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Research Article

Coverage and Correlations Between Open Citations in Crossref and Readership in Mendeley: Different Fields of Brazilian Science

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ABSTRACT

Purpose: This study dwells on the coverage of altmetric indicators in the Mendeley reference manager, citations in the Crossref platform, and the correlations between readers and citations of papers by researchers working in Brazil, according to different fields and subfields of knowledge. **Design/Methodology/Approach:** We analyzed 152,727 scientific papers published between 2017-2018 by researchers working in Brazil. **Findings:** The coverage of Brazilian papers by Mendeley is relatively high (87.91%) and 63% of Brazilian papers had citations in Crossref. In the Brazilian context, Mendeley readership is relatively high (average R^2 reaching 70% in some areas). **Originality/Value:** The correlation between readers in Mendeley and citations in Crossref of Brazilian scientific output is between moderate and high. This indicates that Mendeley and Crossref data can be relevant for evaluating Brazilian science. The data reveal that Mendeley readership can, in many fields, predict citations. These data are generally higher and mor homogeneous than those found in the international researches. The scientific communication of international context (based on international journals) and Brazilian (heavily published in national open access journals) and the information sources used in the studies may partly explain the differences between them.

Keywords: Open citations, Crossref, Brazilian science, Mendeley, Altmetrics, Bibliometrics.

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INTRODUCTION

The Web of Science (WoS) and Scopus databases are the main data sources used for bibliometric studies of publication output and citation. These are very extensive and well-organized databases, but they have coverage limitations of Brazilian papers and high access cost. WoS, for example, covers approximately 50% of the Brazilian outputs of CAPES' Sucupira Platform.[1] The Altmetric platform, from the company Digital Science, is the most commonly used source for altmetric studies. It is a restricted-access database but so far it has provided access to the data free of charge for scientific proposes. Despite its qualities, studies indicate that the representativeness of countries, languages, and fields of knowledge in Altmetric also have limitations.[2]

Although it occupies a prominent position in WoS (13th place), Brazilian scientific outputs are still underrepresented in international databases. According to Mugnaini *et al.*,[3] approximately 60% of journals containing papers published by Brazilians are not indexed in bases such as Scopus and WoS. Moreover, the restricted access to the content of these bases makes studies on scientific outputs and citations a serious obstacle for developing countries.

Van Eck *et al.*[4] highlight the move toward open scientometric data sources, with free citation data. An alternative for production and citation studies emerged more recently, when Crossref began to make citation data openly available for papers with Digital Object Identifier (DOI). Starting in 2017, with the Initiative for Open Citations (I4OC), publishers began to make their references publicly available. Subsequently, Crossref has made it easier to collect data from its platform through a free Application Programming Interface (API). Not many papers use Crossref citation data in combination with altmetric indicators, although there are examples.[5,6] Research that studies this source in isolation is a little more common.[7]

The general objective of this research is to investigate the coverage of altmetrics indicators in the reference manager Mendeley, citations in the Crossref platform, and the correlations between readers of papers by researchers working in Brazil, comparing

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the dynamics according to the different fields of knowledge and subfields.

Based on these objectives, at the end of the research we seek to answer the following questions: i) Is the coverage of Brazilian papers in Mendeley in line with the international scenario? ii) Can the tool, Mendeley and Crossref, be used to evaluate science in the context of Brazilian science? iii) Does the use of citation data from Crossref, based on open science data, provide a more comprehensive evaluation of science developed in the country? iv) Is the correlation between readers in Mendeley and citations in Crossref of Brazilian production in line with the international scenario? v) Are there indications that Mendeley indicators can predict/explain citations in relation to Brazilian papers?

This research is aligned with other studies[8,9] but it goes further by studying these relationships in the Brazilian context from open citation indicators made available by Crossref. The data from this source may be more appropriate for countries with little indexed production in international databases and that publish heavily in open access journals.

Literature review

For Bar-Ilan *et al.*[10] altmetrics measures the impact of scholarly products within social media and networks. It emerged due to the crisis of traditional metrics to determine the quality of science in face of the slowness of the peer review system, and the limitation of citation analysis and the Impact Factor.[11] Among the sources of altmetric data, the reference management tool Mendeley has become a highly relevant resource by providing metadata such as number of users of the tool, academic status of the readers' profiles (librarians, PhD students, professors, etc.), country of profile, and field of activities.[12,13]

According to Zahedi *et al.*,[12] the statistics provided by Mendeley are "[...] commonly known as 'reader statistics,' although in reality the metrics do not necessarily reflect actual 'reading activity'". Saving a document to your Mendeley library does not necessarily mean that the work has been read or even that this will occur in the future.[14] The statistics provided by Mendeley are useful for identifying the readership and the social and educational impact of papers. Haunschild and Bornmann[15] found Mendeley data promising for quantifying the size of a journal's readership within and outside the scientific environment.

Fang *et al.*[16] presented an altmetric data analysis of 12.3 million papers from the Web of Science. They found that the majority of altmetric data are concentrated in papers in the Biomedical and Health Sciences, Social Sciences and Humanities, and Earth and Life Sciences. Specifically on the coverage of Mendeley, Zahedi *et al.*[9] found that the tool has high coverage of scientific papers from WoS (between 60% and 80% depending on the field). Araújo[17] analyzed papers from Brazilian Information Science journals and found that the Altmetric.com platform returned data from 36% of the papers. Of these, Mendeley had 92.43%, Twitter 7.57%, and Facebook returned no data. Mendeley was the tool with the highest coverage, highlighting its potential for altmetric studies. Another study that presented some qualities of Mendeley was published by Haustein and Larivière.[18] These authors use reader data in Mendeley with a sample of about 1.2 million papers in different health disciplines from PubMed, published between 2010 and 2012, covered by WoS.

