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International collaboration in Brazilian science: financing and impact

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Abstract
The study of international collaborations can help in understanding the benefits of such relationships and aid in developing national financing policies. In this paper, the international collaboration of Brazilian scientists was studied using SciVal® and Incites® database, looking at its effect on the universities, financing agencies and different areas of knowledge and research topic clusters. Cluster and principal component analyses of scientometric data were carried out. While the results confirmed known knowledge that international collaboration increases impact, this study shows that Brazilian researchers are contributing to prominent research topics worldwide, in all areas of knowledge. This finding is contrary to several points of view that identify Brazil as a regional and not an international partner in science. Important also to note the impact of Brazilian authors in international collaboration that is well above the world mean. The collaboration of Brazil with foreign partners brings benefits for both sides, creating the opportunity of Brazilian research access to financing from international agencies. Increases in measures of impact are also seen for both sides. Foreign partners likewise benefit from higher impact factors in the same topic cluster, when collaborating with Brazilian partners. Publishing open access in high impact journals is fundamental for maintaining Brazilian science at the forefront.

Keywords Brazilian research · Knowledge area · Citations · OECD · International collaboration

Introduction

The concept of collaboration, a partnership or co-operation (CPC) in science and research means that the different actors make efforts to achieve a common goal (Teixeira da Silva 2011). This collaboration can be local, national or international. The competition to publish

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the research results in high impact, international journals are made harder by the ongoing, exponential generation of knowledge, as well as the costs of this publication (McManus et al. In press). According to Adams (2013), the fourth age of research (the first three being the individual, the institutional and the national) is characterized by international collaborations among elite research groups. This author claims that institutions that do not form international collaborations risk progressive disenfranchisement, and countries that do not nurture their talent will lose out it entirely. Areas such as the Social Sciences and Humanities show an impact that cannot be measured by conventional bibliometric tools (Bulaitis 2017). These include the areas of culture, diplomacy and politics, as well as practice. These areas also tend to show more local impact (Mugnaini et al. 2014) and that those captured by bibliographic resources are more widely disseminated. Nevertheless, the present study looks at international publications and collaboration of which these areas show low representation.

Drivers of international collaboration include mass data storage, grand challenges, electronic communications (Barjak et al. 2013), and less expensive travel (Adams 2012), as well as specific policy implementation by governments. According to Boekholt et al. (2009) other drivers include to improve the quality, scope and critical mass in science and research by linking national resources and knowledge with resources and knowledge in other countries to obtain access to state-of-the-art knowledge abroad as well to attract state-of-the-art knowledge or people to the 'home' country. The same authors show that in less Research & Development (R&D) developed countries an important driver is to build up national Science, Technology & Innovation (STI) capabilities through cooperation. Therefore important drivers are improving national competitiveness, supporting less developed countries by developing STI capabilities, tackling global societal challenges and creating good and stable diplomatic relationships (and indirectly ensuring international security). Joeng et al. (2014) suggest that substantial financial and attentional resources, academic excellence, individual motivation, and active informal communication play significant roles in international collaboration.

The network of international co-authorship is expanding globally (Leydesdorff et al. 2013), thus leading to changes in scientific relationships among countries. For example, the above authors show that scientific ties between Latin America countries are lower than those with Spain and Portugal, and that Spanish and Portuguese speaking countries dominate this relationship.

The citation impact of publications with one or more international partners is well-documented (McManus et al. 2020). The support in collaboration is not only at the level of scientific rigour and infrastructure (Hoekman et al. 2010), the efficient exploitation of scientific efforts (Catalá-López et al. 2014), but also language and writing style, thus increasing the likelihood of acceptance of a manuscript audience (Zeng et al. 2011). This means that the science and data are exposed to a wider audience, driving questions and criticism, improving the quality of the manuscript and future research, as well as invitations for new collaborations. According to Wagner et al. (2017), international connections increase novelty and are more likely to be constituted by well-reputed nodes. These arrangements are attractive to other researchers seeking to enhance their own reputations. Globally connected researchers can, in turn, be highly selective in choosing the next entrant into the network.

This analysis represents Brazilian international scientific cooperation before the onset of Covid-19. It, therefore, serves as a benchmark to evaluate the effects of the pandemic on Brazilian science and its impact internationally. The understanding of the impact of international collaboration on national scientific production is important to direct public

policies and understand underlying trends. The present study looks at Brazilian scientific output and impact in collaboration with countries, universities and financing agencies, to aid in forming public policies on financing and internationalization of Brazilian science. The indicators point out that some science policies of the Brazilian funding agencies were successful.

Material and methods

Two international subscription based databases were used to collect data. InCites® belongs to Clarivate Analytics and uses data from the Web of Science, while SciVal® is from Elsevier and based on Scopus data. Each database provides different types of data.

Incites® was used to evaluate the relationship of Brazilian scientists with their internal and external partners as well as the institutions financing these relationships, from 2004 to 2019. The data was divided by OECD (Organisation for Economic Co-operation and Development) area of knowledge (Natural Science, Engineering & Technology, Agriculture, Medicine & Health, Social Sciences and Humanities). Data were examined by major collaborating countries and universities, as well as financing agencies in Brazil and abroad. From Incites®, the impact of this collaboration was examined looking at Number of documents in Web of Science (Wos), CNCI (Category Normalized Citation Index), Percentage documents in Top 1 and 10% (%Top1%; %Top10%), Percentage of papers in Q1 and Q2 journals (%Q1; %Q2), open access (%OA), industry collaborations (%Ind) and citations per document (Cit/doc), JIF (Journal Impact Factor), JNCI (Journal Normalised Citation Impact), % Highly cited (%High) and Hot (%Hot) papers, % Documents Cited (%DocCit), and % DOAJ (Directory of Open Access Journals) Gold documents (All abbreviations are shown at the end of this document). Source of financing of collaborative publications was also identified, whether by government agencies or private companies. Differences were seen in quality indicators due to publishing open or closed access by funding agency.

Topic Clusters (collection of documents with a common focused intellectual interest), their prominence (which indicates momentum and visibility of the topic due to very recent citations, views and CiteScore) and their frequencies were collected from SciVal® from 2014 to 2019 by knowledge area, i.e., the analysis is focused on the current trend. These were divided by the number of publications worldwide in these topic clusters and those in collaboration with Brazilian authors, including FWCI (Field Weighted Citation Impact) of these topics worldwide, FWCI in collaboration with Brazilian authors, citations per paper, SJR (Scientific Journal Ranking) and Citescore (reflects the yearly average number of citations to recent articles in a Journal). Number of authors per publication and per region were also obtained from SciVal®.

These data are downloaded from the platforms in.csv and.xlsx formats respectively which enables them to be analsyed in the statistical programs. All statistical analyses were carried out using SAS v. 9.4 (SAS Institute, Cary, North Carolina). As several indicators were involved, correlation (PROC CORR) were were carried out to examine the relationship between these quality criteria and then principal component (PROC PRINCOMP) analyses used to transform these criteria into a smaller number of uncorrelated variables. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. Growth in the number of collaborations with foreign universities and researchers was examined using polynomial regression (PROC REG).

Results

The number of papers published abroad by Brazilian authors is increasing at the same rate as the total number of papers published (Fig. 1). While the number of papers published in Brazilian journals with foreign partners is low and stable, those with foreign partners published abroad is increasing. Most papers published with foreign partners were in foreign journals.

Table 1 shows the mean values for collaborations over all areas of knowledge for the top 20 countries collaborating with Brazil. The USA has approximately 3 times the next highest collaborator. In terms of main collaborators by area of knowledge (Supplementary Fig. 1), there is little difference among the top 20, with some changes in the order of major contributors. Current (May 2020) levels of international collaborations are at 40.55%, up from 24.18% in 2009. In 2019, Brazil researchers published approximately 67,000 papers in the Web of Science of which about 26,000 were in collaboration with researchers from other countries (38.9%).

Table 2 and Fig. 2 show that most quality indicators are positively correlated with each other. The number of documents published per country had little effect on quality indicators. Publishing in a journal with a high impact factor shows documents with higher citation impact and higher chance of being cited. In the second vector hot papers are associated with high JNCI and CNCI, but lower % of cited documents. This may be a result of an immediacy factor.

The major contributors are stable over time (Table 3 and Supplementary Fig. 2). Spain becomes more important, with the position of France decreasing, Portugal is also increasing, while counties such as Chile, Switzerland and Russia appear once only. In 2005 was the last time that Japan appeared and Portugal entered. In 2010 Australia entered while in 2015 Argentina left and in the last period the Netherlands entered.

