Journal of Scientometric Res. 2020; 9(1):29-39
http://www.jscires.org

Research Article

Mapping Scientific Collaboration: A Bibliometric Study of Rice Crop Research in India

Avinash Kumar[1,*], Sambit Mallick[2], Pradip Swarnakar[1]
[1]Department of Humanities and Social Sciences, Indian Institute of Technology-Kanpur, Kanpur, Uttar Pradesh, INDIA.
[2]Department of Humanities and Social Sciences, Indian Institute of Technology-Guwahati, Guwahati, Assam, INDIA.

ABSTRACT
This paper aims to capture the pattern of collaboration operating in the field of rice crop research in India. The present study employs both bibliometric techniques as well as social network analysis to analyze the publication output indexed by Scopus database in rice crop research during 1995-2014. The study finds that Indian rice scientists prioritize collaborative research practices. Indian rice scientists demonstrate a preference for mega-authored publications. The increasing trend in the mean values of Degree of Collaboration, Collaboration Coefficient and Modified Collaboration Coefficient indicate that the proportion of multi- or mega-authored papers are accelerating steadily. Moreover, the increase in international collaboration indices manifests that the rice scientists in India have been gradually broadening the ambit of research collaboration to cope with the pace, scope and profoundness of transformations at the global level. The social network analysis of agencies reveals that the State Agricultural Universities, Indian Council of Agricultural Research and International Institutes have emerged as core collaborators in the field of rice crop research. Moreover, weak collaboration profile of industry indicates that although rice crop research has shifted from 'Mode 1' to 'Mode 2' form of knowledge production but its optimization is yet to be realized.

Keywords: Rice Crop, Bibliometric, Multi-Authored, Collaboration Coefficient, Social Network.

Correspondence
Avinash Kumar
Department of Humanities and Social Sciences, Indian Institute of Technology-Kanpur, Kanpur, Uttar Pradesh, INDIA.
E-mail: kavinash@iitk.ac.in

Received: 05-08-2019
Revised: 23-12-2019
Accepted: 27-01-2020
DOI: 10.5530/jscires.9.1.4

INTRODUCTION

Rice is a principal food crop for the world in general and Asians in particular; Asia accounts for 90 percent of global rice production and consumption and total rice demand continues to rise in Asia.[1] This indicates to what extent rice is embedded in Asiatic society and how it serves as an instrument of production for sustaining human life. As rice carries potentials to influence human society, it has become an object of inquiry for scientists, generating knowledge about rice crop and making it one of the most researched crops of the world. According to Tripathy and Garg, over 47% of papers accounted for rice research (to the total publications on all crops) during 2008-2010.[2] However, recent advancements in the field of applied molecular biology have provided new paradigms of looking at life processes and led to the emergence of new technologies. This new set of technologies has brought changes in scientific practices across the globe. It has created the need for new skills, expert knowledge, equipments, institutions and organizational arrangements to carry out agricultural research in laboratory as well as the field. Collaborative research has taken a new meaning and shape in this context. At present, the collaboration between Indian public institutions and those with international universities and research institutes or private enterprises, both locally and abroad, have become necessary. Therefore, it is of paramount significance to capture the patterns of collaboration occurring in the field of rice crop research in the context of India. In this context, bibliometric studies, as a specialty, are critically engaged in exploring such aspects. The bibliometric study involves the quantitative analysis of scientific documents. Sengupta (1985) conceptualized bibliometric as an organization, classification and quantitative evaluation of publication patterns comprising all macro and micro-communications with their listed authorships by employing mathematical and statistical calculus.[3] In the bibliometric study, the number of publications is perceived as one of the indicators of scientific activities. Co-authorship represents a direct working relationship between authors and is often used as a proxy measure for scientific collaboration in bibliometric studies.[4] In the bibliometric method, collaboration is equated with publications listing addresses of two or more authors, institutions, and countries.[5] Therefore, an increase in the incidence of multiple-authorship has been largely perceived

by scholars as evidence of growth in collaboration. Even though co-authorship is by no means a perfect indicator, it is frequently used and widely accepted for the analysis of research collaboration. Simultaneously, the study also employs Social Network Analysis to examine the different forms of collaboration forged between agencies engaged in rice crop research. SNA is the process of investigating social structures through the use of networks.[6] It measures networked structures in terms of nodes (actors) and the ties, edges, or links (relationships or interactions) that connect them. It has its own parameters and methodological tools. Therefore, the study adopts both bibliometric and social network analysis to achieve its research objectives. The bibliometric analysis makes an initial exploration while social network analysis delves deeper into the research topic.