Thelwall and Sud[19] developed a study to analyze the correlation between citations from the Scopus database and readers in Mendeley. The authors analyzed papers from 50 subfields and five broad categories, identifying positive correlations (average 0.618) between citation and readership data, ranging from 0.30 to 0.72 depending on the subfield. Low correlation between altmetrics and citation indicators does not mean altmetrics lack validity.[20] On the contrary, it may be an indication that its metrics make it possible to observe impacts not captured by traditional metrics such as social impact.

Scopus and WoS citations are widely used to evaluate scientific outputs; however, they have received numerous criticisms. Among them is that they do not allow adequate scientific evaluation outputs from countries that are not part of the scientific mainstream. Some countries, e.g. Brazil, have relatively low coverage of their journals (53.44%) and papers (51.66%) in international databases.[1] Publishing in non-English language (a common practice in Brazil) may negatively influence the indexing of certain journals by the databases.[21]

Papers from developing countries always have difficulties to meet certain criteria of some databases, mainly due to the lack of international and commercial appeal of the country's scientific outputs.[22] As an example, Coura and Willcox[23] argue that the papers from Tropical Medicine are often not accepted in foreign journals because they are not considered "universal science" but a "local problem" or of "local interest." This under representation causes biases in analyses of these international databases. Facing the problems of indexing in international databases, some alternatives emerge. One example is the open citation movement, with a prominent role played by Crossref. The use of citation indicators from this database can provide an alternative for countries with low coverage in international databases.

The proportion of open citations in Crossref is increasing, it presents an open alternative to commercial citation databases such as Web of Science (WoS), which only offers citation data through restrictive and fee-based licenses (Chudlarský and Dvořák),[7] or free but with significant access restrictions, like Google Scholar (Martín-Martín *et al.*).[24] This increases the possibilities for the advent of "open scientometrics" advocated by Van Eck *et al.*,[4] where citation data would not need to be obtained from commercial providers.

Many investigations that analyze Crossref's citation coverage use data from papers published in the WoS and/or Scopus databases.[4,7,19,24,25] Such studies demonstrate limitations in coverage of Crossref citations in relation to papers indexed in these databases Visser, *et al.*[25]

However, there is a lack of studies that analyze the occurrence of Crossref citations in relation to other data sets. In other words, it is necessary to investigate whether Crossref's citation data can be considered an alternative to articles that are not indexed in private databases. A study that analyzed coverage with this approach was published by Demachki and Maricato.[26] They analyzed Crossref citations of papers from a journal portal at a Brazilian University (where most of the articles are not indexed in databases such as Scopus and WoS), finding that approximately 15% of the articles had at least one citation taken from Crossref. In another study, Demachki and Maricato[27] analyzed the coverage of papers and journals from a Brazilian university and found that Crossref has higher coverage in terms of indexing and citation than WoS and Scopus.

In 2020, Martín-Martín *et al.*[28] clarified that 59% of the 47.6 million papers with references deposited in Crossref had their references open. The number of citations currently open is certainly greater than that observed by the authors, as, more recently, major publishers such as Elsevier and the American Chemical Society have agreed to open their reference lists. This tool can be useful for monitoring citations especially from countries with intense publication in open access journals, as is the case of Brazil.

METHODOLOGY

We extracted a table from Sucupira Platform, from the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES), in *xlsx* format, with data from 494,802 scientific papers, published between 2017-2018 by researchers linked to graduate programs in Brazil. Excluding duplicates and papers that did not have a functional DOI identifier, 152,727 papers were obtained.

The Sucupira Platform was launched in 2014 by CAPES.[28] The database is produced biannually for the evaluation of Brazilian graduate programs. It has a very large coverage of what is published in the country, but it has some limitations. One limitation is that papers from previous years (2015 and 2016) have a smaller amount of DOIs. Furthermore, the database for the period 2019-2020 had not been made available by CAPES at the time of data collection. For these reasons, the survey was limited to the period 2017-2018. The articles are published in several languages, individually reviewed, in partnership with researchers from the country and from other countries. Approximately 49% of the articles in the database were published in English and 48% in Portuguese.

The papers were grouped and analyzed according to nine major fields of knowledge used by CAPES and 81 types of undergraduate programs (subfields). However, the papers (152,727), depending on the type of analysis, are counted twice, so the total number of papers presented in Table 1 (272,211) is greater than the total number of papers in Table 2 (152,727). Similarly, the total papers in Table 3 (300,297) is greater than the total presented in Tables 2 and 1, since the same paper may be published by a researcher who works or has a partnership in two or more fields or subfields of knowledge.

Citation data were extracted from Crossref and readers from Mendeley between September 10 and 11, 2020. The data were collected using the ODISSEIA Metrics tool,[29] capable of extracting data from its APIs. We retrieved the Mendeley and Crossref data from DOIs of each of the papers available in Sucupira Platform. The Altmetric platform collects information from Mendeley, but only from previously mentioned publications in other social media.[30] Thus, not all papers that have Mendeley readers are collected by the tool. Therefore, it is recommended that data be collected directly from the Mendeley API.

We used Spearman's correlation coefficient to measure the degree of correlation between the readers of papers in Mendeley and citations extracted in Crossref. Finally, the Coefficient of Determination (R^2) was calculated in order to represent, in percentage, the ability of Mendeley readers to explain the variation of citations in Crossref data.