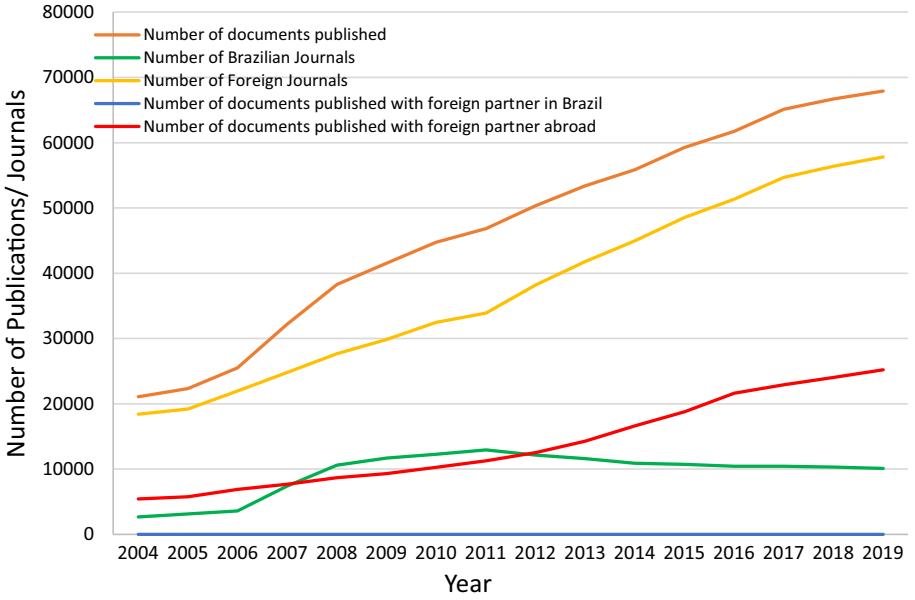

Fig. 1 Journals where Brazilian authors publish

Table 1 Major collaborations with Brazilian science (2004 – 2019)

Name	Web of science docs	Cit/Doc	CNCI	% Docs cited	% All open access docs	% DOAJ gold docs	% Docs in Q1 journals	% Docs in Q2 journals	% Docs in top 10%	% Docs in top 1%	% Highly cited papers	% Industry collab
USA	106,402	26.93	1.96	79.51	39.32	13.42	59.05	23.06	18.38	3.44	2.00	6.15
United Kingdom	39,010	32.65	2.71	82.43	47.85	15.70	62.20	21.85	22.84	5.40	3.80	6.87
France	35,688	31.00	2.43	83.02	39.40	12.94	62.65	21.72	20.76	4.64	3.13	7.25
Germany	32,525	32.75	2.70	82.67	42.17	13.97	63.42	21.80	22.58	5.30	3.56	8.22
Spain	28,660	28.50	2.70	81.63	44.43	16.46	61.56	21.26	21.61	4.96	3.71	6.76
Italy	24,914	32.76	2.87	81.50	42.79	14.26	63.70	21.22	23.27	5.84	4.19	7.95
Canada	22,914	33.57	3.02	79.62	38.67	13.78	59.30	22.64	21.86	5.82	4.24	6.24
Portugal	19,179	20.52	1.85	77.07	40.01	18.22	53.64	24.42	16.68	3.25	2.58	4.14
Australia	15,310	43.46	4.10	82.15	48.92	16.36	64.65	21.29	29.56	8.55	6.68	8.13
Argentina	15,091	28.04	2.02	81.80	38.82	14.19	52.56	24.18	16.83	3.78	2.66	6.05
Netherlands	13,983	41.33	3.50	84.16	52.89	15.75	68.39	20.03	28.58	7.66	5.86	9.79
Switzerland	12,504	42.96	4.07	84.12	57.50	20.40	71.49	17.94	29.93	8.29	6.21	13.79
China Mainland	11,330	43.20	3.92	85.59	57.82	20.01	72.41	17.18	31.00	8.73	7.14	9.39
Japan	10,541	45.53	4.34	83.09	48.12	14.51	64.26	19.66	27.71	8.15	6.13	12.04
Belgium	9900	39.87	3.72	82.38	45.75	14.19	66.33	20.15	26.74	8.05	6.01	15.15
Russia	9767	43.22	3.93	87.31	54.86	18.48	70.44	17.43	27.78	7.52	5.88	10.36
Mexico	9570	36.78	2.90	80.72	49.89	17.27	61.37	19.34	22.92	6.07	4.59	7.45
Chile	9190	27.79	2.57	80.37	48.14	16.33	56.56	20.43	19.84	4.71	3.93	3.51
Sweden	9153	43.93	3.53	84.58	48.97	15.98	69.51	19.45	28.21	8.08	6.15	13.66
Colombia	9074	32.84	2.71	80.52	56.18	25.88	60.27	18.01	22.57	5.88	5.31	3.60

Cit/Doc citations per document; *CNCI* category normalized citation impact; *DOAJ* directory of open access journals

Table 2 Correlations between major quality indicators in Brazilian scientific collaboration

	No doc	% Doc cited	CNCI	% Doc Q1	% Highly cited	% Hot	JNCI	% Open access
% Doc Cited	0.05							
CNCI	−0.07	0.07						
% Doc Q1	0.12	0.55	0.30					
% Highly Cited	−0.05	0.03	0.73	0.29				
% Hot	−0.15	−0.26	0.45	−0.18	0.39			
JNCI	0.04	0.16	0.80	0.38	0.73	0.31		
% Open Access	0.29	0.40	0.33	0.79	0.35	0.01	0.38	
% JIF	0.07	0.77	−0.16	0.29	−0.20	−0.32	−0.05	0.17

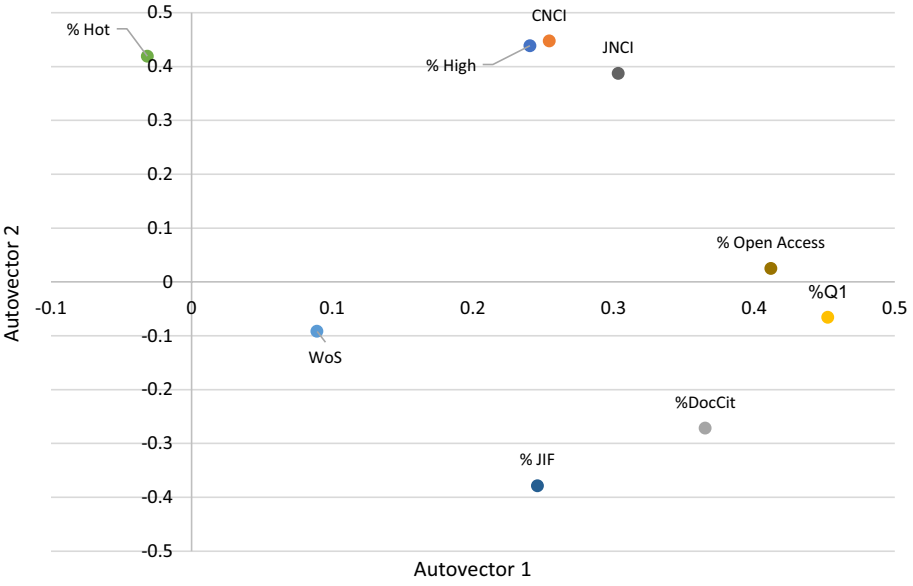

Fig. 2 First two principal components for major quality indicators in Brazilian scientific collaboration

Research Institutions in Collaboration

The Natural and Medical sciences show the highest collaborations in terms of number of institutions and funding sources (Table 4). The Social Sciences and Humanities show low levels of interaction with foreign collaborators in the databases examined.

From Fig. 3 and Supplementary Figure 3, it can be seen that, in general, collaboration within Brazil has lower impact than collaboration with foreign partners. The University of São Paulo (USP) is the institution with highest collaboration in the country in terms of number of papers published (Fig. 3B). Foreign collaborators are mainly North American

Table 3 Major country collaborators with Brazilian authors over time

Order	1985–1990	1990–1995	1995–2000	2000–2005	2005–2010	2010–2015	2015–2019
1	USA	USA	USA	USA	USA	USA	USA
2	France	France	France	France	France	UK	UK
3	UK	UK	UK	UK	UK	France	Spain
4	Germany	Germany	Germany	Germany	Germany	Germany	France
5	Canada	Italy	Italy	Italy	Spain	Spain	Germany
6	Italy	Canada	Canada	Canada	Canada	Italy	Italy
7	Argentina	Argentina	Spain	Argentina	Italy	Canada	Canada
8	Chile	Spain	Argentina	Spain	Argentina	Portugal	Portugal
9	Japan	Japan	Russia	Japan	Portugal	Australia	Australia
10	Spain	Switzerland	Japan	Portugal	Australia	Argentina	Netherlands

Table 4 Number of Institutions with which Brazilian researchers collaborate and funding sources abroad (InCites® 2004–2019)

	Brazil	Natural sciences	Eng and tech	Medical sciences	Agriculture	Social sciences	Humanities
Institutions	8262	6879	4704	5801	2387	3038	913
Funding sources	680	629	500	543	293	292	54
Researchers	1,100,475	646,457	208,343	467,636	56,038	40,610	3778

and European (Fig. 3A). Impact (CNCI) is lower when looking at the Brazilian universities compared to collaboration with foreign institutions.

Collaboration varies between areas of knowledge (Supplementary Fig. 3 and 4). The Engineering and technologies, for example, show high collaboration with Portuguese universities, as do the Humanities and Social Sciences.

Of the 8262 institutions with which Brazil has collaborated with, 771 are responsible for 80% of the production (Fig. 4). These change depending on the area of knowledge (Supplementary Fig. 5), with the number of institutions that are responsible for 80% of publications with Brazilian authors are 7.99% of the institutions for Natural Sciences, 15.39% for Engineering, 15.27% for Medical Sciences, 16.31% for Agricultural Sciences, 23.00% for Social Sciences and 47.05% for Humanities. This may indicate that, while in some areas, such as Natural Sciences, there is the formation of research networks, the lack of concentration in Humanities may reflect a more eventual collaboration. In terms of the number of documents, 12 countries are responsible for 80% of the scientific production. The number of institutions abroad and researchers has been growing exponentially since 1985 (all were quadratic equations with $R^2 > 0.99$ for institutions and $R^2 > 0.88$ for researchers). Humanities, Agricultural and Social Sciences have not grown at the same rate as other areas. In terms of foreign sources of financing, there was a rapid growth during the years 2000.

