Biotechnology and Agriculture Food Engineering Department of Indian Institute of Technology Kharagpur, alone have produced close to 30 publications on food security. Whereas all IITs together have produced around 90 publications. It is also to be noted that the top authors discussed in Table 2 mostly are affiliated with the above-mentioned institutions, reflecting a link between the relevance of authors and affiliations

Even though we have restricted our bibliographic database to include studies that are either originating in India or closely related to India, the mentioned (Supplementary Table 2) geographical distribution gives a rough idea of collaboration among different nations. The indexing technique of WoS is such that a particular paper can appear in multiple countries/regions, if there is collaboration of any form (co-authors, co-funding etc.) We see that India has maximum collaboration with USA followed by England.

Most Influential Publications

In this section we try to have an overview of broad themes related to the most influential documents. We have considered documents with highest number of citations. Both global citations and local citations are taken into account. The quantity of citations an article obtains from other articles in the corpus of publications under consideration is known as its local citation count. The quantity of citations an article receives without any publication dataset filters that is taken into consideration for a study is known as the global citation count. Conceptually global citations demonstrate the impact and influence of a study across disciplinary boundaries and local citation does that within the considered discipline.[22] Citations aid in the measurement of a paper's effect and influence. The total number of global citations shows the impact of a paper regardless of how the dataset is filtered based on the search query, while the local citation shows the impact of a paper within the bibliographic database that was chosen for the research. We assess the highly cited articles both globally and locally to garner details on the most prominent ongoing themes of study not just within the body of research considered for the study but across all the indexed articles in WoS.

In analyzing our most locally influential publications, we see that the theme of conservation agricultural practices, resource management, crop yield, rising temperature and irrigation practices pop out. Table 3 presents the top locally influential

Table 2: Top Authors Productivity Indicators (bibliometrix package).

Authors	Affiliations	*h*_index	*g*_index	*m*_index	TC	NP	PY_start
Jat ML	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).	24	46	2.4	2183	59	2013
Sapkota TB	International Maize and Wheat Improvement Center (CIMMYT).	20	31	2.222	1115	31	2014
Aggarwal PK	BISA-CIMMYT	17	25	0.739	2165	25	2000
Kumar A	International Food Policy Research Institute (IFPRI).	17	31	+	1065	55	+
Jat HS	ICAR-Indian Institute of Maize Research (IIMR).	14	22	1.167	518	29	2011
Kumar S	International Institute for Population Sciences.	13	24	0.565	662	43	2000
Kumar V	*	13	27	+	2150	27	+
Sharma PC	*	13	20	1.083	412	26	2011
Singh A	*	13	20	0.813	459	34	2007
Stirling C M	Mondelez International	13	17	1.444	976	17	2014

Source-WoS Core Collection; Note-h_index is defined as a scientist having index h if h of his or her Np papers have at least h citations each and the other (Np-h) papers have ≤h citations each; g_index is defined as the unique largest number such that the top g articles received together at least g^2 citations; m_index is defined as h/n, where n is the number of years since the first published paper and h is the h-index. NP is number of publications by the particular author; TC is total citations received by the author; PY_start is the year of first publication of the author. + means that the data is not available for PY_start and m_index. * means that the information on affiliation of the authors could not be found. The indicators related to authors are derived from the dataset of our study and is not representative of their entire academic contributions.

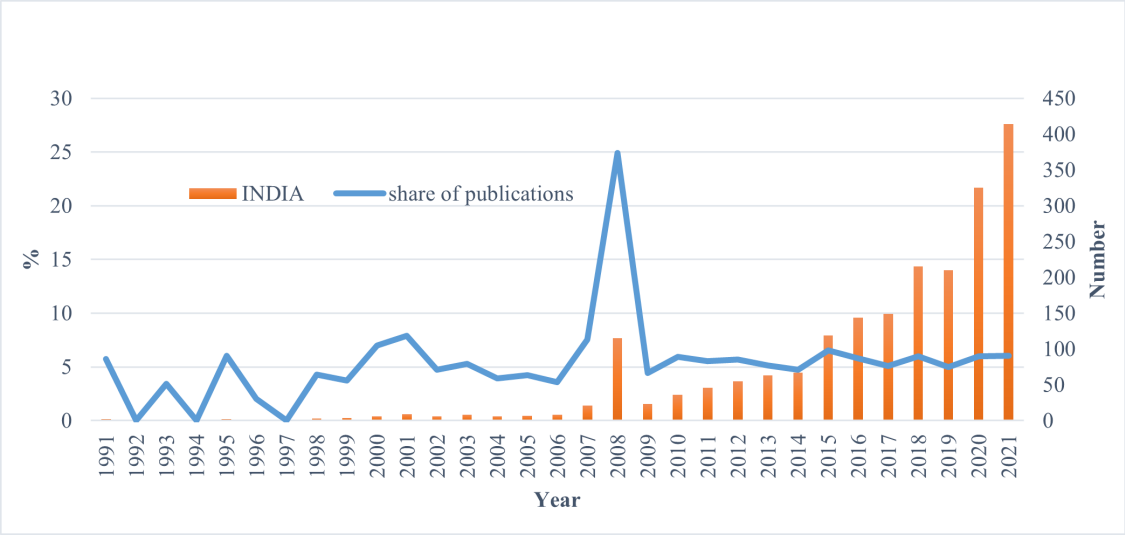

Figure 2: Yearly Trend of Publications; Source WoS Core Collection.