RESULTS AND DISCUSSION

Table 2 presents the total number of papers, Mendeley coverage, average and median readership, and citations distributed between the years 2017 and 2018. Regarding coverage, of the 152,727 papers, approximately 55,824 (37%) did not obtain any citations in the Crossref database, while 96,903 (63%) obtained at least one citation (including self-citations). Approximately 18,468 (12%) of the papers did not present any readers in Mendeley, while 134,259 (88%) of the published papers feature at least one.

The citations coverage in Crossref for the analyzed dataset also seems high to us, since 63% of the articles were cited at least once. We did not find previously published studies that allowed a good comparison. However, Martín-Martín *et al.*[24] studied citations to 2,515 highly cited documents published in 2006 in English. They found that of the total citations searched, the Crossref database recovered 28%. Thelwall and Sud[19] when studying the citation coverage of papers published in Scopus in the period between 2004 and 2014 found, on average, 70% of articles with at least one citation. Despite the need for further investigation and the difficulty of comparing the data with the international scenario, we believe that there is strong evidence that Crossref can be a more appropriate citation source for the Brazilian context.

Table 1: Quantities and correlations of readers in Mendeley, citations in Crossref, by fields of knowledge (2017-2018).

Fields	T	%	MC	%	TR	%	MR	MDR	CC	%	TC	%	AMC	MDC	ρ	R²(%)
Agricultural Sciences	26492	9.73	23658	89.3	610058	9.04	23.03	11	17556	66.27	156443	9.34	5.91	2	0.74	54
Biological Sciences	25019	9.19	22986	91.87	637646	9.45	25.49	13	17665	70.61	155926	9.31	6.23	2	0.74	54
Health Sciences	45815	16.83	41253	90.04	1085464	16.08	23.69	12	31156	68.00	279756	16.71	6.11	2	0.73	54
Exact and Earth Sciences	25420	9.34	23047	90.66	593043	8.79	23.33	13	17673	69.52	142708	8.52	5.61	2	0.73	53
Engineering	30214	11.1	27431	90.79	736341	10.91	24.37	13	20813	68.89	180511	10.78	5.97	2	0.73	53
Humanities	36230	13.31	32688	90.22	950562	14.08	26.24	13	25154	69.43	233263	13.93	6.44	2	0.72	52
Applied Social Sciences	33903	12.45	31027	91.52	899630	13.33	26.54	14	23875	70.42	226300	13.52	6.67	2	0.71	51
Multidisciplinary	33954	12.47	30804	90.72	840806	12.46	24.76	13	23170	68.24	193859	11.58	5.71	2	0.72	52
Linguistics, Letters and Arts	15164	5.57	13812	91.08	396914	5.88	26.17	13	10491	69.18	105521	6.3	6.96	2	0.70	50
General	272211	100	246706	90.63	6750464	100	24.80	13	187553	68.90	1674287	100	6.15	2	0.73	53

Total of papers (T); Mendeley coverage (MC); Total amount of Mendeley readers (TR); Average readers per paper (MR); Median readers per paper (MDR); Crossref Coverage (CC); Total amount of Crossref citations (TC); Average number of citations per paper Crossref (AMC); Median number of citations per paper Crossref (MDC); Spearman's correlation coefficient (ρ) between Mendeley readers (TR) X Crossref citations (TC); Coefficient of determination in percentage(R^2); Mendeley readers (TL) X Crossref citations (TC); Coefficient of determination in percentage (R^2)Source: self-elaborated.

The coverage of Brazilian papers by Mendeley (Table 2) is high, approximately 88% of the papers in both years. The generic coverage of Brazilian papers in Mendeley has still been relatively little studied, since the studies generally conducted dwell rather on the disciplinary coverage of publications, such as Silva Filho and Vanz,[31] who checked the coverage of Brazilian nursing papers indexed in WoS in Mendeley (4.9%) and Borba *et al.*,[32] who studied online attention in Mendeley received by Brazilian journals (71%).

The coverage of papers by researchers linked to Brazilian institutions in Mendeley identified in this research is close to the values found in several studies. According to Alperin,[33] most studies report Mendeley coverage values above 80% (some up to 95%), and that from this perspective coverage of 60% can be considered low. Nevertheless, the author found that Latin American papers, including Brazilian papers, indexed in SciELO have much lower coverage (19%) than those noted in international studies. Hence, this divergence may be associated with different factors, among them that: the scenario has changed since the publication of the research presented by the author (which is possible in the social media context); the SciELO journals publish papers, mostly from the Latin American countries, in Portuguese and Spanish, while the papers extracted through Sucupira platform were published in national and international journals, with part published in English, which may increase the number of readers in Mendeley.

In Table 2, the year 2017, despite featuring fewer published papers, had a higher average number of readers in Mendeley, citations in Crossref, and papers covered by Mendeley, than the year 2018. Albeit presenting a rather low coverage, Alperin[33] found higher mentions in Mendeley of papers indexed in SciELO for publications from the year 2012, which had double the coverage levels of 2013. Time since publication, as with "traditional" citations, can also impact the number of Mendeley readers.[34]

Haustein and Larivière,[8] in a study of paper usage by academic status in Mendeley, analyzed papers from *PubMed* covered by WoS. As a result, they obtained a moderate correlation (ρ=0.512). Haustein *et al.*[18] checked the correlation between PubMed paper citations and Mendeley readers of 390,190 papers, identifying moderate correlation (ρ=0.456). Thelwall, *et al.*[35] meanwhile, used 208,739 PubMed papers and correlated their citations and readers in Mendeley, identifying strong correlations of (ρ=0.69).

The results reinforce that bibliometric and altmetric indicators measure different phenomena and should be used in a complementary way, rending it impossible to predict/explain totally, from the global data analyzed, citations from Mendeley readers, or to replace citation indicators with readers. However, studies with longer periods and use of different data sources are considered necessary so that the conclusions and comparisons with other researches are more accurate. For Thelwall *et al.*,[36]

Table 2: Overall distribution of readership quantity indicators in Mendeley and citations in Crossref (2017-2018).