Looking at the number of authors by publication (Table 5), SciVal® identified 213 collaborating countries/regions with 144,364 co-authored publications between 2014 and 2019. Publications with Africa and the Middle East tended to show a larger group of co-authors, as did publications in Medical and Agricultural Sciences, although Engineering and Natural Sciences showed a higher participation in publications with more than 100 authors. This is due to increase participation of Brazilian researchers in large international

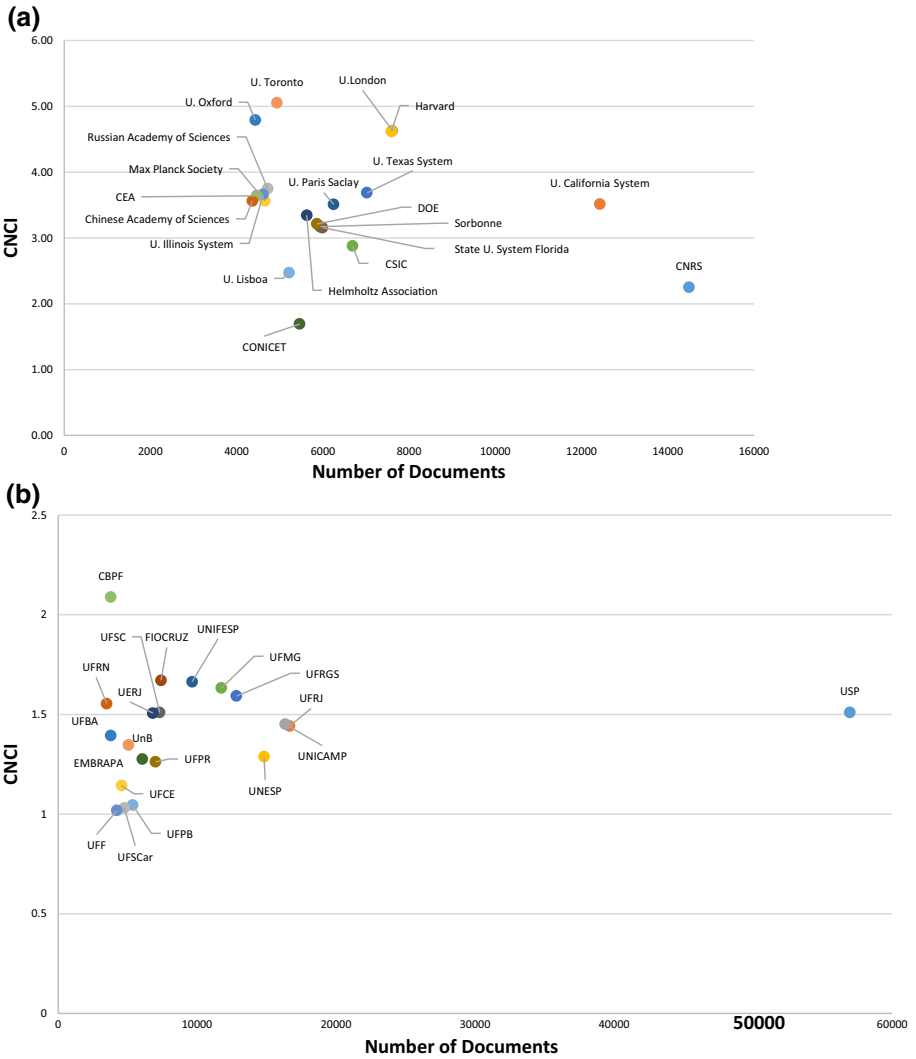

Fig. 3 Impact of Top 20 Collaborating Institutions with Brazilian Science: (**a**) International and (**b**) National and the collaboration impact

efforts by means of collaboration network such as collaborations for using large facilities in high energy physics, or international genomics projects.

The major Brazilian universities and research institutions collaborating with foreign partners (Fig. 5) show that smaller institutions acting in a specific field (CBPF in physics and Fiocruz in Medical Sciences and Health) show higher impact than the larger, more generalized, universities.

Several universities and institutions appear in all areas of knowledge such as the University of São Paulo (USP), as well as Federal Universities of Minas Gerais (UFMG) and Rio de Janeiro (UFRJ) (Supplementary Fig. 6). Others appear in specific

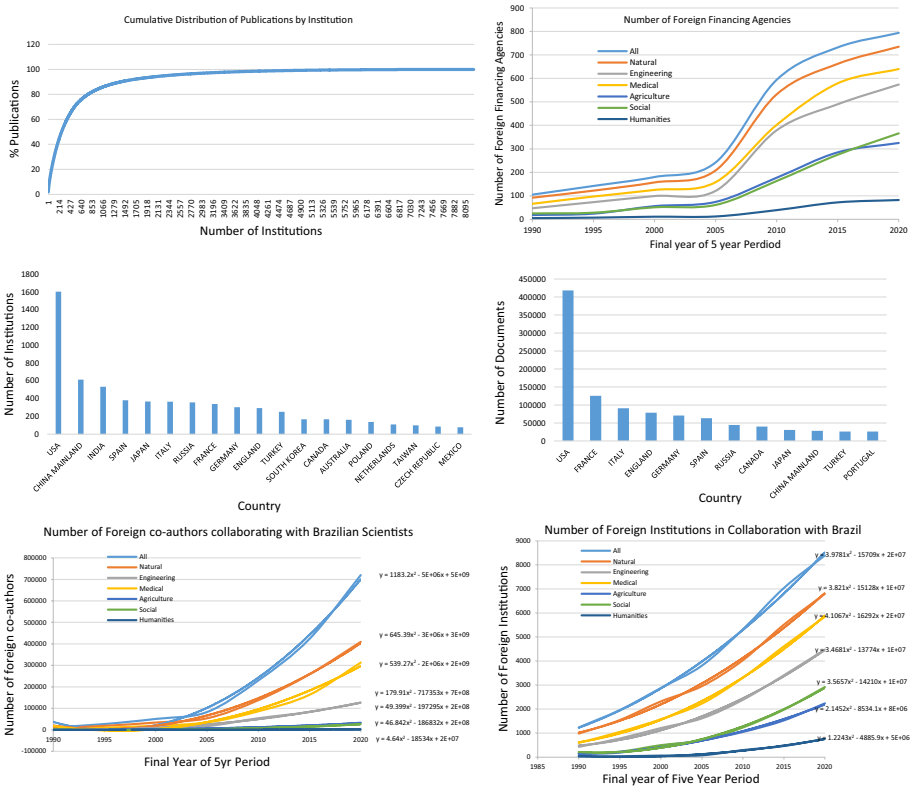

Fig. 4 Number of publications with number of institutions and scientists abroad collaborating with Brazilian research institutions and contributing to 80% of Documents in Collaboration (Incites® 1985–2019). Dotted lines are the regressions with regression equations at the right of the figure

Table 5 Number of authors per paper (SciVal® 2014–2019) by region and area of knowledge

Region	Number		% of Papers by number of authors			
	Countries /regions	Publications	≤ 10	10–≤ 50	50–≤ 100	> 100
Africa	54	7,132	42.18	25.11	5.44	27.27
Asia Pacific	47	24,521	59.66	25.92	3.02	11.40
Europe	48	84,578	80.30	15.24	1.06	3.40
Middle East	18	7,137	43.69	23.65	4.65	28.01
Central and North America	31	62,542	74.99	19.07	1.39	4.55
South America	15	19,643	68.87	16.77	2.65	11.71
Area of knowledge						
Agriculture	178	19,800	73.20	26.48	0.24	0.09
Engineering	156	30,853	93.53	5.22	0.11	1.13
Humanities	108	1,857	96.34	3.28	0.32	0.05
Medical sciences	203	49,726	76.09	22.44	0.81	0.65
Natural sciences	208	92,703	86.17	10.45	0.60	2.79
Social sciences	160	14,165	94.11	5.53	0.30	0.06