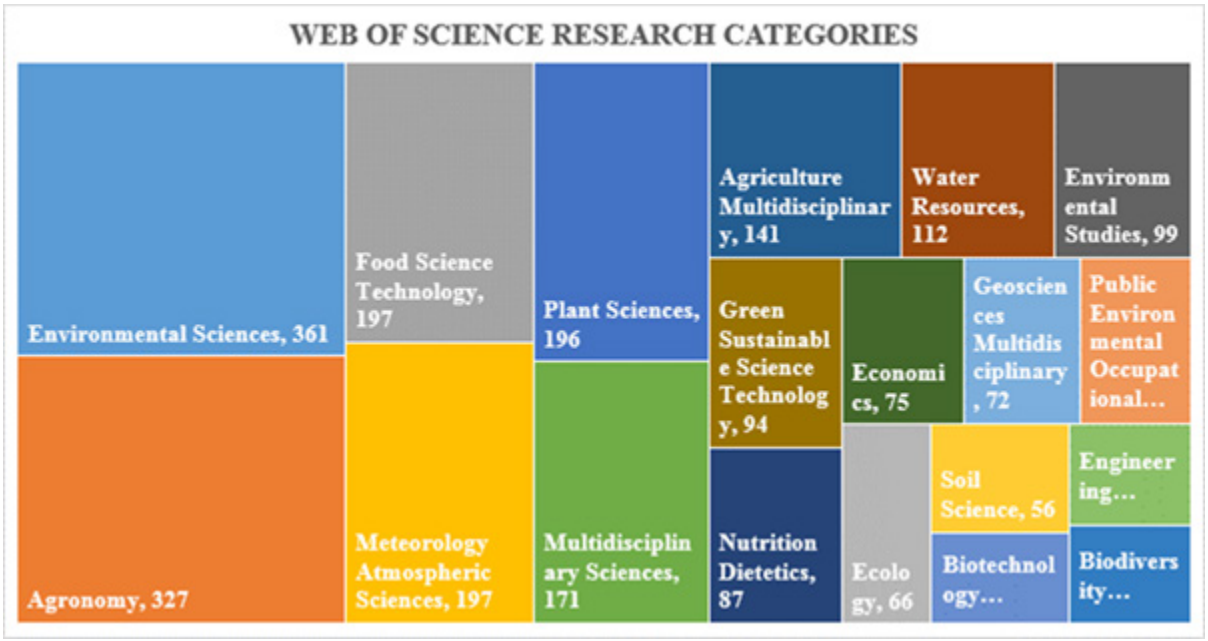

Figure 3: WoS Subject Category Wise Distriution of Publications; Source-WoS Core Collection.

articles. These articles have tried to explore the effectiveness of various agricultural practices for coping with climate change and yet stabilizing the yield, irrespective of scarce resources. Most of the studies are focused on rice- wheat cultivation in Indo-Gangetic plains. Some of these papers have also tried to comprehend the rainfall trend in India and explore the socio-economic factors affecting the food security in vulnerable regions (urban slums of Delhi, Himalayas, tribal states, north-east India etc.,).

Among articles with high global citation count we observe that most influential documents are trying to create genome sequence for various crops that are central to global food security challenge like rice, wheat, chickpeas, pigeon pea etc. (Supplementary Table 3). Genetic trait improvement of a crop is garnering much attention globally as a means to secure sustainable and consistent harvest for meeting ever increasing food demand. A study found that the rise in temperature will reduce global wheat production by 6% for each °C of temperature rise.[23] The articles have also tried to quantify the depletion of groundwater levels and address the issue of water scarcity. These have also explored various agricultural practices for climate change mitigation, enhancing food quality-safety and using nanotechnology for sustainable agriculture. Considering the aim of diversifying the global crop basket, few papers have advocated for giving importance to legume production and consumption for human health and sustainable food production.

Table 3: Most Locally Cited Documents.

Authors	Year	Local citation	Keywords	Motivation
Jat R.K et al.,	2014	39	Double no-till, Direct seeded rice Permanent beds, Residue management System productivity, Zero tillage.	Evaluated agronomical productivity and economical profitability of various combinations of tillage, crop establishment and residue management practices in rice-wheat rotation of Eastern Indo-Gangetic plains of India.
Sapkota T.B et al.,	2014	26	No tillage, Nutrient Expert, Greenhouse gases, Site-specific nutrient management Cool farm tool Green seeker.	Nutrient management practices for no tillage-based wheat production in north western India.
Ladha J.K et al.,	2003	24	Indo-Gangetic plains Long-term experiments Nutrient budget Rice-wheat system Soil fertility Yield decline Yield trends.	To investigate the extent of yield stagnation or decline and identify possible causes of yield decline.
Aryal J.P et al.,	2015	20	Zero tillage, Greenhouse gas emissions, Conventional tillage, cropping system.	Tested the hypothesis that Zero Tillage (ZT) based crop production emits less greenhouse gases and yet provide adequate economic benefits to farmers compared to the conventional tillage.
Jat M.L et al.,	2013	17	Cropping system Double no-till Permanent raised beds Soil physical properties Water productivity.	Agricultural practice of no tillage for maize and wheat and its effect on crop yields, water productivity, profitability and soil physical properties.

Source-WoS Core Collection.