Year	T	%	MC	%	TR	%	MR	MDR	CC	%	TC	%	AMC	MDC	ρ	R^2(%)
2017	73126	47.88	65412	89.45	1831352	54.54	25.04	12	49353	67	487739	58.86	6.66	2	0,74	54
2018	79601	52.12	68847	86.49	1526450	45.46	19.18	9	47550	60	340904	41.14	4.28	1	0,72	52
2017-2018	152727	100	134259	87.91	3357802	100	21.98	11	96903	63	828643	100	5	2	0,73	53

Total of papers (T); Mendeley coverage (MC); Total amount of Mendeley readers (TR); Average readers per paper (MR); Median readers per paper (MDR); Crossref Coverage (CC); Total amount of Crossref citations (TC); Average number of citations per paper Crossref (AMC); Median number of citations per paper Crossref (MDC); Spearman's correlation coefficient (ρ) between Mendeley readers (TR) X Crossref citations (TC); Coefficient of determination in percentage(R^2); Mendeley readers (TL) X Crossref citations (TC); Coefficient of determination in percentage (R^2)Source: self-elaborated.

correlations are probably influenced (tend to be higher) by longer time windows, which was also proven in this research.

The average readership in Mendeley is much higher than the average citations in Crossref (MC) between 2017-2018. The overall average readership per paper for the period was 21.98 while the average citations were 5. The average readership is quite higher and the average citations are slightly lower than those of others research conducted internationally, as illustrated as described further on in this chapter. It seems that the use of the Crossref citations adequately covers Brazilian science, reflecting a proximity to the average citations when compared to the international scenario. In turn, the correlations between citations and readers are also close to those found in other researches.[8,9,19]

We note the proximity of the citation averages, but the readership average in the Brazilian context is considerably higher. The slightly lower number of citations, compared to the international scenario, although not as expressive, may be related to factors such as: Differences between methods, publication time, time between publication and data collection, strong publication of Brazilian publications in Portuguese language journals, interest of national research, with some focus on national issues, etc. The data indicate the relevance of using Mendeley and Crossref citation data to evaluate the science of countries like Brazil: Mendeley, because of the potential to capture other types of impact; and Crossref, for, apparently, providing better citation coverage when compared to international databases.

The fields of knowledge (Table 1) present important differences between the percentages of published papers (between 5.57% and 16.83%). However, coverage in Mendeley among fields is high and very close among them (approximately 90% in all fields). Similarly, the average number of Mendeley readers/citations per paper is close between the fields (between 23.03 and 26.54), as are the respective medians (between 11 and 14). Citations in Crossref likewise show considerably close average of citation coverage (68% to 70.61%), average citations per paper (between 5.61 and 6.96), as well as proximity between their medians (2).

We understand that these data reinforce the assumption that Mendeley altmetric indicators, as well as citations in Crossref, present a promising and possibly fairer way to evaluate different fields of knowledge, especially in peripheral countries, when compared to those performed through international commercial databases. Mugnaini *et al.*[3] noted that Humanities, Linguistics, Literature and Arts, and Applied Social Sciences use a significant percentage of non-indexed journals, while there is greater prominence of papers published in journals indexed in Scopus and/or WoS in the fields of Biology, Engineering, and Exact and Health sciences.

Health sciences has the largest portion of published papers (16.83%), being covered by Mendeley in approximately 90.04%, having 23.69 as average readers, and 6.11 as average citations

Table 3: Quantities and correlations of readers in Mendeley, citations in Crossref, by subfield of knowledge (2017-2018).

