Collaboration patterns of Indian scientists in organic chemistry

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An analysis of 17,344 papers published by Indian scientists and indexed by Web of Science in the discipline of organic chemistry during 2004–2013 indicates that collaborative coefficient has increased during the later years (2011–2013). Of the total published papers, 6312 (36.4%) were due to domestic and international collaboration. The share of papers in domestic collaboration was 77.3% (4882) and international collaboration was 22.7% (1430). Among the international collaborating countries, India had published highest number of papers with the USA followed by Germany. Academic institutions followed by Council of Scientific and Industrial Research (CSIR) contributed the highest number of papers in domestic as well as in international collaboration. However, the value of domestic collaborative index and international collaborative index was less than 100 for both the sectors. The labs funded by CSIR also topped the list of institutions having domestic and international collaborative papers. The compound annual growth rate in domestic and international collaborative papers was 4.7 and 5.3 respectively. The value of domestic collaborative index was highest for CSIR-CDRI, Lucknow and international collaborative index for Madurai Kamaraj University, Madurai.

Keywords: Academic institutions, collaboration pattern, collaborative index, organic chemistry.

MODERN research demands an ever-expanding range of skills and is no longer the pursuit of an individual. Collaboration in science is an important component of scientific output. There is an increasing demand of collaborative relationships among individuals, organizations and countries. International collaboration in scientific research has increased rapidly in recent decades. The share of papers by authors located in two or more institutions rose from about 33% in 1981 to 50% in 1995, and the total papers rose by about 20%. During the same period, the share of co-authored papers rose from about 6% to 15% (ref. 1). Keeping this in view, governments in different countries are taking initiatives to enhance contacts among scientists through collaborative research programmes, both at the national and international levels. According to the Ecosystem Management Initiative[2], collaboration is defined as a 'process where two or more individuals or organizations deal collectively with issues that they cannot solve individually' and 'the working together of researchers to achieve the common goal of producing new scientific knowledge[3]'. Collaboration brings together experience, skill, knowledge and the know-how of different researchers into one particular field of study. By way of collaboration, researchers from different institutions or countries come together for different purposes, among which are sharing of information, transfer of technology and finding solutions to specific problems. Collaboration can be important, especially in developing countries, where there might be a lack of expertise and resources in certain fields. The researchers in developing countries can collaborate with those in developed countries. Collaboration in research can take a variety of paths. Based on the type of participants, their status and location, etc., collaboration can broadly be classified into three categories – local, domestic and international. A local collaboration happens when two or more scientists of the same institution from different divisions work together; and a domestic collaboration happens when two or more scientists from the same country in different institutions come together and international collaboration takes place when two or more researchers from different countries join hands to solve a problem. Among these, international collaboration has received the maximum attention. International scientific collaboration is particularly advantageous for less advanced countries, but also beneficial for highly industrialized countries[4].

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Review of the literature

In the past several studies dealing with collaboration at national and international level have been published in

the literature. For instance, estimation of the extent of international scientific collaboration of India for the period 1990–94 using *Science Citation Index* (*SCI*) was made by Basu and Vinu Kumar[5]. The study found an increase in collaboration both in terms of output and the extent of network and impact. Prakasan *et al.*[6] have also observed that India's share in international collaborative publications has grown from 4.6% in 1991 to 22.8% in 2010. Gupta *et al.*[7] studied India's scientific collaboration with South Asian countries and found that it had strong collaborative links with Bangladesh compared to Pakistan, Nepal and Sri Lanka. Gupta and Karisiddappa[8] studied collaboration patterns in the specialty of population genetics and found that highly productive authors are also highly collaborative and the focus of collaboration is shifting from local to domestic and international collaboration. Garg and Padhi[9] analysed collaboration patterns in laser science and technology and found that most of the papers had bilateral domestic and international collaboration. China, Israel, The Netherlands and Switzerland had higher share of internationally collaborated papers. Dutt and Nikam[10] examined collaboration pattern in solar cell research in India using data from *SCI* for the period 1991–2010. They found that almost half of the output emerged from domestic and international collaboration and South Korea topped the list of collaborating countries, unlike USA in other disciplines. A report by the Department of Science and Technology (DST)[11], New Delhi, found USA as India's most frequent collaborating country during the period 2006–2010 followed by Germany and the UK[11]. He[12] examined international collaboration of China with the G7 countries using *SCI*. The results of the study indicated that international publication output between China and the G7 countries had increased exponentially; and USA was the major collaborator among all the G7 countries. Ma and Guan[13] examined the pattern of collaboration of Chinese publications in molecular biology during 1999–2003 using Web of Science Expanded and found that a significant number of papers had more than three authors. Kim[14] examined the pattern of international collaboration in South Korea during 1994–1996 using *SCI* CD-ROM and found that about 26% of the papers was due to international collaboration; USA and South Korea had the highest number of collaborative papers. Kwon *et al.*[15] also examined the pattern of international collaboration in South Korea and found that the number of papers in international collaboration had increased considerably since late 1900s, while the share of national collaboration had steadily declined. Garg and Dwivedi[16] examined international scientific collaboration in Japanese encephalitis (JE) using papers indexed in Science Citation Index Expanded during 1991–2010. They found that JE was a highly collaborative discipline as about two-thirds of the papers were written in domestic and international collaboration. Owusu-Nimo and Boshoff[17] examined research collaboration in Ghana using Web of Science (WoS) data for 1990–2013. They found that collaboration had increased from 73% in 1990–1997 to 93% in 2006–2013 and international collaboration from 49% to 73% during the same period.