Objectives of the Study

The study is conducted to elucidate the pattern of collaboration operating in the field of rice crop research and aims to achieve the following objectives: (1) to explore the growth characteristics of knowledge productions for India in the field of rice crop research during 1995–2014; (2) to identify the type of co-authorship pattern and measures the strength of collaboration among Indian rice scientists; (3) to construct the domestic and international collaboration profile of Indian rice scientists; and (4) to examine the pattern of collaboration taking place between major agencies active in rice crop research in India. Although bibliometric methods have already received enough attention in the rice crop research, the majority of previous studies[7,8] harbors on traditional methods such as co-author and co-citation analysis, which do not provide a complete picture of collaboration practiced in rice crop research. An attempt is made in the study to apply both co-author and social network analysis to capture broadly the intricacies of collaboration operating in the field of rice crop research in India. By doing so, the present study contributes significantly to our understanding on the different contours of collaboration occurring in rice crop research, though in its own small yet consequential way.

Data and Methodology

This study uses bibliometric techniques to measure scientific collaborations occurring in the field of rice crop research in India. The data for publications were acquired from the online international multidisciplinary edition of the Scopus database published by the Elsevier. It is the largest international multidisciplinary database of peer-reviewed literature that is continuously expanded and updated. Information on publications in the field of rice crop research was retrieved by using the keyword "Rice" OR "Oryza Sativa" OR "Dhan" OR "Paddy" OR "Chawal" but not rice bean. The same keywords were applied by Tripathi and Garg in their bibliometric study of rice crop science research. The search was limited to the year 1995–2014. The rationale behind selecting 1995 as the starting year of the study is that India became a signatory to the World Trade Organisation on 1 January 1995, which led to the beginning of post-Intellectual Property Right (IPR) regime in India. IPR regime has a profound impact on Indian agricultural R&D sector. Furthermore, the search was also limited to three broad areas, i.e. (1) agriculture and biological sciences; (2) biochemistry, genetics and molecular biology; and (3) environmental sciences. The selection of these three areas is based on the suggestions given by experts in the field of rice crop research. The respondents were selected on the basis of intellectual antecedents, publications and projects – mostly interdisciplinary and inter-institutional collaborative. These areas were identified by rice crop researchers as the core areas where most of the publications related to rice biotechnology research are published. Moreover, five document types, namely (1) article; (2) conference paper; (3) book chapter; (4) book; and (5) reviews were selected for the study. The search was also limited to the country India and language English. The bibliometric details for each record contained year, research area, document type, author(s), affiliation, source and country. A total number of 8663 publication output have been indexed during the 20-year time period. The study uses normal/whole count method – giving equal credit to all contributors in multi-authored publications. Also, for comparative purpose, the study period (1995–2014) has been bifurcated into two different blocks viz. 1995–2004 and 2005–2014, each block consists of a period of ten years.

RESULTS AND DISCUSSION

Quantum of Indian Publications in Rice crop research

In this section, we focus on the absolute counts of publications and the growth pattern of publications in the field of rice crop research. The total number of publications (8663) indexed by Scopus database during 1995–2014 has been selected to quantify the knowledge production in the field of rice crop research.

Figure 1 indicates Indian publication output in rice crop research during the period 1995–2014 consists of 8663 records, with an average of 433.15 publications per year. The annual publication output hovers around 1 to 3 per cent during 1995–2004, which further increases to 5 to 10 percent during 2005–2014. The publication output grew by 155 percent between 1995 and 2004 at a rate of 15.5 percent annually. However, the growth rate of publication output decreases to 14.2 in the next ten years (2005–2014). In rice crop research, there is a steady increase, from 2004 onwards, in the number of publications, however, the rate of growth, particularly from 2011 onwards shows a declining trend, when the publications are on a rise.

Authorship Pattern

In this section of the study, an attempt has been made to capture the co-authorship characteristics of India in the field of rice crop research. The following Figure 2 reflects the year-wise authorship pattern of Indian rice crop research.

Among 8663 articles, 5.86 % of articles are single-authored and 94.14% papers are written by two or more authors (Annexure I). Five and above-authored articles comprise the highest percentage (26.49%), following three-authored articles (24.20%) of the total 8663 articles (see Annexure I for data). The authorship pattern depicts a remarkable difference between the number of single-authored and multiple-authored publications. A very smaller number of articles are written by the single author (see Annexure I for data). Thus, this suggests that multiple-authorship research is predominant as compared to solo authorship in case of rice crop research in India. Therefore, co-authorship pattern indicates that collaborative research is prioritized in rice crop research in India.

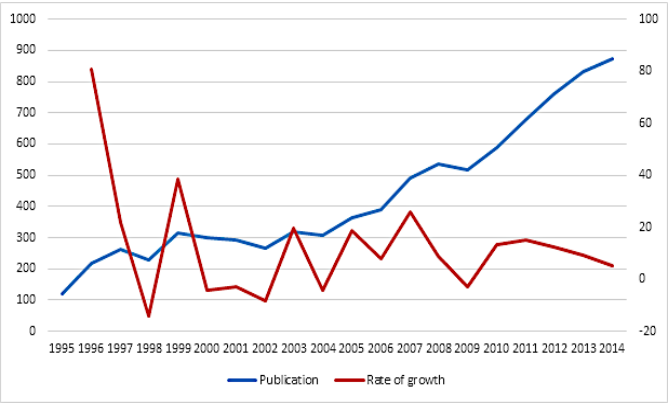

Figure 1: Publication outputs in rice crop research during 1995-2014.