Fields	Subfields	T	%	MC	%	TR	%	MR	MDR	CC	%	TC	%	AMC	MDC	*p*	R^2 (%)
Agricultural Sciences	Fisheries Resources and Fishing Eng.	568	0.19	518	91.2	19264	0.25	33.9	17.5	389	68.49	3728	0.19	6.6	2	0.82	67
	Agricultural Engineering	950	0.32	824	86.7	22758	0.29	24.0	7.5	492	51.79	4342	0.23	4.6	1	0.76	58
	Zootechnics	4058	1.35	3699	91.2	95611	1.24	23.6	14	2889	71.19	24476	1.27	6.0	2	0.76	58
	Food Science and Technology	3991	1.33	3521	88.2	97597	1.26	24.5	11	2682	67.20	24684	1.28	6.2	2	0.75	57
	Veterinary Medicine	5653	1.88	5136	90.9	155880	2.02	27.6	12	3858	68.25	49407	2.57	8.7	2	0.73	53
	Agronomy	11716	3.9	10480	89.5	251327	3.26	21.5	11	7757	66.21	58506	3.04	5.0	2	0.73	53
	Forest Resources and Forest Engineering	1778	0.59	1581	88.9	35514	0.46	20.0	13	1245	70.02	7919	0.41	4.5	2	0.72	52
Biological Sciences	Parasitology	1715	0.57	1580	92.1	41420	0.54	24.2	13	1241	72.36	10304	0.54	6.0	2	0.78	61
	Biophysics	156	0.05	131	84.0	1660	0.02	10.6	4	74	47.44	469	0.02	3.0	0	0.77	60
	Genetics	1772	0.59	1584	89.4	37331	0.48	21.1	11	1166	65.80	9500	0.49	5.4	2	0.76	58
	Microbiology	1789	0.6	1649	92.2	53390	0.69	29.8	16	1343	75.07	13475	0.7	7.5	3	0.76	58
	Biochemistry	1789	0.6	1624	90.8	71126	0.92	39.8	15	1232	68.87	19678	1.02	11.0	2	0.75	57
	Immunology	982	0.33	943	96.0	42871	0.56	43.7	23	799	81.36	8551	0.44	8.7	4	0.75	56
	Botany	2102	0.7	1901	90.4	50472	0.65	24.0	12	1388	66.03	12484	0.65	5.9	2	0.74	55
	Pharmacology	1083	0.36	987	91.1	32841	0.43	30.3	17	775	71.56	7934	0.41	7.3	3	0.74	55
	General Biology	3422	1.14	3153	92.1	84846	1.1	24.8	13	2419	70.69	20770	1.08	6.1	2	0.73	53
	Ecology	4753	1.58	4440	93.4	114303	1.48	24.0	13	3377	71.05	27632	1.43	5.8	2	0.73	53
	Zoology	3871	1.29	3515	90.8	83900	1.09	21.7	12	2708	69.96	19975	1.04	5.2	2	0.72	51
	Physiology	3452	1.15	3316	96.1	106324	1.38	30.8	18	2773	80.33	26633	1.38	7.7	3	0.70	49
	Morphology	417	0.14	358	85.9	6072	0.08	14.6	8	201	48.20	1123	0.06	2.7	0	0.68	47
Health Sciences	Pharmacy	4453	1.48	3854	86.6	117232	1.52	26.3	12	2847	63.93	28985	1.51	6.5	2	0.77	59
	Speech Therapy	757	0.25	674	89.0	24464	0.32	32.3	16	537	70.94	5347	0.28	7.1	3	0.76	58
	Physical Education	2117	0.7	1944	91.8	42698	0.55	20.2	12	1479	69.86	10702	0.56	5.1	2	0.75	56
	Dentistry	6664	2.22	6047	90.7	156189	2.02	23.4	12	4597	68.98	40545	2.11	6.1	2	0.75	56
	Nursing	5906	1.97	5350	90.6	137077	1.78	23.2	14	4048	68.54	34104	1.77	5.8	2	0.74	54
	Collective Health	8007	2.67	7321	91.4	212805	2.76	26.6	14	5789	72.30	64418	3.35	8.0	3	0.73	53
	Medicine	20703	6.89	18849	91.0	515808	6.68	24.9	13	14407	69.59	133634	6.94	6.5	2	0.72	53
	Nutrition	2473	0.82	2276	92.0	63884	0.83	25.8	14	1737	70.24	14987	0.78	6.1	2	0.70	49
	Physiotherapy and Occupational Therapy	1209	0.4	1106	91.5	28663	0.37	23.7	15	924	76.43	8435	0.44	7.0	3	0.69	48