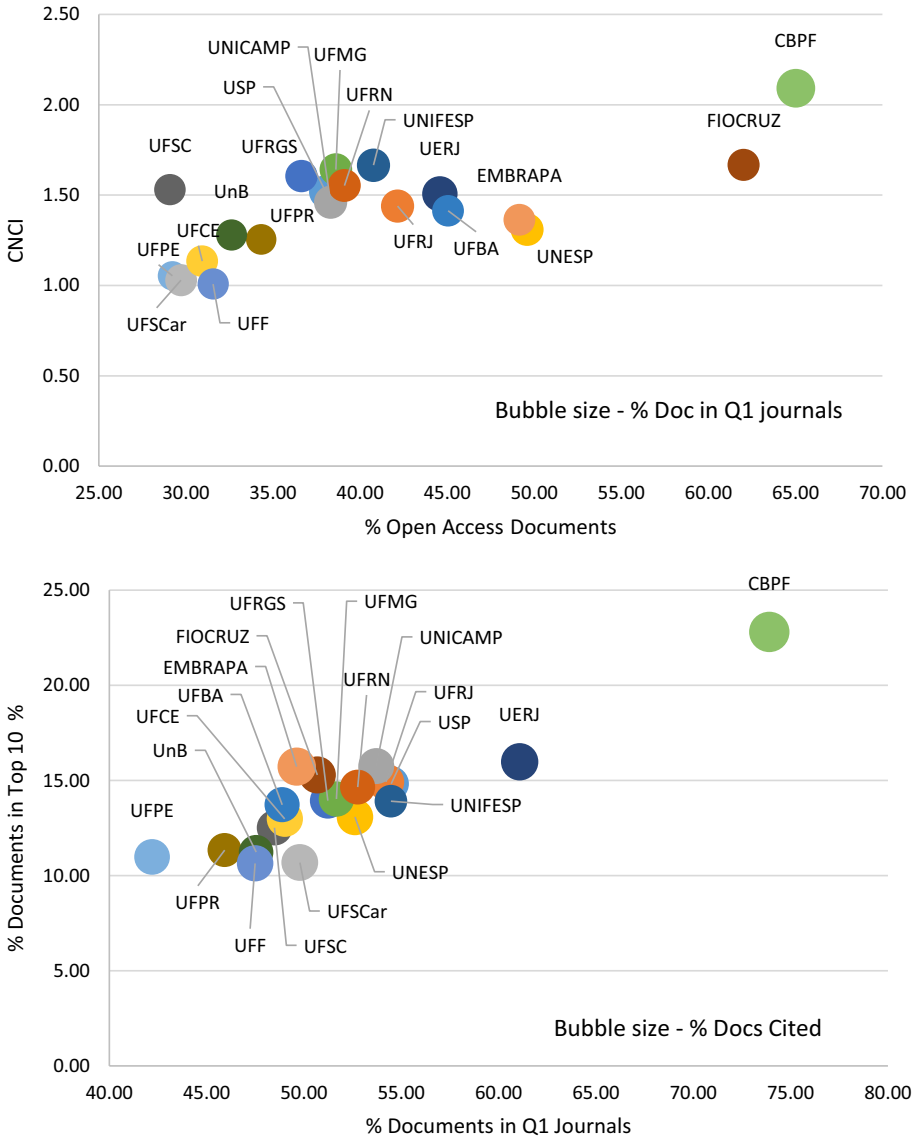

Fig. 5 Impact of international collaboration on quality indicators in Brazilian institutions

areas such as Federal University of São Paulo (Unifesp), Pontifical Catholic University of Rio Grande do Sul (PUCRS) and Federal University of Pelotas (UFPel) in Medical Sciences and Federal Universities of Viçosa (UFV), Santa Maria (UFSM) and Lavras (UFLA) in Agriculture. In the case of Medical sciences, the universities that were specific to that area of knowledge showed higher impacts. This was not true in Agriculture.

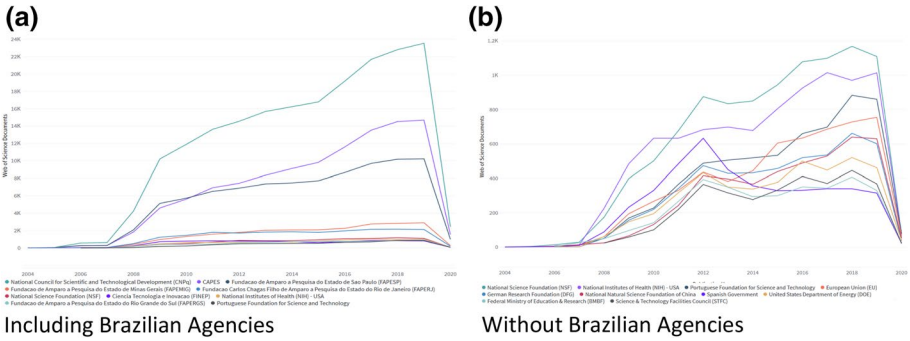

Fig. 6 Number of publications per major financier of collaboration in Brazilian science with (**a**) and (**b**) without Brazilian finance and by area of knowledge

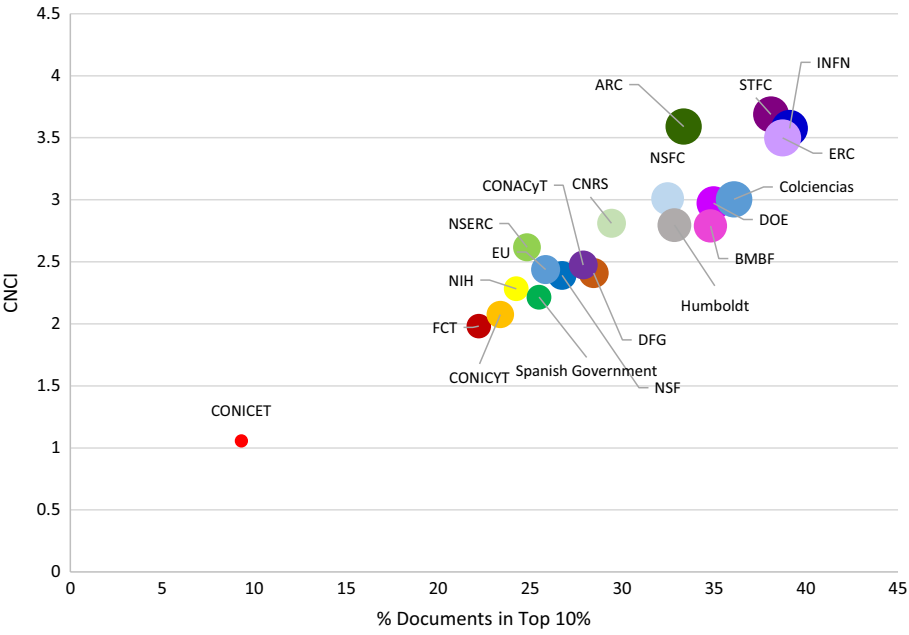

Fig. 7 Effect of the number of papers published in the top 10% on CNCI by the top 15 foreign investors in Brazilian Science. Size of the bubble is % highly cited papers

Financing

Financing (local and foreign) in Brazilian science increased after 2006 (Fig. 6). There are 831 registered international financing sources in Brazilian Science, with most financing abroad coming from North America and Europe, in all areas of knowledge (Supplementary Fig. 7). Many are universities or research institutions and not financing agencies as such.

The NIH and NSF are major financiers of Brazilian cooperation, as are DFG, DAAD, Alexander von Humboldt, the EU and CNRS (Fig. 7). Some areas show specific sources

of financing such as drug companies in the Medical Sciences or USDA in Agriculture. Some South American and Iberian agencies are also present such as from Portugal, Spain or CONICET (Argentina), CONACyT (Mexico) and CONICYT (Chile). These latter show lower impact factors.

More papers were published in open access compared to closed access in collaboration with foreign partners. There were 21.32 more citations per paper (Table 6), thus leading to an increase in CNCI of 1.94 and JNCI of 1.06. There was a lower % of papers in Q2 journals and lower % of industry collaborations in open access papers. All other indicators were higher.

Figure 8 shows that both international collaboration and open access led to an increase in impact of the papers published. The percentage of open access papers has stabilized in recent years (since 2010), but international collaboration continues to increase. There is no difference between the percentage of papers published closed or open access with international collaboration. While in the overall Brazilian publications, there is no difference in the impact between open and closed access, when we look at only papers in foreign collaboration, impact is higher in open access in terms of CNCI, % documents in top 10% and % documents cited. In all cases, documents in open access tend to have more citations.

Collaboration with industry

The two main areas with industrial collaboration are Medical and Engineering and Technology (E&T). Figure 9 shows that while in the E & T area financing is mainly by funding agencies, in the Medical Sciences some private philantropic foundations are seen to finance as well as private companies. In the other areas, collaboration maximum varies from 1 to 2%.

There is considerable similarity between the most published topic clusters worldwide and those where Brazilian authors are collaborating (Fig. 10), showing that, in collaboration, Brazil is contributing to the major study areas worldwide. In the areas of Natural Science, Medical and Engineering & Technologies, Brazilian scientists appeared in almost all of the top 500 clusters in these areas. In terms of impact, Table 7 shows that, compared with world impact in the same areas, Brazilian authors in collaboration in these prominent clusters is higher than the world mean.

This is especially evident in the Medical Sciences. In international collaboration, Brazil publishes more in the areas that show higher prominence worldwide (Supplementary Fig. 10). The first principal component shows that the quality parameters used (FWCI Brazil and World, SNIP, Citescore, numbers of citations, Prominence as well as outputs worldwide and Brazil in collaboration) are positively correlated. In the second component, there is a subset of a lower number of papers per cluster that are highly cited and have a higher impact for Brazil than worldwide but have lower prominence.