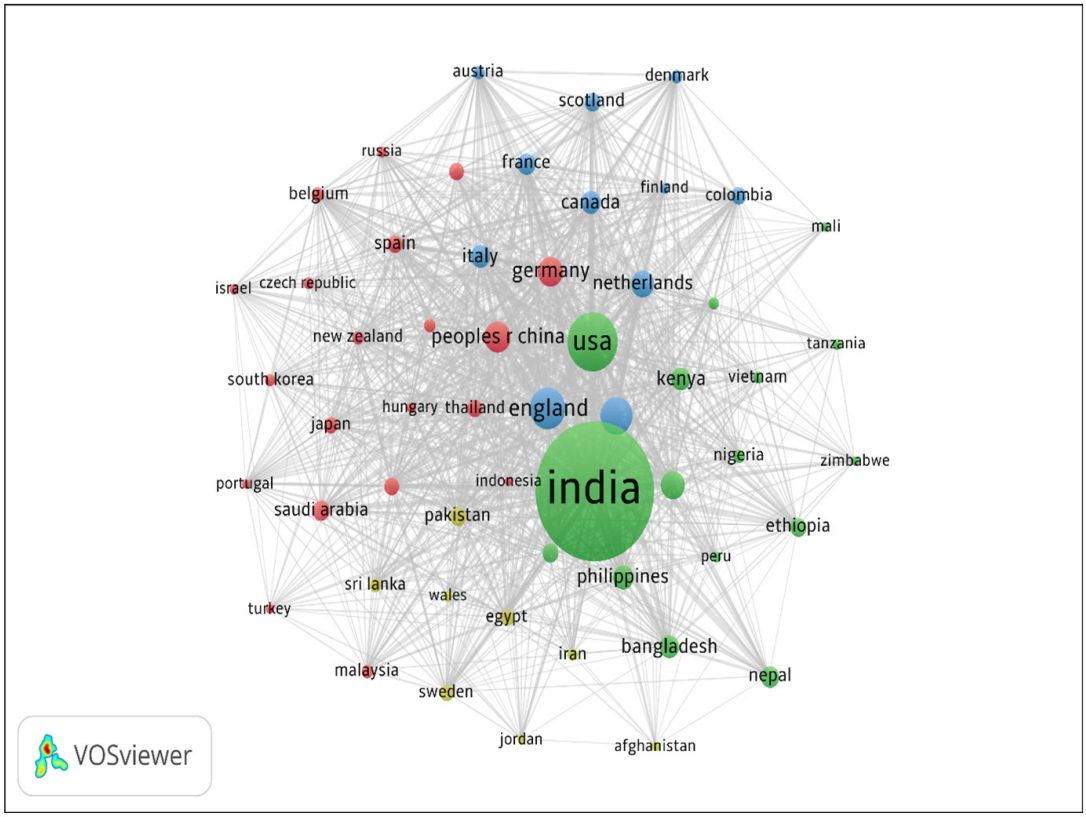

Figure 4: Collaborative Network of Countries based on Co-Authorship; Source- WoS Core Collection.

Science Mapping

Collaborative Network

Co-authorship examines the interaction among scholars across countries, publications or affiliations. It is a formal way of intellectual collaboration. We analyze the collaborative network amongst countries and affiliations. We considered countries with a minimum of 10 publications and 20 citations. Out of 131 countries, 55 countries met our threshold which is then clustered into four groups depending upon their relatedness which is defined by number of co-authored documents. We see that India has maximum co-authored papers with the USA, England, Germany and China. In the Figure 4, sizes of the nodes represent the publication count and color of the nodes represents respective clusters of countries. For example, India, the USA, Bangladesh, Philippines, Nigeria, Ethiopia, Kenya, Vietnam form a single cluster in green. In another cluster Germany and China have high number of co-authored publications with India along with Israel, Belgium, Japan, Spain etc.,

Table 4: Broad theme of the clusters based on co-citation analysis of the cited references.

Cluster	Broad theme
Red	Conservation agriculture practices and better techniques of crop management in line with environmental factors, yield and soil health.
Green	Analyzing changing climatic extremities, degrading resources and their impact on food production and sustainability of agriculture.
Blue	Increasing global demand for food with rise in population and pressing need for agricultural sustainability and intensive production practices.

Source: WoS core collection.

To analyze the collaboration structure within the country, we analyze the co-author interaction between various author affiliations and institutes (Figure 5). We set the threshold at minimum of 10 publications and 20 citations, which gave us 61 affiliations out of 2456 affiliations to be studied. International Crops Research Institute for the Semi-Arid Tropics, situated in Andhra Pradesh and International maize and wheat improvement institute in New Delhi have maximum number of co-authored documents. Indian Council of Agricultural Research-Indian Agricultural Research Institute (ICAR-IARI) in New Delhi has formed its own cluster of collaboration with Banaras Hindu University (BHU). Similarly, Colombia University, University of Oxford are international affiliations that work in the concerned field with All India Institute of Medical Science (AIIMS) Delhi. Similarly, Jawaharlal Nehru University (JNU), Indian Institute of Technology (IITs), Council of Scientific and Industrial Research (CSIR) and The Energy and Resources Institute (TERI) seem to have much collaboration among authors in food security research.

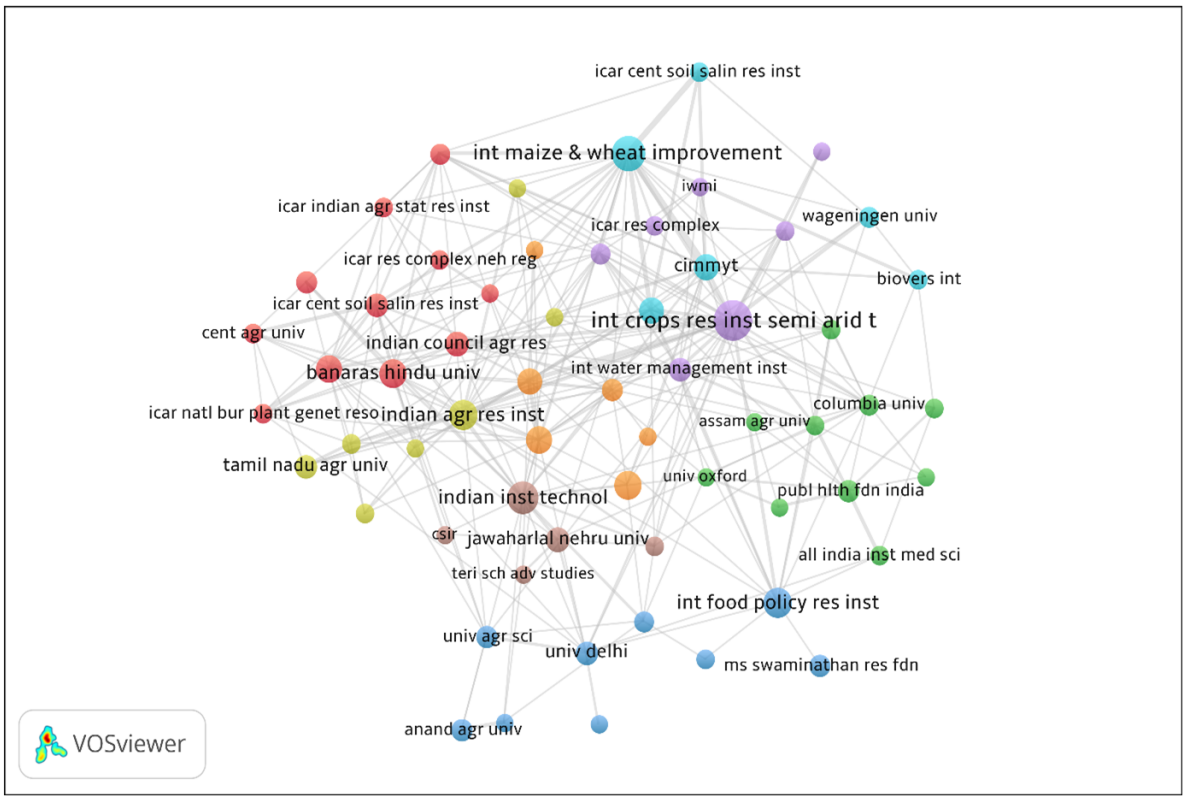

Figure 5: Collaborative Network Between Affiliations Based on Co-Authorship; Source- WoS Core Collection.