Fields	Subfields	T	%	MC	%	TR	%	MR	MDR	CC	%	TC	%	AMC	MDC	*p*	R^2 (%)
Exact and Earth Sciences	Oceanography	466	0.16	401	86.1	8215	0.11	17.6	10	306	65.67	2428	0.13	5.2	2	0.84	71
	Astronomy	890	0.3	839	94.3	20647	0.27	23.2	14	674	75.73	5446	0.28	6.1	3	0.78	60
	Chemistry	7273	2.42	6738	92.6	170119	2.2	23.4	15	5374	73.89	43776	2.27	6.0	3	0.75	56
	Geosciences	3698	1.23	3311	89.5	93503	1.21	25.3	13	2503	67.69	18839	0.98	5.1	2	0.74	55
	Mathematics	4734	1.58	4364	92.2	118593	1.54	25.1	14	3415	72.14	28613	1.49	6.0	2	0.74	55
	Physics	4581	1.53	4059	88.6	108614	1.41	23.7	12	3036	66.27	25125	1.3	5.5	2	0.72	53
	Computer Science	5054	1.68	4590	90.8	121734	1.58	24.1	13	3570	70.64	32591	1.69	6.4	2	0.70	49
	Probability and Statistics	1074	0.36	994	92.6	25707	0.33	23.9	13.5	724	67.41	4722	0.25	4.4	2	0.68	46
Humanities	Geography	3787	1.26	3411	90.1	91645	1.19	24.2	12	2557	67.52	21423	1.11	5.7	2	0.76	57
	Anthropology	1732	0.58	1564	90.3	37170	0.48	21.5	12	1227	70.84	8722	0.45	5.0	2	0.74	54
	Education	10274	3.42	9326	90.8	275341	3.57	26.8	14	7195	70.03	60934	3.16	5.9	2	0.74	55
	Archaeology	500	0.17	472	94.4	16328	0.21	32.7	21.5	409	81.80	3492	0.18	7.0	4	0.73	53
	History	6112	2.04	5543	90.7	146366	1.9	23.9	14	4429	72.46	39051	2.03	6.4	3	0.73	54
	Political Science	3127	1.04	2762	88.3	96403	1.25	30.8	12	2185	69.88	27106	1.41	8.7	2	0.72	51
	Psychology	6730	2.24	6123	91.0	190364	2.47	28.3	15	4622	68.68	48217	2.5	7.2	2	0.72	52
	Sociology	4432	1.48	4072	91.9	145211	1.88	32.8	16	3103	70.01	33180	1.72	7.5	2	0.72	52
	Theology	1183	0.39	1030	87.1	26542	0.34	22.4	9	821	69.40	8092	0.42	6.8	2	0.72	52
	Philosophy	2557	0.85	2392	93.6	76997	1	30.1	15	1975	77.24	18507	0.96	7.2	3	0.70	49
Applied Social Sciences	Demography	793	0.26	740	93.3	40893	0.53	51.6	18	655	82.60	12119	0.63	15.3	4	0.78	60
	Home Economics	133	0.04	126	94.7	2605	0.03	19.6	10	83	62.41	630	0.03	4.7	1	0.78	60
	Communication	3121	1.04	2781	89.1	70384	0.91	22.6	11	1970	63.12	16583	0.86	5.3	1	0.75	57
	Economy	5215	1.74	4775	91.6	135350	1.75	26.0	14	3631	69.63	30931	1.61	5.9	2	0.73	53
	Information Science	1612	0.54	1473	91.4	41043	0.53	25.5	13	1078	66.87	10078	0.52	6.3	2	0.72	52
	Social Services	2485	0.83	2289	92.1	54899	0.71	22.1	14	1753	70.54	13427	0.7	5.4	2	0.72	52
	Architecture and Urbanism	3802	1.27	3585	94.3	117129	1.52	30.8	18	2907	76.46	26995	1.4	7.1	3	0.71	51
	Administration	10818	3.6	10049	92.9	341280	4.42	31.5	16	8080	74.69	90489	4.7	8.4	3	0.71	50
	Law	5117	1.7	4635	90.6	122005	1.58	23.8	13	3554	69.45	31696	1.65	6.2	2	0.69	47
	Urban and Regional Planning	2021	0.67	1859	92.0	54622	0.71	27.0	13	1425	70.51	14352	0.75	7.1	2	0.69	47
	Industrial Design	1294	0.43	1179	91.1	23806	0.31	18.4	10.5	904	69.86	6654	0.35	5.1	2	0.65	42
	Tourism	207	0.07	152	73.4	1671	0.02	8.1	3	65	31.40	170	0.01	0.8	0	0.65	43
	Museology	936	0.31	893	95.4	24089	0.31	25.7	16.5	715	76.39	5840	0.3	6.2	3	0.61	37
Linguistics, Letters and Arts	Letters	8308	2.77	7596	91.4	238228	3.09	28.7	14	5669	68.24	57086	2.96	6.9	2	0.70	49
	Arts	4378	1.46	3983	91.0	101665	1.32	23.2	14	3124	71.36	23568	1.22	5.4	2	0.72	52
	Linguistics	2885	0.96	2623	90.9	70195	0.91	24.3	13	2015	69.84	28013	1.45	9.7	2	0.69	48
Multidisci -plinary	Biotechnology	3722	1.24	3376	90.7	94050	1.22	25.3	14	2486	66.79	19953	1.04	5.4	2	0.73	54
	Environmental Sciences	5128	1.71	4642	90.5	152676	1.98	29.8	13	3403	66.36	36526	1.9	7.1	2	0.72	52
	Teaching	7250	2.41	6580	90.8	190944	2.47	26.3	14	5163	71.21	45319	2.35	6.3	2	0.72	52
	Interdisciplinary	17987	5.99	16344	90.9	427492	5.54	23.8	13	12347	68.64	99143	5.15	5.5	2	0.72	52
	Materials	3101	1.03	2960	95.5	86781	1.12	28.0	18	2379	76.72	20213	1.05	6.5	3	0.68	46

Fields	Subfields	T	%	MC	%	TR	%	MR	MDR	CC	%	TC	%	AMC	MDC	*p*	R^2 (%)
General		300297	100	273526	91	7716033	100	25.6	14	210112	69.97	1925647	100	6.41	2	0.772	60

Total of papers (T); Mendeley coverage (MC); Total amount of Mendeley readers (TR); Average readers per paper (MR); Median readers per paper (MDR); Crossref Coverage (CC); Total amount of Crossref citations (TC); Average number of citations per paper Crossref (AMC); Median number of citations per paper Crossref (MDC); Spearman's correlation coefficient (p) between Mendeley readers (TR) X Crossref citations (TC); Coefficient of determination in percentage(R^2)Source: self-elaborated.

per paper. The field of Linguistics, Literature and Arts has the smallest number of published papers (5.57%) among the nine fields of knowledge analyzed, having approximately 91.08% of its documents covered by Mendeley and an average of 26.17 readers per document, although it is the field with the highest citation average (6.96) among the nine fields.

Bufrem and Nascimento[37] found the distribution of Brazilian scientific outputs in WoS among the fields of knowledge highlight the fields of Engineering, Agriculture and Chemistry to be the most representative. Regarding impact, the Clarivate Analytics report[38] reveals that the fields of Environment, Ecology, Psychiatry, Psychology, and Mathematics have citations in WoS close to the world average. However, the field of Linguistics, Letters and Arts is not among the analysis categories. These findings reinforce that some fields are uncovered in international databases, indicating a better perspective of analysis in databases such as Crossref and Mendeley.

The coverage of readers in Mendeley verified in other studies is quite close to those found in this research. In some cases, they are higher, reinforcing that the use of the tool in the Brazilian context may be relevant. Costas *et al.*[39] verified that Mendeley displays a coverage value between 60% and 80% of the scientific publications of WoS. Regarding the coverage of WoS publications by field of knowledge, Zahedi *et al.*[9] found that 93% of publications in the field of Life and Earth Sciences, 92% of Social Sciences and Humanities, and 77% of publications in the field of Mathematics and Computer Science had at least one reader in Mendeley.

Studying specifically Healthcare, Haustein and Larivière[8] analyzed Mendeley's coverage of indexed papers in PubMed published between 2010 and 2012 and covered by WoS. The authors found that Mendeley covered 65.9% of all papers. This number is notably lower than the coverage of the Health Sciences field identified in the present research, which followed the trend of the other fields and reached a coverage of 90.04%. In the Brazilian context, the coverage in Mendeley is higher and presents fewer differences among the fields of knowledge. This is probably more related to the characteristics of Brazilian scientific communication than specific characteristics of the different fields of knowledge.