Discussion

At this time, also, the need for international collaboration becomes more prevalent (Hossain, 2020). According to Adams (2013), there is a growing divide between the quality of international and domestic research. This will influence each nation's ability to draw on the global knowledge base, and could, in turn, compromise national scientific wealth. The isolation will cause a gradual financial and intellectual separation

Table 6 Difference between open access and closed access journals for top financing agencies in collaboration with Brazilian authors

Name	WoS doc	% Docs cited	CNCI	% Docs in Q1 journals	% Docs in Q2 journals	% Docs in top 1%	% Docs in top 10%	% Highly cited Papers	% Indust Collabs	Docs in J IF journals	JNCI	Cit/Doc
NIH	5763	21.33	1.12	17.85	−8.68	3.25	14.30	2.01	1.92	5496	0.08	17.06
NSF	2479	8.16	1.62	26.60	−11.68	4.90	18.24	4.74	−0.48	2522	0.78	18.09
DFG	2186	4.56	1.80	25.02	−15.68	5.96	23.14	6.40	−0.69	1974	1.02	21.53
EU	1209	5.71	1.85	20.62	−13.74	5.15	18.41	6.03	−0.38	1142	1.02	19.09
NSFC	2174	9.22	2.06	25.64	−12.97	5.58	19.51	5.70	0.22	2005	1.12	26.21
DOE	2345	6.52	2.16	19.79	−12.35	7.29	22.41	7.39	−2.36	2157	1.21	23.77
FCT	332	7.84	1.74	26.86	−17.67	5.27	20.24	6.23	−0.30	513	1.06	24.11
STFC	2973	4.20	2.23	4.12	−1.29	6.00	20.03	7.77	1.09	2658	1.12	25.65
BMBF	2300	4.64	1.76	27.05	−15.97	6.15	21.70	6.83	−1.33	2069	1.11	19.40
INFN	2513	13.10	1.87	46.15	−19.93	6.41	35.18	6.69	0.78	2234	0.39	25.26
Spanish gov	613	3.68	1.48	22.07	−15.20	5.25	19.45	5.17	0.37	626	0.78	20.86
ERC	1832	8.01	1.55	19.11	−13.55	4.74	13.12	6.04	−0.52	1609	1.20	17.61
CNRS	1450	4.23	1.89	18.99	−12.17	4.47	19.50	5.03	0.55	1288	1.13	17.33
Humboldt	1459	8.36	1.80	21.58	−9.69	5.09	18.86	5.94	−0.27	1320	1.28	18.42
Chinese acad sci	1785	−0.95	1.46	18.05	−7.02	3.07	20.96	4.41	0.60	1614	1.00	18.93
Colciencas	1639	9.15	1.59	28.95	−11.86	4.24	26.15	4.34	0.05	1481	1.29	17.56
NOW	1723	10.65	2.46	24.89	−16.61	4.85	22.10	2.23	−1.21	1555	1.38	28.42
GSRT	1820	−5.10	2.36	39.75	−40.80	8.28	44.30	9.21	0.93	1628	1.47	29.64
Min education Czech	1584	−0.32	1.33	4.63	−1.86	4.31	16.98	6.00	−0.42	1410	0.84	6.34
Swiss NSF	1445	5.41	2.36	21.86	−11.82	6.07	21.89	6.46	−2.84	1314	1.09	25.11
NSERC	275	8.50	2.66	24.70	−13.97	5.51	20.24	7.16	−0.37	373	1.22	29.19
Netherlands gov	1569	−1.84	1.93	7.79	−0.12	7.13	25.89	6.48	0.00	1423	1.08	16.35
Max planck society	1539	14.38	2.24	29.58	−16.66	6.88	22.27	4.48	−1.38	1410	1.31	30.13

Table 6 (continued)

Name	WoS doc	% Docs cited	CNCI	% Docs in Q1 journals	% Docs in Q2 journals	% Docs in top 1%	% Docs in top 10%	% Highly cited Papers	% Indust Collabs	Docs in J IF journals	JNCI	Cit/Doc
ARC	1065	7.29	2.60	27.41	−14.34	7.09	24.94	6.52	−1.48	1001	1.19	24.67
Russian found basic research	1108	6.32	3.04	42.30	−17.42	8.09	26.16	7.58	0.05	974	1.28	33.63
Min education Japan	1316	5.99	1.71	24.23	−8.87	4.92	22.03	7.23	0.09	1190	1.09	16.31
Min sci high ed Poland	1518	5.04	1.28	35.61	−28.98	3.81	24.14	2.74	−7.28	1338	1.42	13.89
Min Sci Tech China	1559	2.13	1.66	13.00	−13.95	7.72	15.80	8.54	1.14	1357	0.90	8.83
CONACyT	846	9.77	1.86	31.89	−14.13	5.74	24.19	5.57	0.56	801	1.09	25.85
CONICyT	623	9.25	1.86	30.95	−14.59	4.97	21.40	5.57	−0.01	614	0.81	23.16
Royal society	1247	3.75	2.24	18.56	−13.92	5.32	20.19	5.92	−0.43	1111	0.82	10.08
FWF	1366	5.96	2.03	23.11	−9.39	5.02	28.96	7.33	−0.74	1164	1.17	19.84
JSPS	1008	10.46	2.22	26.93	−9.89	5.49	23.28	6.26	−1.36	925	1.29	26.79
Sci found Ireland	1131	7.81	2.21	16.52	−12.37	6.03	22.04	6.46	−0.36	1042	1.67	24.47
FOM	1209	−0.77	1.82	-0.84	1.04	7.51	23.59	7.05	0.00	1206	1.21	19.86
DAE	1106	−4.26	1.24	-0.06	1.60	2.16	11.21	4.42	1.29	993	0.90	4.63
ANPCyT	521	6.29	2.14	34.96	−19.59	5.80	29.27	7.15	−1.88	491	1.13	27.23
Acad Finland	1035	5.04	2.66	30.37	−20.60	8.54	30.32	9.26	−0.81	928	1.72	34.95
Leverhulme trust	1082	11.46	1.80	35.29	−25.66	4.86	18.39	6.82	−1.88	952	0.81	18.68
ANR	344	8.10	1.70	16.14	−11.64	5.45	16.26	6.14	−0.29	355	0.75	13.68
Alfred P. Sloan Found	1001	12.21	1.19	6.54	2.21	5.28	11.56	6.32	0.98	900	0.81	22.75
Czech republic	938	−2.20	1.65	– 1.29	5.44	2.88	16.23	6.21	0.00	854	1.08	8.35
NASA	638	11.16	2.08	24.90	−17.09	5.24	14.45	3.26	1.40	630	1.00	18.85

Table 6 (continued)

Name	WoS doc	% Docs cited	CNCI	% Docs in Q1 journals	% Docs in Q2 journals	% Docs in top 1%	% Docs in top 10%	% Highly cited Papers	% Indust Collabs	Docs in J IF journals	JNCI	Cit/Doc
FWO	748	6.24	1.74	23.07	−14.35	5.59	19.85	5.23	2.03	665	1.34	24.41
Wellcome trust	145	1.84	2.36	3.26	−3.87	6.69	11.00	5.32	−0.63	140	0.16	16.95
Depart Sci and Tech India	790	0.50	1.57	25.37	−11.80	3.69	22.45	4.37	1.62	706	0.53	18.39
Canada found innov	800	6.64	2.18	12.30	−6.67	7.43	28.81	8.91	0.22	733	1.30	26.83
Danish nat sci res counc	953	10.86	2.16	32.79	−22.01	5.97	29.67	9.63	0.00	876	1.36	24.33
ICREA	734	7.35	2.75	23.80	−20.55	9.48	24.81	9.27	−2.54	742	1.35	41.21
Means	1384.44	6.20	1.94	22.02	−12.71	5.64	21.75	6.16	−0.33	1275.69	1.06	21.32

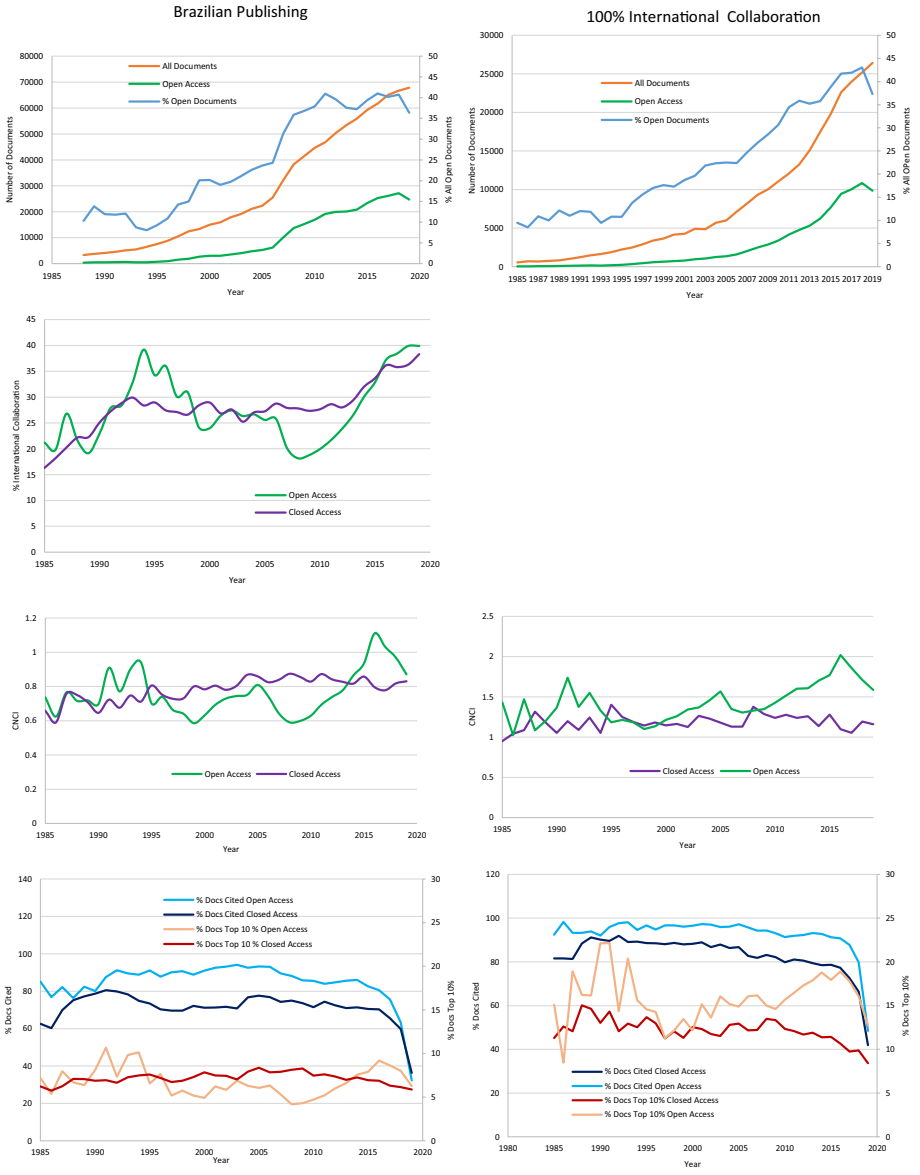

Fig. 8 Impact of papers published by Brazilian authors (with or without collaboration) and only with international collaboration in closed and open access

between institutions into those that are primarily international and those that are mostly national. Such a departure could lead to the erosion of adequate regional competency for future research training and collaboration and for knowledge flow to the national industrial base. This is especially important in a country such as Brazil where international collaboration is relatively new but is growing exponentially (Fig. 1 and 4). Few institutions in the less-favoured regions of the country are in the top 20 in terms