Objectives of the study

In an earlier study, Dwivedi *et al.*[18] had analysed 17,344 papers published by Indian authors in the discipline of organic chemistry during 2004–2013. They found that the output in organic chemistry had grown continuously during the period of study and research papers published in organic chemistry and its sub-disciplines formed a part of the mainstream science as reflected by the pattern of publications by journal publishing countries, their impact factor and the citations of these papers. It was also observed that academic institutions published the highest number (46.6%) of papers, but the Council of Scientific and Industrial Research (CSIR) made the maximum impact and had highest number of prolific institutions, prolific authors and highly cited papers. The present study examines the pattern of domestic and international collaboration of Indian scientists in organic chemistry during 2004–2013 with the following objectives.

- To examine the change in the pattern of co-authorship during 2004–2013 using collaborative coefficient (CC).
- To examine the pattern of growth of domestic and international collaborative research papers during 2004–2013.
- To examine the magnitude and pattern of local, domestic and international collaboration and measure the compound annual growth rate (CAGR) for domestic and international collaborative papers.
- To measure the domestic collaborative index (DCI) and international collaborative index (ICI) among different performing sectors.
- To identify the most prolific Indian institutions and their patterns of domestic and international collaboration.
- To identify countries and institutions with which India had international collaboration.

Data and methodology

The source of data for the present study is Thomson Reuters WoS used by Dwivedi *et al.*[18] in their study on organic chemistry research in India. From the 17,344 records published by Indian authors during 2004–2013, 6312 papers were identified which were written either in domestic or international collaboration. The present study examines the pattern of domestic and international collaboration of Indian authors in organic chemistry based on these 6312 papers. DCI and ICI were calculated for

different performing sectors and prolific Indian institutions. The number of domestic and international links each published article were also identified. For instance, if a paper has authors from two domestic institutions and one international institution, then the number of domestic and international links is one each. The indicators used for measuring domestic and international collaboration are described below.

Collaborative coefficient

This examines the strength of co-authorship. The measure has been suggested by Ajiferuke *et al.*[19] and is based on fractional productivity defined by Price and Beaver[20], and is given by the formula

$$\mathrm{CC} = 1 - \frac{\sum_{j=1}^{k} (1/j) F_j}{N}.$$

Here F_j is the number of j authored research papers, N the total number of research papers published and k is the maximum number of authors per paper. According to Ajiferuke *et al.*[19], CC tends to zero as single-authored papers dominate and to $(1 - 1/j)$ as j-authored papers dominate. This implies that higher the value of CC, higher the probability of multi-authored papers.

Domestic collaborative index

DCI has been suggested by Garg and Padhi[9] and is obtained by calculating proportional output of domestically co-authored papers in a way similar to activity index[21]. For calculating DCI, papers in local and domestic collaboration have been added together. The measure has been used for calculating DCI for performing sectors and prolific institutions. Here

$$\mathrm{DCI} = \frac{D_i/D_{io}}{D_o/D_{oo}} \times 100,$$

where D_i is the number of domestically co-authored papers by a performing sector or an institution i, D_{io} the total number of papers of the performing sector or the institution i, D_o the number of domestically co-authored papers for all performing sectors or institutions and D_{oo} is the total number of papers.