Regarding the comparison between average readership and citations, we observed in the present study that they are quite close among the nine fields of knowledge (MR between 23.03 and 26.54 vs. MC between 5.61 and 6.96). Zahedi, Costas and Wouters,[33] with WoS, found: Mathematics and Computer Science (MR=7.52 vs. MC=8.0); Natural Sciences and Engineering (MR=8.21 vs. MC=15.16); Biomedical and Health Sciences (MR=13.60 vs. MC=20.18); Social Sciences and Humanities (MR=18.14 vs. MC=10.28); and Life and Earth Sciences (MR=18.64 vs. MC=17.63).

Thelwall and Sud[19] performed analyses of average readership in Mendeley and citation averages in Scopus. They used slightly more specific field categorization; nevertheless, some more generic fields can be mentioned by way of comparison: Agricultural and Biological Sciences (ML=3.5 vs. MC=5.2); Business, Management and Accounting (MR=3.4 vs. MC=1.8); Health (MR=4.1 vs. MC=4.3); and Social Sciences (MR=4.1 MC=3.8).

Although we have not found papers comparing medians for citations and readership, we highlight the work of Serghiou and Ioannidis[5] who, when studying citations in Crossref for preprints contained in bioRxiv in the period between 2013 and 2016, found a slightly higher median than the one found in this research (5); yet, the different context makes conclusive comparisons difficult.

These indicators identified are in line with international indicators and, in other fields, they are dissonant. The relative proximity of the citation data of Brazilian papers among the different fields, and the differences of these with the citations of the fields identified in other studies raise questions. One example is the possibility that a portion (26%) of the science produced by Brazil is published in restricted access journals,[40] whose publishers may not have joined the open citation movement, and their counts may be underestimated in some fields.

With regard to the correlation between readers and citations in the present research, we found that they are strong and close in all nine fields. They are highest in the areas of Agricultural Sciences and Biological Sciences (ρ=0.74) and the lowest in the field of Linguistics, Letters and Arts (ρ=0.70). The coefficients of determination are also very close across all fields (between 50% and 54% depending on area). Therefore, we found that there is great homogeneity between the indicators in the different fields.

Thelwall and Sud[19] analyzed several fields and perceived the correlation was, in average, moderate (ρ=0.62). The average found by the authors is smaller, but very close to the average found in our research. However, the correlations observed by us are more homogeneous than those found by the authors. To illustrate some differences and similarities, it is appropriate to mention that: in the field of Agronomy, the authors identified:

ρ=0.62 vs. ρ=0.73; Pharmacy: ρ=0.69 vs. ρ=0.77; Ecology: ρ=0.67 vs. ρ=0.73; Archeology: ρ=0.64 vs. ρ=0.73; Information Science: ρ=0.65 vs. ρ=0.72; Zoology ρ=0.54 vs. ρ=0.72 and; Demography: ρ=0.68 vs. ρ=0.78.

Haustein and Larivière,[8] when analyzing Health papers indexed in PubMed, found no strong correlations between citations and readership in Mendeley. They found two moderate correlations: in Biomedical Research (ρ=0.57) and Psychology (ρ=0.54); and two weak correlations: in Health (ρ=0.43) and Clinical Medicine (ρ=0.49). Also using PubMed Health data, Thelwall *et al.*[35] found correlations between citations and readers in Mendeley slightly higher (0.69).

Thelwall and Sud[19] noted the following correlations between Mendeley readers and Scopus citations: Agricultural and Biological Sciences (ρ=0.64); Business, Management and Accounting (ρ=0.62); Health (ρ=0.63); and Social Sciences (ρ=0.61). Using citation data from Crossref, but in a more specific context and with a different methodology, Nuredini and Peters[6] analyzed preprints in working paper format in the Economics and Business field, and they identified negative correlation between citation indicators and Altmeric score (-0.0157). Although the comparison is rather questionable, the correlations they presented are considerably lower than those found in this research.

The correlations between readers and citations in the Brazilian context are commonly higher than those found in other studies. Crossref data source may have greater citation coverage than commonly used databases (e.g., WoS and Scopus) for correlation studies between citations and Mendeley readers. The data indicate that, in the Brazilian context, Mendeley's reader/citation data may predict/explain citations (equally or more strongly than presented in other research). Among the coefficients of determination presented, we found that Mendeley's reader data explain citations between 50% and 54%, depending on the area.

Table 3 is ordered by field of knowledge and then, decreasingly, by the correlation between readers in Mendeley and citations in Crossref, by the respective subfields. The correlations between the subareas are between strong and moderate. Therefore, there are no subfields with weak, very weak, or very strong correlations. The medians of citations per paper do not present large variations (between 0 and 4 citations per paper), and the medians of readers/citations present moderate variation (with a few fields that differ, between 2 and 23). The data show that the subfields are, in general, homogeneous with regard to the dynamics of scientific communication.

The citations coverage in Crossref is generally high and there is a certain homogeneity, in the different subfields. However, some differences are evident. Regarding coverage in Mendeley (Table 3), there is also no proximity of coverage linked to the fields of knowledge, i.e., a strong homogeneity is observed regarding this indicator. The homogeneity and high level of coverage results of this research differ to some extent from that perceived in the research of Mohammadi *et al.*,[14] who verified the coverage of WoS papers in Mendeley, specifically analyzing papers from the Social Sciences and Humanities disciplines. The average number of readers in Mendeley per paper (Table 3), presents important discrepancies among subfields. There is no relationship between the subfields and the fields of knowledge, with homogeneity being observed as to the average number of readers in Mendeley per paper.