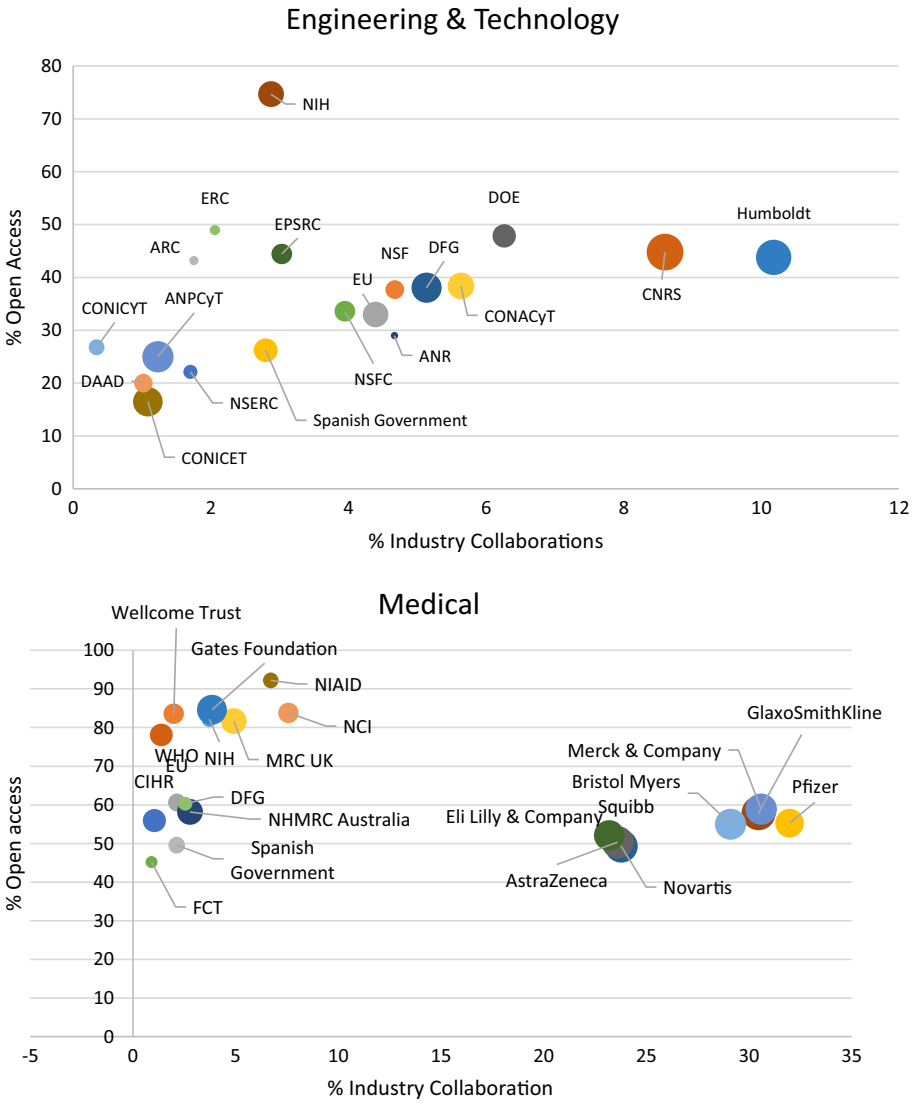

Fig. 9 Major sources of financing of industry collaborations in the engineering and medical sciences in collaborative works with Brazilian authors

of international collaboration. At the same time, those in the southeast (especially São Paulo and Rio de Janeiro) are more prevalent (Fig. 3). Without specific financing for the less favoured regions and areas of knowledge, focusing on where institutions in each region have the competency to develop (McManus et al. 2020), Brazil could compromise the future of these regions, and the country as a whole.

The question of financing publications in highly cited journals (McManus et al., In press) is also relevant to maintain the impact of Brazilian research. Without partner financing on the Brazilian side, it will be difficult to maintain these partnerships in the future and

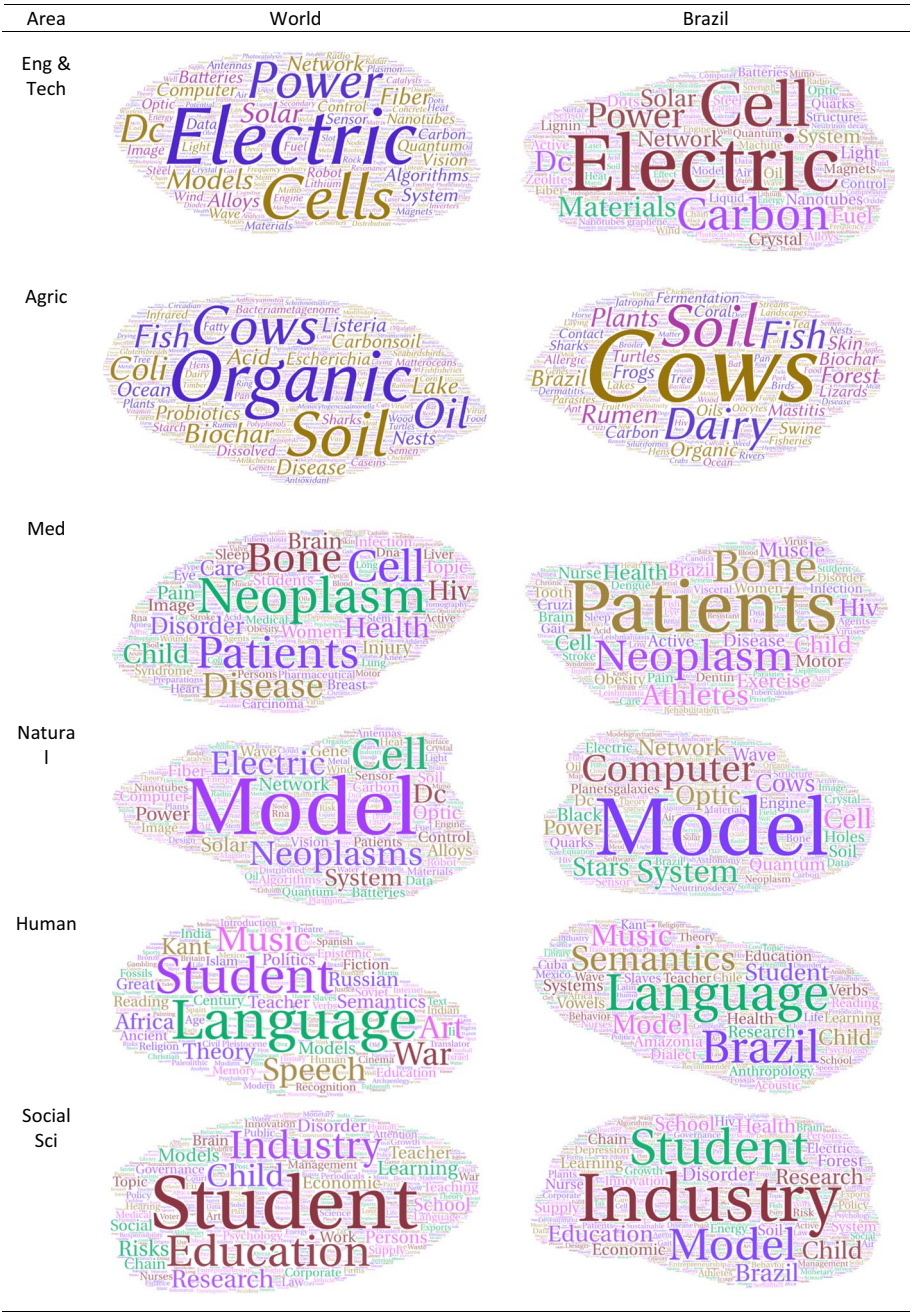

Fig. 10 Word clouds by topic clusters (SciVal®) worldwide and with collaboration with Brazil

the above-mentioned paper calls attention to a recent increase in the % of publications in closed-access journals. As shown here, this can lead to a fall in impact of science produced in the country (Figs. 5 and 8).