Intellectual Structure

Co-citation analysis involves tracking pairs of papers that are cited together in the source articles. It assumes that the publications that are frequently cited together are thematically similar. It helps in identifying the underlying themes of the field and make thematic clusters. Since it concentrates only on highly cited publications, it helps recognize seminal publications and knowledge foundations.[22] For our analysis we have considered cited references with a minimum of 20 citations. This threshold gave us 40 publications which are divided into three thematic cluster-red, green and blue (Figure 6). To understand the themes of the papers categorized into the three clusters we have summarized the broad idea of each cluster in Table 4.

This analysis highlights the fact that the food security research is actively concerned about exploring agricultural practices or techniques that take the given condition of environment, natural resources and increasing population into consideration simultaneously. Several trends and strategies are proposed to mitigate climate change while maintaining a stable and consistent production of food.

Bibliographic-Coupling

Bibliographic coupling occurs when two works reference a common third work in their bibliographies**.** It is also a method of discovering similarities in documents. Here it is assumed that two publications sharing common references are also similar in their content. The thematic cluster of citing publications helps identify recent and niche themes of research. Bibliographic-coupling provides a representation of 'present' of the field.[22] In line with the overall h-index (h number of publications having at least h citations) value of our bibliographic data base, i.e. 88, we consider documents with at least that many citations. Only 89 publications meet our thresholds which are grouped into six thematic clusters (Figure 7). We have summarized the theme of each cluster in Table 5.

Further we have also tried to explore the recent collaboration cum intellectual trends amongst nations using bibliographic coupling (Figure 8). From the figure - 8, which uses average year of publication of the citing publications, we find that in the recent times India is collaborating with countries like japan, Belgium, South Korea, Israel, Turkey, Portugal and others. Average year of publication of the citing publications is the mean of the year of publication of all such publications that are bibliographically coupled for each country. Slowly the thematic collaboration of India is moving away from USA, England, Philippines to explore other intellectual nation partner we find that in the recent times India is collaborating with countries like japan, Belgium, South Korea, Israel, Turkey, Portugal and others. Slowly the thematic collaboration of India is moving away from USA, England, Philippines to explore other intellectual nation partner.

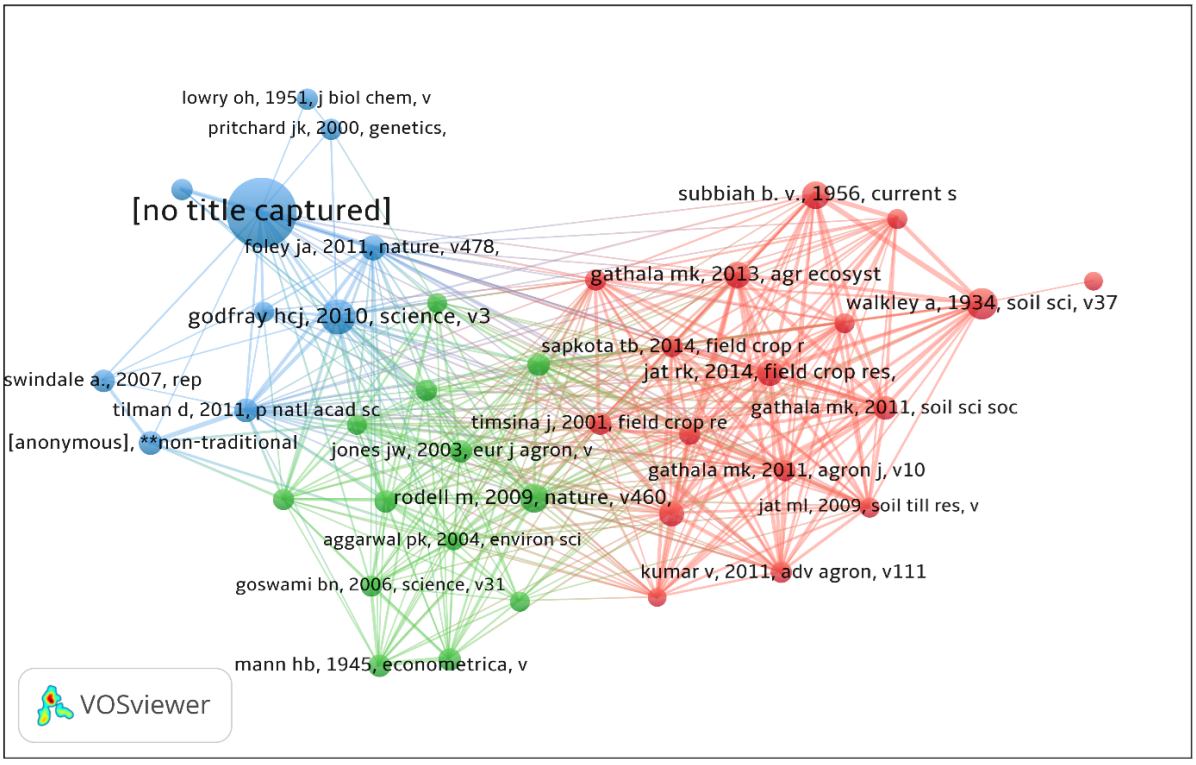

Figure 6: Intellectual Structure using Co-Citation Analysis of Cited References; Source- WoS Core Collection

Keyword Co-Occurences

This method helps us identify the most prominent and frequently occurring theme of the field. This helps identify the hot topics and trace future path of research in the field. Analyzing keywords along with intellectual structures gives a better understanding of research gaps. Here we considerd author's keywords, with a minimum frequency of 50 for each term. In the Figure 9 we have 212 keyword terms grouped into four thematic cluster. The size of the node is directly proportional to the frequency of the term. With this understanding, we observe that climate change, agriculture, rice, wheat, yield, productivity, impact, management are the most prominently used keywords for food security research in India. Socio-economic aspects of the research need more exploration as the nodes for malnutrition, undernutrition, women, poverty are smaller in size. Even though climate change is quite visible, but the decomposed aspects of the same like groundwater, temperature, precipitation needs more attention.