Regarding the averages of citation in Crossref per paper (Table 3), we noticed important differences among them and among the subfields. The subfields with higher or lower average citations are not related to a particular field of knowledge. The correlations between readers in Mendeley and citations in Crossref, among the subfields, vary from ρ=0.61 to ρ=0.84. This reinforces arguments that the particularities of different fields and subfields of knowledge should be carefully known so that the indicators, especially comparative ones, are not mistakenly used for evaluation and decision-making purposes in approximation; for example, research funding, distribution of scholarships etc. Santos *et al.*[41] emphasize that the dynamics of communication and scientific outputs among the subfields of knowledge present their own characteristics, whether from the point of view of bibliometric or altmetric indicators.

In Table 3, among the 68 subfields of the nine fields of knowledge: none has very strong correlation; 58 have strong correlations (0.70 to 0.84), representing 81% of the subfields; 10 have moderate correlations (0.61 to 0.69), representing 15%; none have weak or very weak correlations. Thus, it is clear that about 100% of them have moderate to strong correlations. Thus, it is clear that about 100% of them have moderate to strong correlations. This result is different from that found in other studies. In this, the results demonstrate that, in the Brazilian context, readings in Mendeley can strongly explain the citations received by the papers.

In Haustein and Larivière[8] study with 66 subfields divided among Psychology, Biomedical Research, Health and Clinical Medicine, none of the subfield obtained very strong or strong correlation, 59 (89%) of the subfield had moderate correlations, 6 (9%) weak correlation, 1 (2%) obtained very weak correlation. The subfield with the highest correlations were General Biomedical Research (ρ=0.689), Social Psychology (ρ=0.687) and Embryology (ρ=0.649). Those with lower correlations were Social Studies of Medicine (ρ=0.281), Veterinary Medicine (ρ=0.236), and Psychoanalysis (ρ=0.137).

Thelwall, *et al.*[42] found that the correlation between citations in Scopus and readers in Mendeley were low for the fields of Industrial and Manufacturing Engineering (ρ=0.32), Genetics (ρ=0.26), History (ρ=018), Electrochemistry (ρ=0.18), Sociology and Political Science (ρ=0.14), Computer Science (ρ=0.09), Condensed Materials Physics (ρ=0.15), and Geochemistry

and Petrology showed a negative correlation (ρ=-0.04), and Maternity and Occupational Therapy had no citations. The author emphasizes, for example, that low citation or lack thereof impacts correlations.

Unlike the cited research,[8,42] we noted strong correlations between readership in Mendeley and Citations in Crossref (across 89% of knowledge subfields). This result is in line with studies that have found that reader counts in Mendeley correlate more strongly with citations than altmetric indicators obtained by other data sources.[35] In this research, it is possible to state that in most subfields, the possibility exists to predict citations to a large extent. The coefficient of determination (R^2) data in Table 3 shows high percentages for the subfields, and it is possible to predict/explain between 37% and 71% of Crossref citations from Mendeley's reader data.

CONCLUSION

The results show that the coverage of Brazilian papers in Mendeley is high (87.9%). Even if the fields of knowledge present important differences among the percentages of papers published, the coverage in Mendeley among the fields is also high, i.e. these findings indicate that they are higher and heterogeneous than the international scenario. This indicates the potential for using these data to evaluate the research developed in the country.

Concerning the citation data from Crossref, 63% of Brazilian publications had citations in this tool. Coverage in Crossref among fields is generally high and without significant oscillations between them. The data, suggest that Crossref can provide important citation data for a more comprehensive evaluation of science developed in developing countries such as Brazil. This fact is supported mainly by the characteristics of Brazilian scientific outputs containing a predominance of open access publications, of national circulation, with much of it published in non-English language and therefore not indexed in international databases.

The correlation between readings in Mendeley and citations in Crossref of Brazilian production was considered strong (ρ=0,73), being in general higher and more homogeneous than that found in other studies conducted in the international scenario. The data indicate that, in the Brazilian context, Mendeley readership data can, in major fields, predict/explain citations.

In terms of subfields of knowledge, we found that, in general, they are homogeneous. Even so, there are significant differences between subfields of the same fields of knowledge, in relation to the number of papers, readers, citations, correlations and coverage levels. This reinforces arguments that the particularities of different fields of knowledge should be known and taken into account in decision-making.

This study has some limitations that can be highlighted. One of the limitations refers to the geographic scope of the study, which cannot be generalized to other countries, since the articles analyzed were published by Brazilian researchers (at least one of the authors). Although the number of papers analyzed is expressive, these are not all articles published by Brazilian researchers. Furthermore, a relatively high number of articles had no DOI, making it impossible to collect their data on the Sucupira platform. Therefore, it is recommended that similar studies be carried out with articles from other data sources, both Brazilian and from other countries whose scientific production is underrepresented in international commercial databases.

Another important limitation refers to the comparisons made between the previous literature and the research results. It is not possible to make a perfect comparison between the previous literature and the results of this research due to the great methodological variation of the works. Each methodological choice produces biases, and a perfect comparison between the findings is not possible.

Some examples of variations in research methods were: different data collection data and time period analyzed; variations in the correlation technique used (Pearson or Sperarman); different classifications of knowledge areas adopted by the research; diversity of types of publications considered in the analyses; data sources/databases used for selection of publications to be analyzed, etc.

Therefore, any indicator presented in this article carries methodological biases (as all the studies cited have their own). Therefore, the comparisons made between this research and other previous studies must be relativized, as the comparisons are limited by the methodological approaches adopted by each one. Despite this, the results suggest that the Crossref and Mendeley data may have advantages for the scientific evaluation of Brazilian outputs.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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