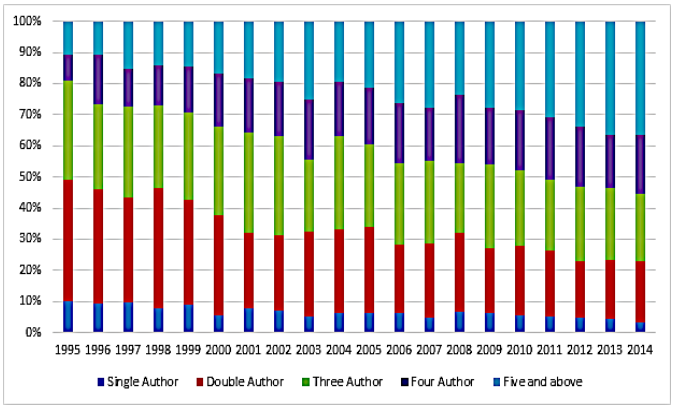

Figure 2: Year-wise authorship pattern of India in the field of rice crop research.

Table 1: Profiles of CAI from 1995-20014.

Year	Single Author	Double Author	Multi-authored	Mega-authored
1995-2004	199 (7.57)	810 (30.10)	1171 (44.58)	449 (17.08)
CAI	129.08	127.28	102.54	64.47
2005-2014	309 (5.12)	1287 (21.33)	2592 (42.96)	1846 (30.59)
CAI	87.33	88.11	98.84	115.48

*Note: Values in the parenthesis represent the percentage

Co-authorship Activity Index

Co-authorship Activity Index (CAI) has been calculated by using the method suggested by Garg and Padhi.[9] They classify publications in different categories depending on the number of authors, namely single-authored papers, two authored papers, multi-authored and mega-authored papers. Publications authored by three or four authors are classified as multi-authored papers, while authored by five or more authors are categorized as mega-authored papers.

Mathematically,

$$CAI = \{(N_j/N_0) / (N_{0j}/N_{00})\}^{*}100$$

Where:

N_j= number of publications co-authored by j authors in the country in a particular period,

N_0 = total number of publications in the country in a particular period,

N_{0j} = total number of publications co-authored by j authors in the country,

N_{00}= total number of publications in the country and

j = 1, 2, (3, 4) and (>5)

CAI=100 implies a specific type of authored publications corresponds precisely to the average of the country. CAI>100 reflects higher than the average and CAI<100 indicates lower than the average. Table 1 indicates the profiles of CAI for the year of 1995-2004 and 2005-2014, respectively.

As depicted in Table 1, during 1995-2004 the CAI values for single-authored and two-authored papers are higher than the average level of the country and are lower than country's average for multi-authored and mega- authored papers. However, contrary to these figures, the values of CAI in 2005-2014 for single-authored, double authored and multi-authored papers have dropped and goes below the country's average. Surprisingly, the CIA value of mega-authored papers depicts the highest increase among the other authorship category during 2005-2014. There is a decreasing trend in case of single-authored, double authored and multi-authored papers and an increasing trend in case of mega-author papers. This suggests that the scientists engaged in rice crop research

in the context of India are transforming their research from small groups to big groups with more collaborators. They are more interested to work with five and above scientists.

Measures of Collaboration

In this section, the degree of collaboration and collaboration coefficient are determined based on the year-wise output of publications.

Degree of Collaboration (DC)

DC is easy to calculate and easily interpretable as a degree (for it lies between zero and one), gives zero weight to single-authored papers and always ranks higher a discipline for the period with a higher percentage of multiple-authored papers. However, DC does not differentiate among levels of multiple authorship. Here in this section, the formula proposed by Subramanyam (1983) has been used to calculate the degree of collaboration.[10]

The degree of collaboration $C = N_m / (N_m + N_s)$

Where:

C = Degree of collaboration in a discipline

N_m = number of multi-authored papers in the discipline

Ns = number of single papers in the discipline

Collaboration Coefficient (CC)

CC was proposed to surmount the above drawbacks concerning DC. The CC is defined as:

$$CC = 1 - \frac{\sum_{j=1}^{K} j f_j}{N}$$

Where fj is the number of j-authors research papers published in the discipline during a certain period of time, N is the total number of research papers published in the discipline during a certain period of time (excluding anonymous authors) and K is the greatest number of authors per paper in a discipline.[11]

Modified Collaboration (MCC)

The Modified Collaboration Index (MCC) was proposed by Savanur and Srikanth in 2010.[12] The derivation of MCC is almost equivalent as that of CC, as given by Ajiferuke *et al*. Imagine that each paper carries with it a single "credit", this credit being shared among the authors. Modified Collaborative coefficient (MCC) can be mathematically expressed as:

$$MCC = \frac{A}{A-1}\left\{1 - \frac{\sum_{j=1}^{A}(1/j) f_j}{N}\right\}$$

Table 2: Authorship collaboration.