Table 5: Broad theme of clusters based on bibliographic coupling of citing references.

Cluster	Broad Theme
Dark blue	Sustainable intensification of agriculture for global sustainability and coping with climatic variability, special attention to indo-gangetic plains.
Red	Genome sequence of crops like potato, sorghum, legumes for genetic trait improvement.
Green	Soil carbon sequestration, no tillage agriculture, conservation agriculture, crop diversification as strategies for climate change mitigation and better yield of rice- wheat majorly.
Purple	Developing geospatial database of paddy rice cultivation in south Asian countries to effectively help with irrigational issues, food security and GHG emissions.
Yellow	Impact of rising temperature, ozone pollution, erratic climatic conditions on rice-wheat yield in India.
Light blue	Study of Fungal diversity in crops.

Source: WoS Core Collection.

Thematic Evolution of the Research Field

The broad theme of food security research in India has evolved over the years. We text mine abstracts of our bibliographic database to understand the trend of themes (Supplementary Figure 1). We know that food security research in India saw its peak around 2008; therefore, the theme trend analysis has been carried out since then. Initially around the beginning of this research field, major focus was on using traditional knowledge and closing the gap between potential and actual yield. In terms of region, Himalayas and indo-Gangetic plains have held scholar's attention for the longest time. Green revolution is also a much-explored

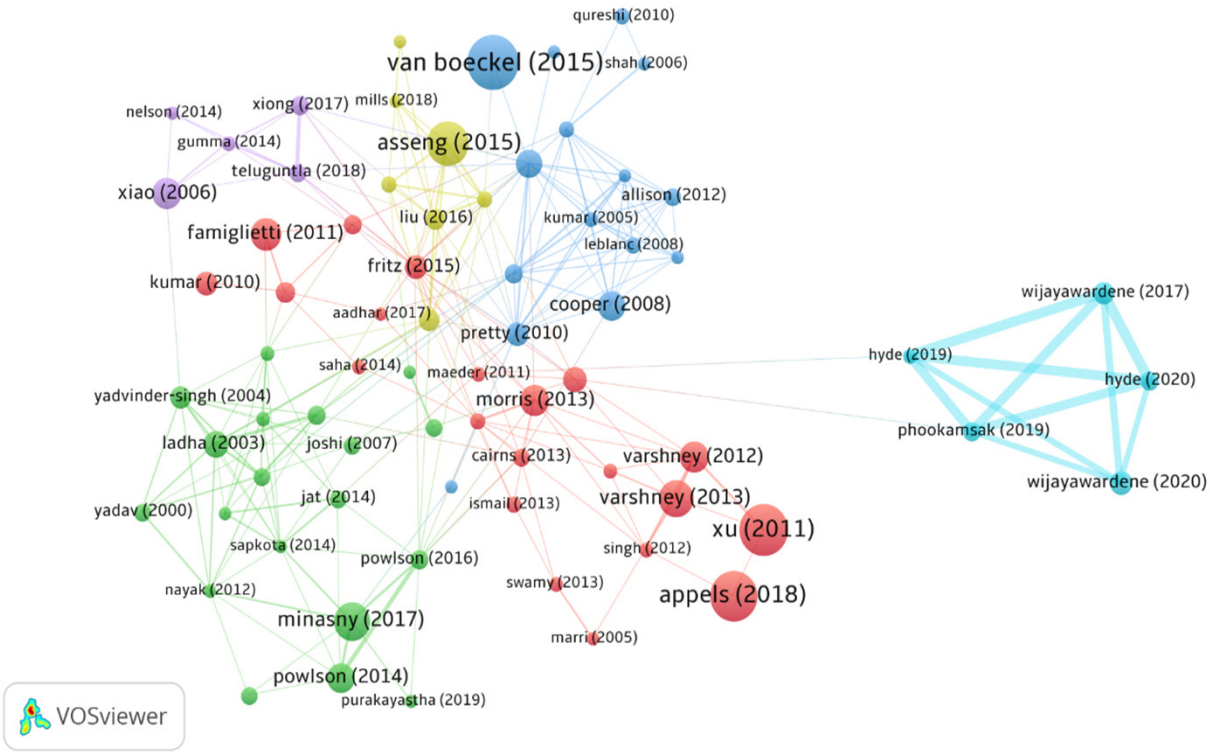

Figure 7: Bibliographic-Coupling of Publications Source-WoS Core Collection.