International collaborative index

This measure has also been suggested by Garg and Padhi[9] and is obtained by calculating proportional output of internationally co-authored papers in a way similar to DCI. This has also been used for measuring ICI for performing sectors and institutions. Here,

$$\mathrm{ICI} = \frac{I_i/I_{io}}{I_o/I_{oo}} \times 100,$$

where I_i is the number of internationally co-authored papers by a performing sector or an institution i, I_{io} the total number of papers for the performing sector or the institution i, I_o the number of internationally co-authored papers for all performing sectors or institutions and I_{oo} is the total number of papers.

The value of DCI or ICI = 100 indicates that collaborative effort for a performing sector or an institution corresponds to the Indian average. DCI or ICI > 100 reflects collaboration higher than the Indian average, while DCI or ICI < 100 reflects collaboration less than the Indian average.

The major advantage of using DCI or ICI is that it takes into account both the size of the performing sector or institution as well as the field of investigation.

Results and discussion

During 2004–2013, Indian scientists published 17,344 papers on different aspects of organic chemistry. Among these, more than one-third, i.e. 6312 (36.4%) papers were published in domestic and international collaboration. The number of papers published in domestic and international collaboration was 4882 and 1430 respectively. These constituted 28.2% and 8.2% of domestic and international collaborative papers respectively, of the total output. This indicates that the share of papers in domestic collaboration was about three and half times more than those in international collaboration. We now describe the results of the study on several indicators.

Collaborative coefficient

Figure 1 depicts the pattern of collaboration based on the total number (17,344) of papers published during 2004–2013.

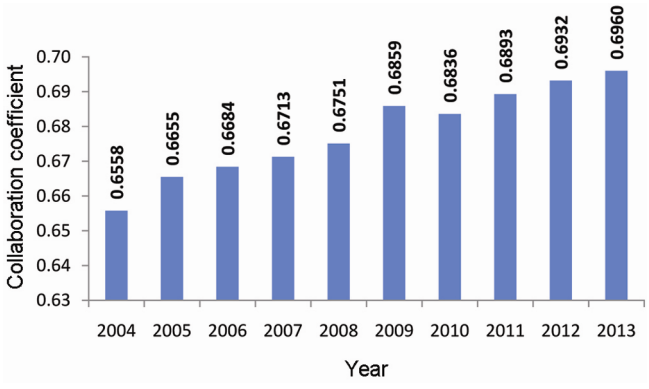

Figure 1. Collaboration coefficient of Indian authors during 2003–2013 in organic chemistry.

Table 1. Pattern of domestic and international collaboration during 2004–2013

Year	TNPDC	TNPIC	TNP	(L + D)	(I)	DLPP	ILPP
2004	388	119	507	422	144	1.1	1.2
2005	429	119	548	479	148	1.1	1.2
2006	488	141	629	571	175	1.2	1.2
2007	476	135	611	542	163	1.2	1.2
2008	440	118	558	513	142	1.2	1.2
2009	452	122	574	532	143	1.2	1.2
2010	487	142	629	570	180	1.2	1.3
2011	549	163	712	672	199	1.2	1.2
2012	590	182	772	719	225	1.2	1.2
2013	583	189	772	747	240	1.3	1.3
Total	4882	1430	6312	5813	1759	1.3	1.2
CAGR	4.6	5.3	4.7	6.6	5.8	1.8	0.0

It indicates that the CC value was constantly on the rise, except a slight dip in 2010 over the previous year (2009). The CC value varied from 0.6558 in 2004 to 0.6960 in 2013. This implies that the share of multi-authored papers was constantly on the rise during 2004–2013. The CC value for papers published by Indian authors in organic chemistry was almost the same as for JE[16], but higher than those published by Indian authors in the sub-discipline of laser science and technology[9] during 1970–1994.