Year	Single author	Two authors	Three authors	Four authors	Five and above	DC	CC	MCC
1995	12	47	38	10	13	0.9	0.56	0.56
1996	20	80	59	35	23	0.91	0.57	0.57
1997	26	89	77	32	40	0.9	0.57	0.58
1998	18	87	61	29	32	0.92	0.58	0.58
1999	28	106	88	46	46	0.91	0.58	0.58
2000	17	96	86	52	50	0.94	0.61	0.61
2001	23	71	94	50	54	0.92	0.61	0.61
2002	19	65	85	47	52	0.93	0.62	0.62
2003	17	87	74	62	80	0.95	0.63	0.64
2004	19	82	92	54	59	0.94	0.62	0.62
Mean	**19.9**	**81**	**75.4**	**41.7**	**44.9**	**0.92**	**0.59**	**0.60**
2005	23	100	96	67	77	0.94	0.62	0.62
2006	25	86	101	76	103	0.94	0.64	0.64
2007	24	116	131	84	137	0.95	0.65	0.65
2008	36	135	120	117	127	0.93	0.63	0.63
2009	32	108	141	94	144	0.94	0.64	0.64
2010	32	132	144	113	168	0.94	0.65	0.65
2011	35	144	153	137	209	0.95	0.65	0.65
2012	36	139	182	147	257	0.95	0.66	0.67
2013	36	157	192	143	303	0.96	0.67	0.67
2014	30	170	190	164	321	0.96	0.67	0.68
Mean	**30.9**	**128.7**	**145**	**114.2**	**184.6**	**0.94**	**0.65**	**0.65**

Where A is a normalization constant to be determined. Setting A = 1 yields the measure CC. The requirement that j = 0 for single authorship does not restrict. The above equation is not defined for the trivial case when A = 1, which is not a problem since collaboration is meaningless unless at least two authors are available. CC approaches MCC only when $A \rightarrow \infty$, but is otherwise strictly less than MCC by the factor 1-1/A.

The positive trend in the mean values of DC, CC and MCC in two different blocks of the study period indicates that co-authorship pattern in rice crop research is in transition, moving from single authorship to multi-or mega-authorship.

Domestic and International Collaboration Profile

The Domestic Collaborative Index (DCI) and International Collaborative Index (ICI) as suggested by Garg and Padhi have been calculated to examine the domestic and international collaborative pattern. The two indicators are described below.

Domestic Collaboration Index (DCI)

Mathematically,

$$DCI = \{(D_i / D_{io}) / (D_o / D_{oo})\} \times 100$$

Where,

D_i = Number of domestically co-authored publications in a particular time span,

D_{io} = Total publications of the country in that particular time span,

D_o = Number of domestically co-authored publications,

D_{oo} = Total publication of the country.

International Collaboration Index (ICI)

Mathematically,

$$ICI = \{(I_i / I_{io}) / (I_o / I_{oo})\} \times 100$$

Where,

I_i = Number of domestically co-authored publications in a particular time span,

I_{io} = Total output of the country in that particular time span,

I_o = Number of domestically co-authored publications,

I_{oo} = Total publication of the country.

The value of DCI or ICI=100 reflects that the collaborative efforts correspond to the average of a given country. DCI or ICI>100 reflects higher than the average and DCI or ICI>100 indicates lower than the average.

Table 3 exhibits that during 1995-2004 the value of DCI is slightly higher than 100 while during 2005-2014 it has decreased minutely to 99.28. On the contrary, the value of ICI has increased from 84 to 106 during the above two-time spans. It implies that international collaboration has increased during 2005-2014 as compared to 1995-2004. This depicts that scientific collaboration in rice research is both national and international in character. Furthermore, it can be also inferred that rice scientists in India have been gradually broadening the ambit of collaborative research practices and further integrated themselves into the international research community. They are coping with the pace, scope and profoundness of transformations that are taking place in the field of rice crop research at the global level.

Collaboration Profiles according to Institutions

Research publications in the field of rice crop research come from several agencies. This section of the study examines the patterns of collaboration occurring between the various agencies. An adjacency matrix of the collaborating agencies has been prepared to achieve this objective. To understand the relationships among various agencies, institutional affiliations of all the authors, which were listed in their publications, were categorized broadly under the following agencies:

- SAU: covers institutes coming under State Agricultural Universities;
- ICAR: includes institutes sponsored by Indian Council of Agricultural Research;
- CUA: consists of Central Universities having the faculty of agriculture;
- OCU: comprises other Central Universities;
- INI: constitutes Institutes of National Importance (IITs, NIITs, IIMs, ISI, etc.);
- CSIR: implies institutes sponsored by Council of Scientific and Industrial Research;
- CGIAR: covers institutes coming under Consultative Group on International Agricultural Research, which are active in India;
- II: represents other International Institutes and Research Organizations;
- INDUSTRY**:** consists of private research organizations;
- OTHERS: covers other public and private institutions, research foundations and so forth.

Table 3: Domestic Collaborative Index (DCI) and International Collaborative Index (ICI) for rice crop research in India.