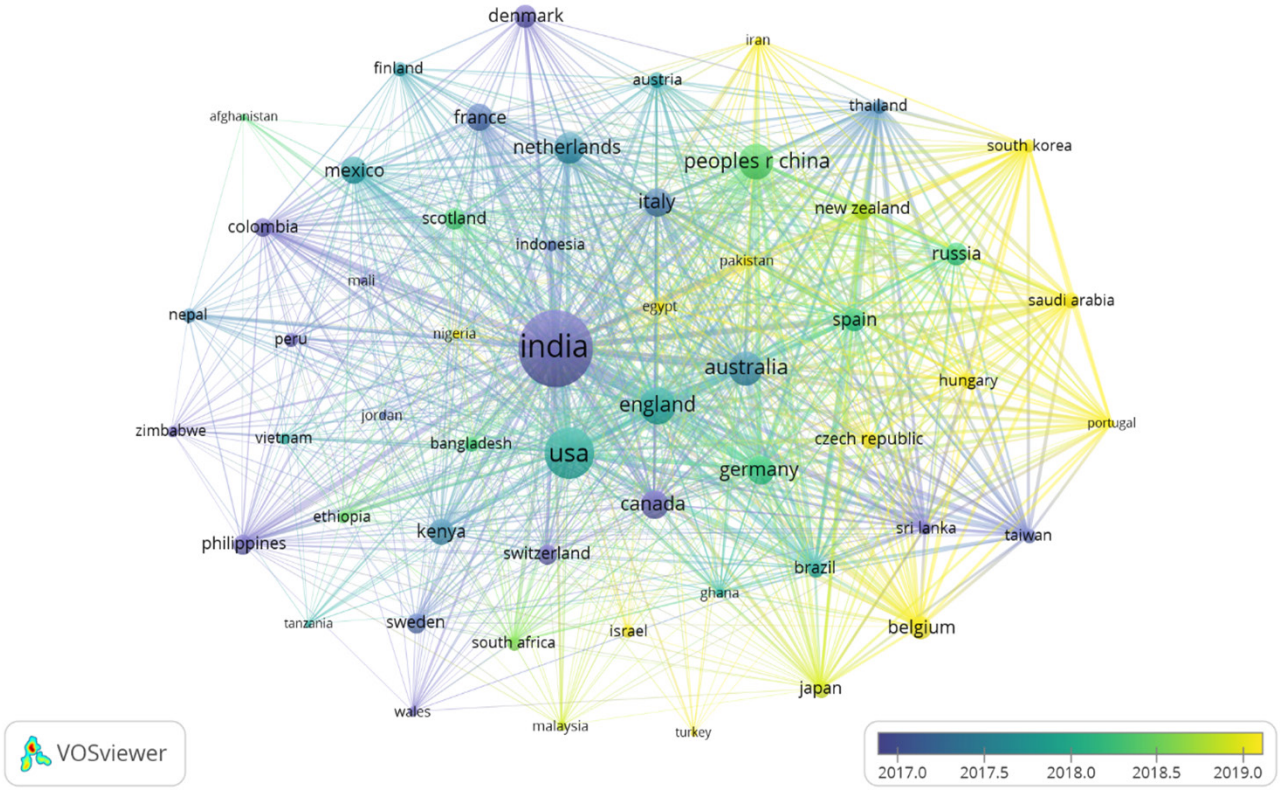

Figure 8: Bibliographic-Coupling of Publications based on Countries; Source- WoS Core Collection.

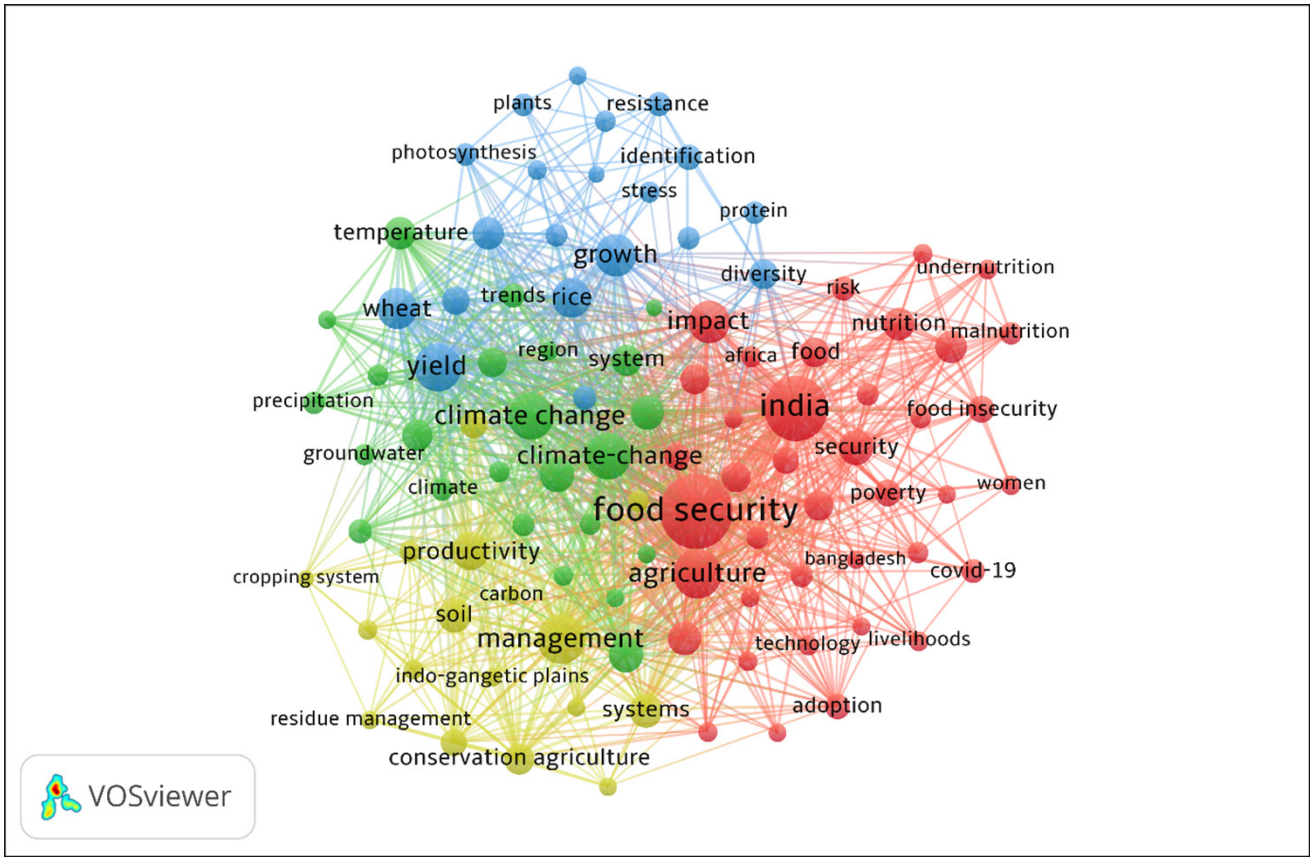

Figure 9: Keywords Co-occurrence Map; Source- WoS Core Collection.