Growth pattern of domestic and international collaborative papers

Pattern of growth was examined for seven different aspects of collaboration. These are (i) total number of papers in domestic collaboration (TNPDC); (ii) total number of papers in international collaboration (TNPIC); (iii) total number of domestic and international collaborative papers (TNP); (iv) local and domestic links (L + D), (v) international links (I), (vi) domestic links per paper (DLLP) and (vii) international links per paper (ILLP). Domestic and international links per paper were obtained by dividing the total number of links with the total number of papers. Table 1 presents data on these parameters. The table indicates that the number of domestically co-authored papers increased from 388 in 2004 to 583 in 2013 with a CAGR of 4.6, and the number of internationally co-authored papers increased from 119 in 2004 to 189 in 2013 with a CAGR of 5.3. Thus the international co-authored papers increased at a faster rate than domestic co-authored papers. However, the number of domestic links increased at a faster rate (6.6) compared to international links (5.8). Further analysis of data for the number of papers published in domestic and international collaboration during 2004–2013 indicated a strong Pearson correlation coefficient value $R = 0.96$, i.e. a strong positive correlation. This shows that a large number of papers in domestic collaboration also indicates a large number of papers in international collaboration, and vice versa. Analysis of data for domestic and international links per paper indicated that domestic links per paper varied between 1.1 and 1.3 during 2004–13 with a CAGR of 1.8, whereas the pattern of links per paper for internationally co-authored papers remained almost constant.

Domestic and international collaborative index for different performing sectors

Table 2 shows the results of DCI and ICI, besides the number of papers written in domestic and international collaboration and total output for different performing sectors. The table indicates that like total output, the number of papers written in domestic and international collaboration is also highest for academic institutions (AI) followed by CSIR. Academic institutions published about 16% of the total Indian output in organic chemistry in collaboration. Of these, 12% was published in domestic collaboration and the rest in international collaboration. In absolute terms, the share of collaborative papers by academic institutions and CSIR was more than the other performing sectors listed in Table 2. However, the two performing sectors had lower values of DCI and ICI compared to other performing sectors. The DCI value was highest for PC (pharmaceutical colleges) closely followed by private institutions (PI) and Government of India (GOI) institutions. The ICI value was highest for GOI institutions. The ICI value did not differ significantly for other agencies except for AI and CSIR. The ICI value was lowest for CSIR. One possible reason for this might be that the organization has well-established chemistry laboratories and hence does not need international collaboration. Higher values of ICI for different performing sectors imply that the proportion of papers published by them in international collaboration is more than the Indian average.

Most prolific institutions and the pattern of their collaboration

Table 3 lists the 20 most prolific institutions along with their DCI and ICI values. These institutions contributed

Table 2. Domestic collaboration index (DCI) and international collaboration index (ICI) values for different performing sectors

Performing sectors	Number of papers in DCI**	Number of papers in ICI**	Total papers in collaboration	Total output
AI	2138 (94)	674 (101)	2812	8080
CSIR	1247 (99)	280 (76)	1527	4496
IITs/ENGC	719 (108)	241(123)	960	2373
PI	314 (132)	81(117)	395	843
PC	175 (140)	39 (106)	214	445
DST	77 (69)	42 (128)	119	397
GOI	67 (132)	22 (148)	89	181
DAE	35 (68)	18 (119)	53	183
Others*	110 (113)	33 (116)	143	346
Total	4882	1430	6312	17,344

*Others include Defence Research and Development Organization, Indian Council of Agricultural Research including State Agricultural Universities, Indian Council of Medical Research and Indian Space Research Organization (ISRO). **Figures in parenthesis indicate DCI (column 2) and ICI (column 3) values.
AI, Academic institutions; CSIR, Council of Scientific and Industrial Research; IITs/ENGC, Indian Institutes of Technology and Engineering colleges; PI, Private institutes; PC, Pharmaceutical Colleges; DST, Department of Science and Technology; GOI, Government of India; DAE, Department of Atomic Energy.