Year	Domestic	Local	DCI	International	ICI
1995-2004	422	1576	101.65	432	84.83
2005-2014	1638	2841	99.28	1246	106.60

Table 4: Top ten domestic collaborative institutes.

Sl. No.	Institute	No. of Publications	Non-collaborative publications	Collaborative publications
1	ICAR - Indian Agricultural Research Institute	673	24	649
2	Punjab Agricultural University India	448	12	436
3	Tamilnadu Agricultural University	445	12	433
4	ICAR - National Rice Research Institute	346	38	308
5	Banaras Hindu University	295	5	290
6	Central Food Technological Research Institute India	226	12	214
7	G B Pant University of Agriculture and Technology	225	7	218
8	CCS Haryana Agricultural University	221	6	215
9	ICAR - Indian Institute of Rice Research	215	3	212
10	University of Delhi	213	4	209

Table 5: Top ten international collaborative institutes.

Sl. No.	International Institutes	Collaborative Publications
1	International Rice Research Institute (IRRI)	333
2	International Crops Research Institute for the Semi-Arid Tropics	136
3	International Centre for Genetic Engineering and Biotechnology	135
4	Cornell University	50
5	University of California, Davis	35
6	Kansas State University	34
7	Wageningen University and Research Centre	32
8	International Rice Research Institute	28
9	USDA Agricultural Research Service, Washington DC	26
10	International Maize and Wheat Improvement Centre CIMMYT	23

Table 6: Top ten collaborating countries with India.

Country	Collaborative Publications
United States	479
Philippines	315
United Kingdom	145
Japan	121
Germany	117
Australia	109
China	91
South Korea	87
Canada	70
Bangladesh	63

Table 7 illustrates that during 1995-2014, SAU and ICAR have contributed substantially in the field of rice crop research. The share of SAU and ICAR accounts to around 44 per cent of the total publication output. The second major contribution is from international institutes (CGIAR and II). The category CGIAR and II jointly command over 22 per cent of the total publication output. Meanwhile, the category OTHERS occupy the third position by contributing 18.26 per cent to total publication output. The rest 16 per cent of publication is shared by other categories, such as CUA (2.66 percent), OCU (3.98), CSIR (4.60 per cent), INI (3.09 per cent) and Industry (1.71 per cent). The contribution of industry is the lowest with only 1.71 percent. From this result it can be inferred that industries have less inclination towards publication activities and they might be interested in developing patentable products or other non-publication-oriented research and development. Further analysis of the output of different agencies during 1995-2004 and 2005-2014 also indicates that the output of SAUs has declined considerably (by 5 per cent) during 2005-2014 as compared to 1995-2004. The output of ICAR-sponsored also confronts a slight decrease (1 percent) in 2005-2014 as compared to the earlier period (1995-2004). However, the contribution of the category OTHERS has increased considerably by almost 6 per cent in the second block (2005-2014) of the study. The proliferation of private academic institutes and research foundations in India may be a reason for the increase in publication output of the category OTHERS. Except for SAUs, ICAR and CGIAR, all other mentioned-above agencies depict an increase in publication output during 2005-2014.

Frequency of Research Collaboration

In this section, based on publication outputs, an adjacency matrix has been constructed to examine the frequency of collaboration taking place between agencies in the field of rice

Table 7: Publication output of different agencies during 1995-2004 and 2005-2014.

Agency	Year 1995-2004		Year 2005-2014		Year 1995-2014	
	Publication	Percentage	Publication	Percentage	Publication	Percentage
SAU	1243	30.93	2564	23.14	3807	25.22
ICAR	785	19.54	2060	18.59	2845	18.84
CUA	95	2.36	307	2.77	402	2.66
OCU	115	2.86	486	4.39	601	3.98
CSIR	190	4.73	504	4.55	694	4.60
INI	108	2.69	358	3.23	466	3.09
CGIAR	261	6.49	626	5.65	887	5.87
II	590	14.68	1790	16.16	2380	15.76
INDUSTRY	67	1.67	191	1.72	258	1.71
OTHERS	564	14.04	2193	19.79	2757	18.26
Total	4018	100	11079	100	15097	100

crop research. The adjacency matrix, sometimes also called as the connection matrix, of a simple labelled graph is a matrix with rows and columns labeled by graph vertices, with a 1 or 0 in position (fi, fj) according to whether fi and fj are adjacent or not. For a simple graph with no self-loops, the adjacency matrix must have 0s on the diagonal. For an undirected graph, the adjacency matrix is symmetric.[13] Firstly, agencies were listed in both columns and rows. Then, the number of collaborations between any pair of agencies were counted and inserted to form a symmetrical matrix. Firstly, the frequency of collaboration taking place between agencies during 1995-2014, 1995-2004 and 2005-2014 has been calculated (Annexure II, III and IV). Next, social network analysis was carried out to capture the major collaboration pattern between agencies. Thereafter, the degree of centrality was calculated to analyze the change in the collaboration's strength of agencies during the two blocks (1995-2004 and 2005-2014) of the study period.