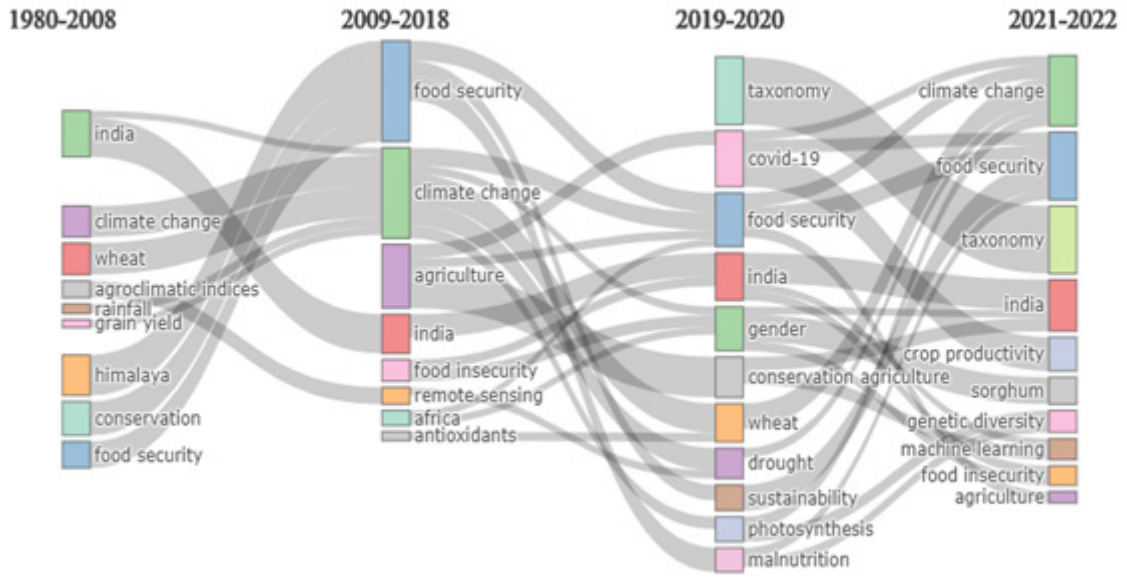

Figure 10: Sankey-Diagram of Thematic Evolution of Research Field; Source-WoS Core Collection.

facet of food security research in context of India. Moving towards the recent years, post 2018 we see climate change, sustainability and resilience of agriculture for food security garnering scholar's attention. Rice and wheat are majorly researched, whereas millets have lacked attention as a central crop for food security despite being more environmentally sustainable. Slowly, in the recent years the intra-household dynamics and gendered impact of food insecurity are also being explored. Keeping up with the innovation in data analytics field, machine learning and big data are also being used in food security research in India.

We also present a Sankey-Diagram (Figure 10), to trace the evolution of research field. The time slice for evolution flow is based on structural break years, as discussed earlier. We realize that climate change has consistently been into attention over the years, with special recognition as research potential post 2008. The role of droughts, precipitation, genetic diversity and conservation agriculture in food security are being recently explored. The trend analysis of themes points out that the socio-economic aspects of food security need further exploration. Also, the agricultural productivity discussions need to move away from rice-wheat towards millets, legumes, fishery and livestock productions.

CONCLUDING REMARKS

Noting the importance of the issue of food security and governmental efforts to promote research on the topic, it is expected that the quantum of literature on food security will be on a rise. Food security, in the most general terms, means having reliable access to sufficient, safe, nutritious and culturally preferred foods.[24] The tools of scientometric analysis have been effective to explore and understand the multidisciplinary nature of food security research in India. It can be seen that India's share of food security literature in global food security literature has been consistent. The authors and publications exploring the mitigation of climate change, genetic trait improvement of crops and sustainable agricultural practices in context of food security are of much relevance and influence. Also, the International Crops Research Institute for the Semi-Arid Tropics, situated in Andhra Pradesh is the most active affiliation in terms of publication count followed by International maize and wheat improvement institute in New Delhi. India collaborated most with the USA and England, but recently countries like Belgium, Israel, Kenya and South Korea are new intellectual collaboration partners. 'Field Crops Research' and 'Food Security' are most impactful journals. Locally influential publications explore the themes of conservation agricultural practices while globally influential documents are creating genome sequence for crops that are central to global food. Climate change (n=267), agriculture (n=153), rice (n=95), wheat (n=103), yield (n=145), productivity (n=92), impact (n=81), management are the most prominently used keywords for food security research in India. Over the years a shift in focus of food security research is also observed. The focus has shifted from crop yield of indo-Gangetic plains to a more specialised exploration of agricultural practices in context

of climate change and food security. Slowly the socio-economic aspects of food security are also explored. In due course of time, we can expect to see rise in understanding the dynamics of nutrition security as part of food security. With innovative data analytic techniques, we can have better geo spatial maps, potential crop yield in accordance with climate variability and overall sustainable approach towards achieving the four pillars of food security.

The field of food security offers multiple avenues for further research. According to our analysis, present research initiatives are mostly concentrated on the supply side of the issue by examining the effects of climate change on agricultural productivity and developing resilient and sustainable farming methods. But it's also critical to investigate the demand side of the problem with equal rigor by looking at the socioeconomic variables influencing the many aspects of food security. Concurrently, creative solutions for comprehensive food security measures must be developed. To develop successful food security plans, more multidisciplinary research is required that combines the latest developments in production and processing technologies with cultural norms and consumer behaviour. To determine what influences people to choose nutrient-dense food, in-depth analyses should be done for various population groups. There is great potential for more research on the effects of gender, community involvement and education on food security outcomes. Building climate resilient food consumption patterns, investigating the dietary diversity of indigenous peoples, examining the connections between gender and food/nutrition security and investigating other micro-level, intra-household dynamics can all be looked at in future research. Examining food governance and policy in light of the several barriers to achieving global food security would be interesting. The three pillars of food security-affordability, accessibility and availability-have been thoroughly studied. It's time to contribute strategies for increasing food consumption and maintaining the integrity of the food system during difficult times. Adopting a comprehensive research approach can assist in foreseeing and reducing future threats to global food security and helping solve present issues.