Table 3. Most prolific institutions and patterns of their collaboration

Institution	DCP	ICP	TCP	DCI	ICI	TNP
CSIR-IICT, Hyderabad	447	104	551	74	59	2158
CSIR-NCL, Pune	195	36	231	93	59	745
CSIR-CDRI, Lucknow	263	27	290	130	46	720
Indian Institute of Science, Bengaluru	87	12	99	45	21	683
Indian Institute of Technology Bombay	110	19	129	84	50	465
Indian Institute of Technology Kanpur	81	24	105	71	72	405
University of Hyderabad, Hyderabad	58	18	76	54	57	383
University of Delhi, Delhi	73	25	98	75	88	346
Indian Institute of Technology Kharagpur	87	14	101	90	49	344
University of Rajasthan, Jaipur	90	24	114	98	89	327
Dr. Reddy's Lab Ltd, Hyderabad	82	14	96	103	60	283
IACS, Kolkata	52	15	67	66	65	282
Indian Institute of Technology Chennai	67	13	80	86	57	276
University of Madras, Chennai	64	13	77	82	57	276
NIPER, Chandigarh	57	14	71	85	72	237
Guru Nanak Dev University, Amritsar	54	19	73	86	103	224
Indian Institute of Technology Guwahati	45	15	60	73	83	220
CSIR-NIIST, Thiruvanthapuram	70	18	98	116	102	214
Banaras Hindu University, Varanasi	45	17	62	80	103	201
Madurai Kamaraj University, Madurai	48	20	68	88	125	194
Subtotal	2075	461	2536	81	62	9094
Others	2807	969	3776	121	143	8250
Grand total	4882	1430	6312	100	100	17,344

CSIR-IICT, CSIR-Indian Institute of Chemical Technology; CSIR-NCL, CSIR-National Chemical Laboratory; CSIR-CDRI, Central Drug Research Institute; CSIR-NIIST, CSIR-National Institute of Interdisciplinary Science and Technology; IACS, CSIR-Indian Association for Cultivation of Science; NIPER, National Institute of Pharmaceutical Education and Research. DCP, Domestically collaborative papers; ICP, Internationally collaborative papers; TCP, Total collaborative papers; DCI, Domestic collaborative index; ICI, International collaborative index; TNP, Total number of papers.

1% or more papers in domestic and international collaboration. They also contributed 40% of the total collaborative papers. Of these, 32.8% papers was in domestic collaboration and the rest 7.2% in international collaboration. These 20 institutions were distributed among academic institutions (8), Indian Institutes of Technology (5) and CSIR institutions (4). The remaining three institutions, namely Indian Association for Cultivation of Science and National Institute of Pharmaceutical Education and Research are funded by DST and the Ministry of Chemicals and Fertilizers, GoI respectively, whereas Dr Reddy's Lab Ltd is a private funded R&D institution.

Among all the institutions CSIR-IICT had the highest number of papers in domestic and international collaboration followed by CSIR-CDRI and CSIR-NCL. CSIR-CDRI had the highest (130) DCI value. Other institutions having DCI value more than 100 were CSIR-NIIST and Dr Reddy's Lab Ltd. This indicates a higher proportion of papers by these three institutions in domestic collaboration. However, these institutions had a low ICI value, except CSIR-NIIST. This implies that the proportion of papers published by these institutions in international collaboration was low compared to those in domestic collaboration. Three other institutions for which the ICI value was more than 100 were Madurai Kamaraj University, Madurai; Banaras Hindu University, Varanasi and University of Delhi, Delhi, in that order. This implies that these institutions published more papers in international collaboration than the Indian average.

International collaboration of India in organic chemistry

During the period of 2004–2013, Indian scientists published 1430 papers in international collaboration. These papers resulted in 1759 international collaborative links with 64 different countries. These 64 countries were scattered among the developed and developing countries. Table 4 lists 15 countries with which India had more than 30 collaborative links. The highest number of collaborating links was with USA followed by Germany, France, Japan, UK and South Korea, contributing about 60% (1056) of the links. The rest was scattered among 58 countries. Among these, the share of Saudi Arabia, Italy, Australia, Spain, Malaysia, Switzerland, Taiwan, Belgium and Denmark was about 22.2% (390) of the links.