In above-mentioned Figures (3, 4 and 5) the size of the bubble represents the frequency count of publications, while the thickness of the line indicates the strength of the co-occurrence of the publications. Figure 3 demonstrates that core collaborators are occupied by SAU, ICAR, II, OCU, CGIAR and OTHERS during 1995-2004. Perhaps, SAU has the strongest association with ICAR and II. Nevertheless, during 2005-2014, the social networking of agencies gets more expanded and diverse by the entry of new collaborators (Figure 4). During 2005-2014, the collaboration network is dominated by SAU, ICAR, II, CGIAR, OCU, CUA and OTHERS. Hence, this shows that rice crop research is moving towards multi-disciplinary and multi-institutional research, carried out in a growing variety of institutions. Figure 5 exhibits that overall (1995-2014) SAU, ICAR and II have emerged as the three major collaborating agencies

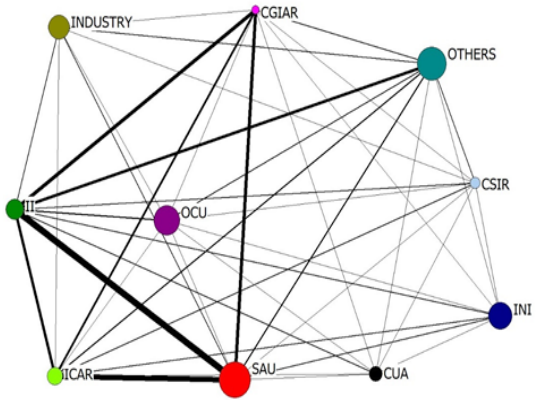

Figure 3: Collaboration networks of agencies (1995-2004).

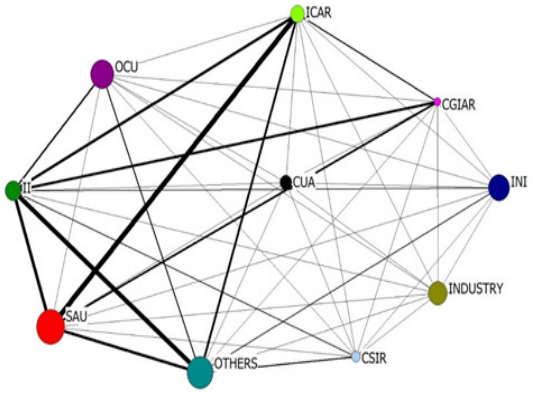

Figure 4: Collaboration networks of agencies (2005-2014).

in rice crop research in India. In other words, a majority of collaboration are formed between these agencies. These institutional settings form the nucleus of collaboration activities in rice crop research, whereas other agencies remain on the periphery. The dominance of SAU, ICAR and II in collaboration network implies that if a new researcher not located in SAU and ICAR, should collaborate with SAU or

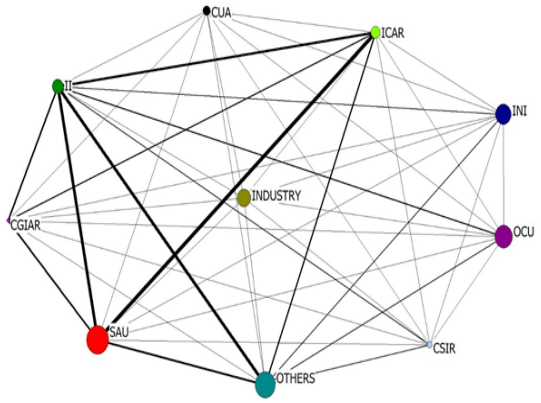

Figure 5: Collaboration networks of agencies (1995-2014).

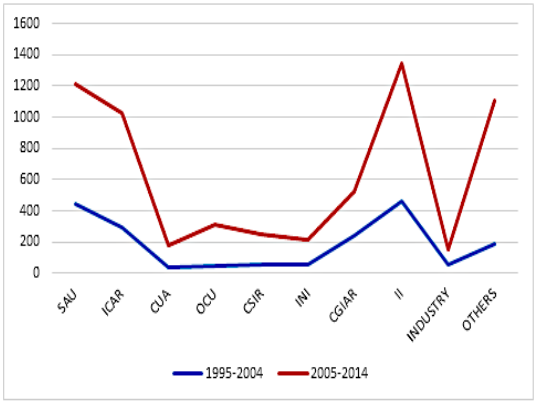

Figure 6: Change in degree centrality.

ICAR to get a quick prominence. Besides, another option is to collaborate with II. However, it will be a bit difficult for a new researcher to forge direct collaboration with II because most of the II are directly or indirectly connected to SAU and ICAR. It will be strenuous for new researchers, who is outside this connection to break the existing connection and create a new connection with the international collaborators. Therefore, SAU and ICAR forms a bridge between new researchers or institutes and overall established existing researcher in the world.