The study has its limitations arising from the bibliographic dataset. The considered publications for analysis do not form the universe of food security literature in India. The dataset does not exclusively contain studies that are about India. It is only a representation of indexed literature on food security research in India. Also, the nature of indexing lacks in inclusiveness of literature as the regional publications are often ignored in these databases. Thus, we can expect to have missed some underlying facets of the field. We abstained from analysing the status of research in relation to any of its dynamics, which could facilitate a detailed exploration. There is scope of future research in exploring various other aspects of food security with specific search string and niche body of literature. Also analysing the research profile of authors, journals or topics at micro-level and their collaboration will give better insights about the concerned field.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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Supplementary Table 1: Relevant Journals and Performance Indicators.

Journals	h_index	Total Ciitation	No. of publication	PY_start
Field Crops Research	23	2104	37	2000
Food Security	20	1123	61	2009
Current Science	15	790	55	1998
Scientific Reports	15	635	32	2013
Science of the Total Environment	13	351	21	2015
Global Change Biology	12	1137	12	2014
Agricultural Systems	11	329	20	2015
Agriculture Ecosystems & Environment	11	1055	12	2000
Plos One	11	454	25	2011
Environmental Monitoring and Assessment	10	297	14	2006
Global Food Security	10	359	25	2014
Remote Sensing	10	528	13	2009
Agricultural Water Management	9	304	12	1993
Food Chemistry	9	231	9	2015
Food Policy	9	189	12	1995
Frontiers in Plant Science	9	292	14	2015
Geophysical Research Letters	9	983	9	2011
Journal of Cleaner Production	9	213	13	2016
Sustainability	9	171	17	2017
Crop Science	8	314	10	2010

Source – WoS.

Supplementary Table 2: Geographical Distribution of Papers.

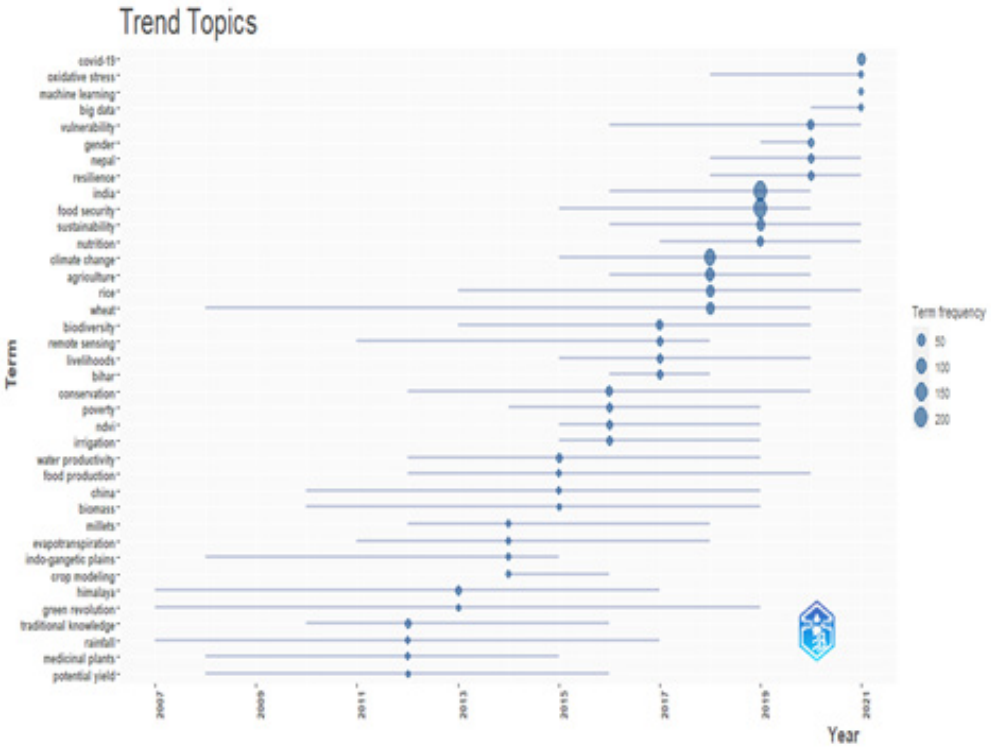
Countries/Regions	Record Count
India	2066
USA	384
England	188
Australia	160
Peoples R China	106
Germany	103
Mexico	90
Netherlands	80
Italy	65
Philippines	63

Source – WoS.

Supplementary Table 3: Globally Cited Documents.

Authors	Year	Broad theme	Motivation
Van Boeckel *et al.*	2015	Livestock practices and impacts.	Antimicrobials are used in livestock production to maintain health and productivity, thus present a global map of antibiotic consumption in livestock.
Xu X, *et al.*	2011	Genetic improvement of a crop and food security.	Genome sequence and analysis of potatoes for genetic improvement as its central to global food security.
Appels R *et al.*	2018	Genetic improvement of a crop and food security.	Presenting annotated reference genome for wheat, for stabilizing yield and adapting the crop to region specific stresses.
Asseng S, *et al.*	2015	Climate change, crop yield and food security.	Understanding how rising temperature will impact wheat production and proposing adaptation strategy.
Minasny B, *et al.*	2017	Soil carbon sequestration for climate change mitigation.	Surveyed the soil carbon stock estimates and sequestration potential from 20 regions in the world, as soil carbon sequestration can be solution for mitigating climate change.
Varshney R K, *et al.*	2013	Genetic improvement of a crop and food security.	Draft genome sequence of chickpea, providing a resource for trait improvement as chickpeas are second most widely grown legume crop.
Famiglietti J. S, *et al.*	2011	Water resource management and sustainable agriculture.	Satellites measuring recent rates of groundwater depletion in California's central valley.
Grill G *et al.*	2019	Water resource management.	Applying a new method to quantify riverine connectivity and map FFRs, we provide a foundation for concerted global and national strategies to maintain or restore them.
Xiao X M *et al.*	2006	Geospatial database for a crop.	Developing a new geospatial database of paddy rice agriculture for 13 countries in south and south east Asia.
Varshney R K, *et al.*	2012	Genetic improvement of a crop.	Genome sequence for pigeon pea which is an important legume crop grown by smallholder farmers.

Source – WoS.



Supplementary Figure 1: Temporal Evolution of Frequent Terms in Abstracts of Publications; Source – WoS.