Table 4. International partners of India in organic chemistry research

Country	Number of Links	Links %
USA	424	6.7
Germany	172	2.7
France	133	2.1
Japan	126	2.0
UK	119	1.9
South Korea	82	1.3
Saudi Arabia	62	1.0
Italy	56	0.9
Australia	48	0.8
Spain	40	0.6
Malaysia	42	0.7
Switzerland	43	0.7
Taiwan	35	0.6
Belgium	33	0.5
Denmark	31	0.5
Total	1446	82.2
49 other countries	313	17.8
Total	1759	100

Thus, these 15 countries shared more than four-fifths (82.2%) of the total collaborative links. The remaining 313 (17.8%) links were scattered among 49 countries, and the extent of collaboration varied between a single link each for 15 countries to 27 links for the People's Republic of China (PRC). Details of links with different countries are PRC 27; South Africa 25; Canada and Czech Republic 22 each; Singapore and Sweden 18 each; The Netherlands and Portugal 17 each; Austria and Russia 14 each; Israel 13; Hungary 8; Egypt 7; Chile, Greece, New Zealand, Iran and Republic of Georgia 6 each; Thailand, Pakistan, Mexico, Finland, Croatia, Ukraine, Morocco and Fiji 3 each; Ireland, Vietnam, Bangladesh, Trinidad and Tobago, and Botswana 2 each; United Arab Emirates, Jordan, Iraq, Ethiopia, Slovenia, Slovakia, Serbia, Nigeria, Namibia, Libya, Mauritius, Bulgaria, Estonia, Algeria and Argentina 1 each.

Table 5. Prolific foreign institutions having collaborative links with India

Institution	Number of links
Howard University, USA	59
King Saudi University, Saudi Arabia	56
University of Reading, England	35
University Sains Malaysia, Malaysia	29
University Rhode Island, USA	23
University Rennes 1, France	22
University of Zurich, Switzerland	20
CNRS, France	20
Katholieke University Leuven, Belgium	19
Kitasato Institute, Japan	19
University Munster, Germany	19
Kansai University, Japan	17
RMIT University, Australia	16
Free University of Berlin, Germany	16
Tulane University, USA	16
Pukyong National University, South Korea	14
University of Regensburg, Germany	14
University of Complutense, Spain	14
National University of Singapore, Singapore	14
University of Munich, Germany	13
Ewha Women University, South Korea	13
National Institute of Material Science, Japan	13
Yonsei University, South Korea	12
Academia Sinica, Taiwan	12
Chorghade Enterprise, USA	12
University of Kentucky, USA	12
University of Southern Denmark, Denmark	12
University of Mississippi, USA	12
University of Florence, Italy	12
Youngstown State University, USA	11
Russian Academy of Sciences, Russia	11
Deakin University, Australia	11
University of Texas, USA	10
University of Pardubice, Czech Republic	10
University of Copenhagen, Denmark	10
Purdue University, USA	10
Total	638
641 other institutions with less than 10 links	1121
Grand total	1759

Foreign institutions having collaborative links with India in organic chemistry

An analysis of 1759 international links were scattered among 677 foreign institutions. Table 5 lists 36 institutions with which India had 10 or more international collaborative links. Of these, nine were from USA, four from Germany, three each from Japan and South Korea, two each from Australia, Denmark and France, and one each from Saudi Arabia, England, Malaysia, Switzerland, Belgium, Spain, Singapore, Taiwan, Italy, Russia and Czech Republic.

Conclusion

This study indicates that the pace of domestic as well as international collaboration in the discipline of organic chemistry had increased during 2004–2013. The CC value increased from 0.6558 in 2004 to 0.6960 in 2013, implying that the share of multi-authored papers was constantly on the rise during 2004–2013. Domestic links per paper varied between 1.1 and 1.3 during 2004–2013 with a CAGR of 1.8, whereas the pattern of links per paper for international co-authored papers remained almost constant. Like the total scientific output in organic chemistry, academic institutions and CSIR also had the highest number of domestic and international collaborative papers. However, the DCI and ICI values for the two performing sectors were lower than those in the other sectors. India had international collaborative links with 677 institutions scattered in 64 countries of the globe. The highest number of collaborating links of India similar to China[10] and South Korea[12] was with USA. The other countries with which India had more international collaborative links were Germany, France, Japan, UK and South Korea. Only a few institutions, namely CSIR-CDRI, CSIR-NIIST and Dr Reddy's Lab Ltd had DCI more than 100. Similarly, Madurai Kamaraj University, Guru Nanak Dev University, IIT Guwahati, Banaras Hindu University and CSIR-NIIST had a higher ICI value, indicating that the proportion of papers in international collaboration was more than the Indian average. Among all the prolific institutions, CSIR-NIIST was the only one for which the DCI and ICI values were more than 100, indicating that it had more domestic and international collaborative papers.

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