Moreover, if we compare the collaboration strength of SAU and ICAR with II we find that SAU has strong ties with II vis-à-vis ICAR. This indicates that institutes coming under the aegis of SAU prefer to collaborate with international institutions. Exploring new funding avenues to support their R&D activities may be a reason behind this since SAU's are governed by the provincial government and frequently suffers from fund scarcity. On the contrary, ICAR-sponsored institutes have a comparatively good flow of funds because they are centrally funded. Additionally, strong collaboration between ICAR and SAU highlights the healthy coordination between both agencies, which will have a positive impact on the performance of National Agricultural Research System (NARS) because these two institutional settings are the two nodal agencies of NARS. Besides, one can notice in above-mentioned three figures that the category 'OTHERS' constitutes an important member of core collaborators. However, it would be worth mentioning here that this category is beyond the scope of the present study since the type of institutes that forms this category are unknown. Nevertheless, the category 'OTHERS' can be studied in future to capture a more nuanced picture of collaborators operating in the field of rice crop research.

The change in degree centrality (Figure 6) depicts that category II marks the highest increase. High degree centrality suggests that II have many ties, they are often third-parties and bridge in collaboration among agencies and are able to benefit from this advantageous position. Besides, SAU and ICAR are the two collaborating agencies in tandem that shows a high change in degree centrality. Therefore, the SAU and ICAR are the two most preferred domestic agencies to forge collaboration in rice crop research. Furthermore, these findings highlight that SAUs have benefited more from international collaborations vis-à-vis ICAR-sponsored institutes. Indeed, these two institutional setups command over a substantial amount of international collaboration across the world. One of the remarkable features of the above dataset is that industry exhibits the weak collaboration profile with regards to other agencies in terms of degree centrality. This implies that the academic - industry linkage, a phenomenon quite common and established in the 'Mode 2' form of knowledge production is yet to be realized in the context of rice crop research in India. 'Mode 1' form of knowledge production involves new knowledge being produced primarily within individual disciplines, mainly in universities and other academic institutes, whereas 'Mode 2' forms of knowledge production generally involves multi-disciplinary or trans-disciplinary research carried out in a growing variety of institutions (i.e. not just universities) and with a blurring of the boundaries between the traditional sectors (university, industry etc.).[14] Therefore, it can be inferred that although rice crop research in India has shifted from 'Mode 1' to 'Mode 2' form of knowledge production but its optimization is yet to be realized.

CONCLUSION

Some of the key findings suggest that the multiple-authorship paper is predominant as compared to single-author paper from 1995 to 2014. The Co-authorship Index reflects decreasing trend in case of single-authored, double authored and multi-authored papers and an increasing trend in case of mega-author papers during the two blocks of the study period (1995-2004 and 2005-2014). Similarly, the mean values of the degree of collaboration and collaboration coefficient indicate and modified collaboration coefficient highlights

an increasing trend when two blocks of the study period are compared. Therefore, the collaboration pattern in the field of rice crop research in India can be best characterized by the proportion of multi-or mega-authored paper accelerating steadily. The domestic and international profile indicates that the collaboration pattern is in the transition from local (intra-institutional) papers via domestic papers (inter-institutional (national) to international papers. Besides, international collaboration has been increasingly strengthened. This has enhanced the international recognition and visibility of Indian rice scientists. The collaboration profile of major agencies reflects that most of the collaboration activities in rice crop research are driven by three key actors viz. SAU, ICAR and II. One of the important findings of the study is that there is a weak industry collaboration. This implies that although rice crop research in India has shifted from 'Mode 1' to 'Mode 2' form of knowledge production but it is yet to take-off.

The findings of the study provide a deeper insight into collaborative practices of agencies involved in rice crop research in India. Admittedly, it will be in the interest of a novice researcher to rope in SAU or ICAR because these institutes form an important link to get associated with international collaborators. Furthermore, Indian rice researchers should further catalyze their linkages with industry to optimize benefits of multi-institutional collaboration. Perhaps, collaboration with industry is important not only for research and innovation but also commercialization of research.

The study is limited in its scope in the sense that it only identifies major collaborators in terms of authors, institutes (national and international) and agencies (national and international), but do not reflect on why these actors more than others engage and benefit from the network within which they are embedded. Therefore, future research can be undertaken to address these research questions. In this context, preferential attachment model network theory by Barabassi[15] may be used as a theoretical framework of the study. Other major limitation is that it has no clear meaning on the category OTHERS as to who or what institutions included in this category which emerged as an important category in the collaborations.