Table 7 Brazilian participation in the top 500 prominence clusters worldwide in each area of knowledge (SciVal® 2014–2019)

	Number clusters[a]	FWCI[b] world	FWCI[c] Brazil	Citations/paper	SJR	Citescore
Agriculture	197	0.88	1.23	7.77	0.91	2.09
Engineering	459	0.90	1.12	9.01	1.22	3.07
Natural sci	497	1.01	1.29	9.72	1.32	2.88
Medical sci	499	0.96	2.43	15.74	1.70	2.97
Social sci	232	0.89	1.11	5.22	0.83	1.54
Humanities	101	0.79	1.07	1.96	0.43	0.72

[a]Number of clusters in top 500 worldwide where Brazilian authors publish in collaboration with foreign authors

[b]Mean FWCI on a worldwide basis for the clusters studied

[c]FWCI Brazilian authors in topic clusters in top 500 worldwide

McManus and Neves (2020) showed that areas of knowledge differ in publishing practices and languages. This is also evident in the present study in relation to partnerships in publishing and in agreement with Choi et al. (2015). Here also, impact of the different areas in collaboration can be seen, so policies for improving impact but be relevant for the area in question. While this is still incipient in the Humanities and Social Sciences, it should be remembered that publications in collaboration are not common in these areas but are increasing (Haddow et al. 2017). The present study goes beyond that seen by Martinez and Sá (2020) who stated that engagement with the academic Anglosphere is necessary for highly cited status, derived from co-authored publications with collaborators from the United States, the United Kingdom, and Australia. Here, despite the importance of these countries, non-Anglophone countries were also important for Brazilian collaborations. The focus of the cited paper was the researcher, different from here. Nevertheless, these authors found that international experience was important for the production of papers with a high number of citations.

The relationship with France and Germany may be a reflection of the language barrier, as well as cultural and historical ties. French universities are also evident in the Engineering and Technology areas (de Sandes-Guimaraes et al. 2020). This may be due to the creation of specific programs, such as the 40 year old Brafitec program (Grochocki and Guimarães 2017) based on undergraduate student mobility from the Brazilian Federal Agency for Support and Evaluation of Graduate Education (Capes, Brazilian Ministry of Education) and the CAPES-Cofecub agreement (Nunes 2006). While US and English universities are visible in all areas, the lack of German universities is notable, given Brazil´s history of co-financing with German agencies such as DFG, DAAD, Alexander von Humboldt and BMBF (Schuch and Hellingrath 2014), as seen in Fig. 7. Only Helmholtz and Max Plank appear among the main German research institutions.

While Leta and Chaimovich (2002) found higher impact with collaborative vs non-collaborative publications, they stated that higher impact values were observed within publications coauthored with Argentina and Chile. This is not true in the present study, whereby cofinanced studies with these countries had a lower impact than Northern Hemisphere collaborations.

The number of institutions with which Brazilian authors are collaborating has been steadily increasing over time. As more institutions, regions and researchers in Brazil enter the postgraduate system, where over 95% of research is carried out in Brazil (McManus and Neves 2020), the demand for collaboration increases. Programs such as Science without Borders (McManus and Nobre 2017) increased Brazilian presence abroad but does not seem to have changed the growth in the number of collaborating institutions or researchers (2011 – 2016).

In terms of the financing agencies, impact increases with foreign financing. It should be noted that Brazil finances mainly mobility, such as sandwich doctorates or visiting lecturers abroad for 6 months or one year, rather than collaborating with financing for research projects. This type of financing is important as it introduces the Brazilian student or researcher to groups abroad, it works as a seed from which collaboration can grow, if it does not already exist. Collaboration also improves the quality of future generations of researchers, which is important for a developing country (Huang and Lin 2010). This sets the need for Brazilian agencies to look at their financing procedures to improve these indicators. Also, the main financers for international collaboration in the Medical sciences are private companies (Fig. 9), which also may indicate a higher competition for research grants. This area also tends to show the highest impact of all areas. A broad basis of financing sources increases options for Brazilian researchers to maintain collaboration, especially in times of financial restriction.

Geographically dispersed research collaborations, however, impose search and coordination costs for bridging geographic distance and institutional differences (Cummings and Kiesler 2007). These authors highlight that, due to these costs, multi-institute collaborations tend to have less frequent and less effective coordination, leading to more conflict, free-riding, lack of monitoring and diverging interests (Hinds and Bailey 2003). In line with Hoekman et al. (2010), this study showed that regions and countries differ in their propensity to collaborate (Table 1). The previous authors attribute this to differences in size, quality and accessibility. In the case of Brazil, mainly in the life and exact sciences, researchers contribute significantly to research efforts in distant rather than geographically close collaborations. In part, this may reflect the size of the country which is the largest in South America. Nevertheless, further investigation is needed into research networks with Brazilian authors in order to get a more detailed picture.

McManus et al. (In press) showed the cost of publishing in open access in international journals. These authors show that the correlation between the cost of publishing and the number of citations was positive and significant. Effective international collaboration can help in the payment of these fees and thereby help in increasing the impact of local research.

According to Martinez and Sá (2020), Brazil exerts regional leadership in scientific production in Latin America but remains relatively peripheral to global science. This is not seen here, where Brazilian researchers are seen to be effectively collaborating to world prominent themes of high impact and to advance the innovative science. In fact, in terms of international collaboration, there has been an increase not only in numbers but also in the quality of the production. This has not been due to a specific public policy, but to a convergence of different efforts from agencies, institutions and the research community. Although financing for bilateral or multilateral projects has existed for some time (for example Cofecub with France, or programs with DFG or DAAD in Germany), only with the launch of the PrInt program (Program for Institutional Internationalization) (Arruda 2017) was international collaboration and impact defined as an institutional priority.

Leta and Chaimovich (2002) studied Brazilian collaboration from 1981 to 1999 and found that at that time collaborations we mainly with European and Central & North American institutions, while Middle East and African countries constituted about 1.5%. Westphal (2013) looks at the role of Capes (which at present is the largest financing agency in Brazil) in the process of internationalization of graduate education and therefore research collaboration in Brazil, noting that this began effectively from the year 2000 with bilateral agreements to cofund research projects between university lecturers and stimulate student exchange. One of the major factors in opening Brazil to collaboration is the creation of a publications portal (Portal de Peridiocos) which, since 2000, has been maintained by Capes (Atallah and Puga 2007). This portal (https://www.periodicos.capes.gov.br/) provides free access to 414 institutions in Brazil and hundreds of thousands of university lecturers and students at their desktops. Increase in Brazilian collaboration is seen to steadily increase from this point. At the end of 2018 this base had 48,325 scientific jounals, as well as books, reports, and other databases of complete texts, references and abstracts, patentes, books, and statistics. According to Chinchilla-Rodríguez et al. (2010), in the Latin-American realm, Brazil is a country with high internal but low external collaboration. This may be in part due to the fact that most science in Brazil is carried out in post-graduate courses in public universities. This system has increased by 100% in the last 10 years (McManus et al. 2020). Visibility of Brazilian research, and therefore citation rates, also depends on the area of knowledge and who the international partner is (Chinchilla-Rodríguez et al. 2010).

McManus et al. (2020) stated that international collaboration also led to an increase in citation impact, reaching almost five times the world average. This is also more evident here, where the analysis of topic clusters showed that Brazilian authors are collaborating at a high level in all areas of knowledge. While this paper deals with published papers, international collaboration and its impact should not be limited solely to this subject. As this study is based on bibliometric databases (Incites® and Scival®), several factors are not examined, especially in the Humanities and Social Sciences. These areas, along with Agriculture, many times deal with specific problems of the country but international collaboration can be used to improve the quality of knowledge generated whose main concepts are universal and then contribute to overall science. This paper also does not examine the size or stability of research networks. Bozeman et al. (2013) reviewed the effect of collaborations (Individual and institutional collaboration and collaborator attributes) on collaboration choices and outcomes.

Several studies compare these databases (Gray and Price 2020; Springer and Milligan, 2017). Waltman (2016) describes the databases and a short history and coverage, as well as a discussion on differences in Social Sciences and Humanities, overrepresentation of English language journals, and conference proceedings. Mongeon and Paul-Hus (2016), analysing the coverage of journals in WoS and Scopus, found that Scopus covers a much larger number of journals and that almost all journals in WoS are also covered by Scopus. They state that in both databases, Social Sciences and arts and Humanities are underrepresented, as well as an overrepresentation of English-language journals. Citation counts tend to be higher in Scopus than in WoS (e.g., Haddow and Genoni 2010; Kulkarni et al. 2009; Torres-Salinas et al. 2009). Depending on the area of knowledge one data base may be better than others, for example Fest et al. (2017) suggest that there is better cover in the Social Sciences in SciVal. Many publications are not in either database. The type of indicator also varies between database, for example funding information, highly cited and hot papers are only available in InCites while Topic Clusters and Prominence only in SciVal®.