ACKNOWLEDGEMENT

The authors thank the anonymous referees of Journal of Scientometric Research for their comments and suggestions to improve the quality of the paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

1. Food and Agriculture Organization. The state of food and Agriculture, UN, Rome, Italy. 2009.
2. Tripathi H, Garg KC. Scientometrics of Indian crop science research as reflected by the coverage in Scopus, CABI and ISA databases during 2008-2010. Annals of Library and Information Studies. 2014;61(1):41-8.
3. Sengupta IN. Bibliometrics: A Birds Eye View. ASLIC Bulletin. 1985;30(4):167-74.
4. Youngblood M, Lahti D. A bibliometric analysis of the interdisciplinary field of cultural evolution. Palgrave Communications. 2018;4(1):1-9.
5. Katz JS, Martin BR. What is research collaboration?. Research Policy. 1997;26(1):118-32.
6. Otte E, Rousseau R. Social network analysis: A powerful strategy, also for the information sciences. Journal of Information Science. 2002;28(6):441-53.
7. Liu B, Wang X. Scientometric profile of global rice research during 1985-2014. Current Science. 2017;112(5):1003-11.
8. Marooka K, Ramos MM, Nathaniel FN. A bibliometric approach to interdiscplinarity in Japanese Rice Research and Technology Development. Scientometrics. 2014;98(1):73-98.
9. Garg KC, Padhi P. A study of collaboration in laser science and technology. Scientometrics. 2001;50(2):415-27.
10. Subramanyam K. Bibliometric studies of research collaboration: A review. Journal of Information Science. 1983;6(1):33-8.
11. Ajiferuke I, Burell O, Tague J. Collaborative coefficient: A single measure of the degree of collaboration in research. Scientometrics. 1988;14(5-6):421-33.
12. Savanur K, Srikanth R. Modified Collaborative Coefficient: A new measure for quantifying degree of research collaboration. Scientometrics. 2010;84(2):365-71.
13. Garg KC, Padhi P. A study of collaboration in laser science and technology. Scientometrics. 2001;50(2):415-27.
14. Chartrand G. Introductory Graph Theory. New York: Dover. 1985.
15. Barabási AL, Albert R. Emergence of scaling in random networks. Science. 1999;286(5439):509-12.

Annexure I: Year-wise authorship pattern of India in the field of rice crop research.

Year	Single Author	Double Author	Three Author	Four Author	Five and above	Total
1995	12	47	38	10	13	120
1996	20	80	59	35	23	217
1997	26	89	77	32	40	264
1998	18	87	61	29	32	227
1999	28	106	88	46	46	314
2000	17	96	86	52	50	301
2001	23	71	94	50	54	292
2002	19	65	85	47	52	268
2003	17	87	74	62	80	320
2004	19	82	92	54	59	306
2005	23	100	96	67	77	363
2006	25	86	101	76	103	391
2007	24	116	131	84	137	492
2008	36	135	120	117	127	535
2009	32	108	141	94	144	519
2010	32	132	144	113	168	589
2011	35	144	153	137	209	678
2012	36	139	182	147	257	761
2013	36	157	192	143	303	831
2014	30	170	190	164	321	875
Total	508	2097	2204	1559	2295	8663

Annexure II: Matrix of research collaboration between agencies during 1995-2004.

Agencies	SAU	ICAR	CUA	OCU	CSIR	INI	CGIAR	II	INDUSTRY	OTHERS
SAU	101	127	9	4	9	20	77	157	14	31
ICAR	127	102	4	4	10	13	45	68	6	21
CUA	9	4	1	1	1	1	3	13	0	3
OCU	4	4	1	4	1	2	2	22	1	10
CSIR	9	10	1	1	4	2	2	15	3	15
INI	20	13	1	2	2	4	1	11	0	9
CGIAR	77	45	3	2	2	1	8	87	8	14
OII	157	68	13	22	15	11	87	124	15	71
INDUSTRY	14	6	0	1	3	0	8	15	3	10
OTHERS	31	21	3	10	15	9	14	71	10	51

Annexure III: Matrix of research collaboration between agencies during 2005-2014.

Agencies	SAU	ICAR	CUA	OCU	CSIR	INI	CGIAR	II	INDUSTRY	OTHERS
SAU	293	380	42	33	32	33	143	291	34	225
ICAR	380	392	39	27	31	21	111	209	28	184
CUA	42	39	4	6	8	6	8	32	2	33
OCU	33	27	6	9	19	7	9	112	3	97
CSIR	32	31	8	19	28	10	6	58	5	85
INI	33	21	6	7	10	17	7	74	5	56
CGIAR	143	111	8	9	6	7	72	182	17	44
II	291	209	32	112	58	74	182	400	36	352
INDUSTRY	34	28	2	3	5	5	17	36	14	27
OTHERS	225	184	33	97	85	56	44	352	27	365

Annexure IV: Matrix of research collaboration between agencies during 1995-2014.

Agencies	SAU	ICAR	CUA	OCU	CSIR	INI	CGIAR	II	INDUSTRY	OTHERS
SAU	394	507	51	37	41	53	220	448	48	256
ICAR	507	494	43	31	41	34	156	277	34	205
CUA	51	43	5	7	9	7	11	45	2	36
OCU	37	31	7	13	20	9	11	134	4	107
CSIR	41	41	9	20	32	12	8	73	8	100
INI	53	34	7	9	12	21	8	85	5	65
CGIAR	220	156	11	11	8	8	80	269	25	58
II	448	277	45	134	73	85	269	524	51	423
INDUSTRY	48	34	2	4	8	5	25	51	17	37
OTHERS	256	205	36	107	100	65	58	423	37	416