Most of Brazilian international collaboration is seen within small bilateral or individual programs in the major financing agencies such as Capes and CNPq (Ministry of Science, Technolgy and Innovation). Two major noteworthy exceptions are the Science without Borders program (McManus and Nobre 2017) and PrInt Program (Arruda 2017). The former was mainly based on undergraduate STEM one year scholarships abroad, but suffered due to lack of planning and financial restrictions. Thereby, graduate and visiting lecturer quotas were not met, while finacing was diverted by research and postgraduate courses in Brazil to pay fees abroad, including for periods of English training of students. This led to the creation of a Brazilian based progam Language without borders (Dorigon 2016) to improve English teaching in Brazilian universities. The second progam (PrInt- Program for Institutional Internationalization) underwent extensive planning, with universitites proposing their goals within a fixed annual budget. This program began effectively in August 2018 with the selection of 36 higher education institutions, but together with government attacks on univertity productivity, along with the financial impacts of the COVID crisis leading to severe cuts in the major financing agencies and public universities, threatens this program for discontinuation in the near future. The increase of Brazil in world ranking of publications (Leta et al. 2013) is seen to be a combination of internal and external factors including the continuous investment of the public sector in qualifying human resources and improving infrastructure as well as the inclusion of dozens of new Brazilian titles in major scientific databases (Leta 2011). In 1980 there were six Brazilian journals in Web of Science, while in the period 2010–2020 this increased to 164 journals. The major increase was in the period from 2005 to 2010 (148 journals) up from 30 in the previous period (2000–2005).

As such Brazilian scientists will have to use creativity to maintain and increase international collaboration in the near future, facilitated by the development of information and transportation technologies, better definition of priorties and priority partnerships, as well as strategic cofunding with industry and international partners (Choi 2012).

Conclusion

This paper shows that collaboration of Brazillian researchers with foreign partners brings benefits for both sides, with Brazilian authors having access to financing from international agencies. Increase in measure of impact are also seen in these collaborations. Foreign partners also benefit from higher impact factors in the same topic cluster, when collaborating with Brazilian partners. This finding clearly points out a successful convergence of science policies of Brazilian funding agencies with efforts from institutions and researchers in fostering the connection of brazillian science with the international community to move science frontiers forward.

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Abbreviations

Cit/Doc Number of citations per document

CNCI Category Normalized Citation Impact of a document is calculated by dividing the actual count of citing items by the expected citation rate for documents with the same document type, year of publication and subject area. This is used in InCites® and based on the Web of Science

CS CiteScore of an academic journal is a measure reflecting the yearly average number of citations to recent articles published in that journal

DOAJ Directory of Open Access Journals is a community-curated online directory that indexes and provides access to high quality, open access, peer-reviewed journals

DocCit Number of documents in the database in the period studied that had at least one citation in the database

FWCI Field Weighted Citation Index - is the ratio of the total citations actually received by the denominator's output, and the total citations that would be expected based on the average of the subject field. Similar to CNCI, this is from SciVal® based on data from Scopus

High Highly cited papers are papers that perform in the top 1% based on the number of citations received when compared to other papers published in the same field in the same year

Hot Hot papers - are papers published in the last two years that are receiving citations quickly after publication. These papers have been cited enough times in the most recent bimonthly period to place them in the top 0.1% when compared to papers in the same field and added to the database in the same period

Ind papers published with Industry Collaboration

Inter papers published with International Collaboration

JCR Journal Citation Reports (JCR) is a resource tool published annually by Thomson Reuters (formerly ISI) to provide citation and publication data of academic journals in the science and Social Science fields

JIF Journal impact factor – A tool for evaluating and comparing journals. It is the average number of times articles from the journal published in the past two years have been cited in the JCR year

JNCI The Journal Normalized Citation Impact indicator is a similar indicator to the Normalized Citation Impact, but instead of normalizing per subject area or field, it normalizes the citation rate for the journal in which the document is publishing

OA Open Access - is a set of principles and a range of practices through which research outputs are distributed online, free of cost to the reader or other access barrier

Publications in Top Journal Percentiles indicates the extent to which an entity's outputs are present in the most-cited journals in a database source. This metric calculates how many publications, as an absolute count or a percentage, are in the top 1%, 5%, 10% or 25% of the most-cited journals indexed by the database source. An entity can be an institution, a research group or an individual researcher. In this paper we used **%Top1% and %Top10%**

Q1, Q2, Q3, Q4 Quartile rankings are therefore derived for each journal in each of its subject categories according to which quartile of the IF distribution the journal occupies for that subject category. Q1 denotes the top 25% of the IF distribution, Q2 for middle-high position (between top 50% and top 25%), Q3 middle-low position (top 75% to top 50%), and Q4 the lowest

	position (bottom 25% of the IF distribution). In this paper we used %Q1 and %Q2
Scopus	is Elsevier's abstract and citation database launched in 2004 and covers three types of sources: book series, journals, and trade journals. All journals covered in the Scopus database, regardless of who they are published under, are reviewed each year. Searches in Scopus also incorporate searches of patent databases
SJR	Scimago Journal Rank is a measure of the prestige of scholarly journals. The methodology accounts for number of citations as well as the source of citations, with citations from high prestige journals being worth more than those from journals with lower prestige. The prestige value depends on the field, quality and reputation of the source journals that citing article is published in. The average SJR value for all journals in Scopus is 1.000
SNIP	Source-normalized Impact per Paper is a field normalised assessment of journal impact. SNIP scores are the ratio of a source's average citation count and 'citation potential'. Citation potential is measured as the number of citations that a journal would be expected to receive for its subject field. SNIP allows for direct comparison between fields of research with different publication and citation practices. A journal with a SNIP of 1.0 has the median (not mean) number of citations for journals in that field
STEM	refers to the Science, Technology, Engineering, and Mathematics areas of knowledge
WoS	Web of Science is a website which provides subscription-based access to multiple databases that provide comprehensive citation data for many different academic disciplines. It was originally owned by the Institute for Scientific Information (ISI) and is currently maintained by Clarivate Analytics (previously the Intellectual Property and Science business of Thomson Reuters

Financing Agencies

ANPCyT	Agencia Nacional de Promoción Científica y Tecnológica - Argentina
ARC	Australian Research Council
BMBF	Bundesministerium für Bildung und Forschung - Federal Ministry of Education and Research - Germany
CNRS	Centre national de la recherche scientifique- French National Centre for Scientific Research
Colciencias	Administrative Department of Science, Technology and Innovation – Colombia
Conacyt	Consejo Nacional de Ciencia y Tecnologia - Mexico
Conicet	National Scientific and Technical Research Council (Consejo Nacional de Investigaciones Científicas y Técnicas) - Argentina
Conicyt	Comisión Nacional de Investigación Científica y Tecnológica - Chile
DAAD	Deutscher Akademischer Austauschdienst **-** German Academic Exchange Service

DOE	Department of Energy - USA
EPSRC	Engineering and Physical Sciences Research Council -UK
ANR	French National Research Agency - L'Agence nationale de la recherche
ERC	European Research Council
EU	European Union
FCT	Fundação para a Ciência e a Tecnologia – Portugal - Foundation for Science and Technology
Humboldt	Alexander von Humboldt Foundation - Alexander von Humboldt-Stiftung - Germany
INFN	Istituto Nazionale di Fisica Nucleare - National Institute for Nuclear Physics - Italy
NIAID	National Institute of Allergy and Infectious Diseases – USA
NHMRC	National Health and Medical Research Council - Australia
CIHR	Canadian Institutes of Health Research
WHO	World Health Organization
MRC UK	Medical Research Council UK
NIH	National Institute of Health – USA
NSF	National Science Foundation – USA
DFG	Deutsche Forschungsgemeinschaft – German Research Foundation
NSERC	Natural Sciences and Engineering Research Council of Canada
NSFC	National Natural Science Foundation of China
STFC	Science and Technology Facilities Council - UK
USDA	United States Department of Agriculture

Brazilian Financing Agencies

Capes	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Ministry of education)
CNPq	National Council for Scientific and Technological Development - Conselho Nacional de Desenvolvimento Científico e Tecnológico
Fapemig	Fundação de Amparo à Pesquisa do Estado de Minas Gerais -Minas Gerais State Agency for Research and Development
Fapergs	Fundação de Amparo à Pesquisa do Estado de Rio Grande do Sul
Faperj	Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro
Fapesp	Fundação de Amparo à Pesquisa do Estado de São Paulo
Finep	Financiadora de Estudos e Projetos, or Funding Authority for Studies and Projects
Fund. Araucaria	Fundação de Apoio à Ciência, Tecnologia e Inovação do Paraná

Brazilian Universities and Research Institutions

CBPF	Centro Brasileiro de Pesquisas Físicas
Embrapa	Brazilian Agricultural Research Corporation
Fiocruz	Fundação Oswaldo Cruz

PUCRJ	Pontifícia Universidade Católica de Rio de Janeiro
PUCRS	Pontifícia Universidade Católica do Rio Grande do Sul
UEL	Universidade Estadual de Londrina
UEM	Universidade Estadual de Maringá
UERJ	Universidade do estado de Rio de Janeiro
UFBa	Universidade Federal de Bahia
UFC	Universidade Federal de Ceará
UFF	Universidade Federal Fluminense
UFMG	Universidade Federal de Minas Gerais
UFPB	Universidade Federal de Paraiba
UFPE	Universidade Federal de Pernumbuco
UFPR	Universidade Federal de Paraná
UFRGS	Universidade Federal de Rio Grande de Sul
UFRJ	Universidade Federal de Rio de Janeiro
UFRN	Universidade Federal de Rio Grande do Norte
UFSC	Universidade Federal de Santa Catarina
UnB	Universidade de Brasilia
UNESP	Universidade Estadual Paulista Júlio de Mesquita Filho
Unicamp	Universidade Estadual de Campinas
Unifesp	Universidade Federal de São Paulo
USP	Universidade de São Paulo

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