

Brazil's scientific production in mathematics: Contribution to mainstream science (2002-2011)

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ABSTRACT

This research aims to conduct a diachronic study of the scientific production in the mathematics area with the presence of Brazilian researchers, based on Scopus from 2002 to 2011, identifying its impact on the international scientific community. Moreover, the study highlights the major journals in mathematics where these publications were disseminated, the most productive Brazilian institutions in this set of scientific publications, the main Brazilian partner countries in mathematics studies and visualizes the international network of scientific collaboration in which the country participates. Totally 12,240 articles with Brazilian authors were collected in the studied period. For each year, the annual growth rate of Brazilian scientific production in the area was calculated. The Brazilian scientific collaboration network with its main collaborators was visualized using the software Ucinet. It was observed that the Brazilian scientific production in the area presented a positive annual growth rate in medium and long term. Brazil's mathematics research tends to have a significant impact and visibility internationally. The most productive Brazilian institutions have graduate programs and most are public universities. A significant part of Brazilian production in mathematics area was developed in international scientific collaboration.

Keywords: Bibliometric indicators, Brazilian scientific production, scientific collaboration, scientific production in mathematics

INTRODUCTION

Mathematics is an area of research with great international collaboration due to its peculiarities, such as language understood worldwide and little restriction in relation to material resources for carrying out researches, which are mostly theoretical.^[1]

In Brazil, scientific research in mathematics area has been consolidated and occupy significant presence internationally, especially in the last decade, as evidenced by the prominent position of the country in the International

Mathematical Union, through the participation of its researchers in various international decision making organs, and the marked presence of Brazilian mathematicians as guest lecturers in major international events in the area.^[2,3]

With continued strengthening in the country, the Brazilian scientific production in mathematics constitutes about 2% of the world's scientific literature in the area, taking the 16th position in production rankings, as seen in SCImago Journal and Country Rank portal, in the period from 1996 to 2011.^[4] As a result of this significant presence in mainstream science, the use of methodologies to identify, highlight and analyze their impact and integration into the international arena becomes a necessity in order to contribute to the visualization of its main actors, as well as provide insight to decision making that enable planning development strategies.

In the analysis and evaluation process of scientific literature, the bibliometric analysis provides an objective view of the performance and impact of a group of scientific researchers.^[5] Associated with qualitative analyzes,

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bibliometric studies subsidize discussions and evaluations regarding research relevance^[5] and constitute essential elements to identify producers of new knowledge, its scientific elite, front of research, current issues, among others, in different areas of knowledge, regionally, nationally, and internationally.

In light of the presented issues, this research aims to analyze the Brazilian scientific contribution in the mathematics area to the mainstream science, through articles published in journals indexed in Scopus in order to visualize its insertion and its impact on international area in the period from 2002 to 2011.

More specifically, this study proposes to conduct a diachronic analysis of researches in mathematics with the presence of Brazilian researchers in Scopus, in the period from 2002 to 2011, identifying the impact of these researches in the international scientific community through analysis of citations received, as well as highlight the major journals in the mathematics area that disseminated this knowledge, the most productive Brazilian institutions in this set of scientific publications, as well as identify key partner countries to Brazil in mathematics studies and visualize the international scientific collaboration network in which Brazil takes part.

This research is justified once bibliometric and scientometric studies have been continuously conducted to assess the scientific production of specific disciplines, its impact on the academic community and the development of Research and Development, surpassing the specific universe of Information Science, responsible for the creation of bibliometric indicators.

Furthermore, articles that assess the scientific production in mathematics in some countries are highlighted such as Braun,^[6] which examined the scientific production in mathematics in Croatia and the effects of war on it and Behrens and Luksch,^[7] who presented an important bibliometric study of mathematics in the period from 1868 to 2008 worldwide.

In this context, the need to assess the Brazilian scientific production in mathematics is reinforced, given the importance of mathematical studies that support the framework of different knowledge areas, contributing to the development of science as a whole, and the lack of studies that assess the scientific production in mathematics in Brazil.

MATHEMATICS SCIENTIFIC PRODUCTION: SCIENTOMETRIC INDICATORS

The international scientific literature in mathematics area has increased and can be described by an exponential growth model in the 19th century and the first half of the 20th century, except during the period of the two World Wars. After World War II, a linear model describes the annual growth of quantitative scientific publications. The increase in communities of mathematicians shows the same increasing behavior associated with the number of papers published each year.^[7]

In Brazil, despite the scarce studies that identify the growth model in the mathematics area, advances are observed in the databases regarding Brazilian research, taking the 16th position in the accumulated ranking of scientific production in the last decade, as observed on the portal SCImagoJR Country Rankings, with scientometric indicators of international indexed science in Scopus.

In this scenario, especially in Brazil, universities have a vital role in the growth of scientific production, particularly the graduate programs because of the scientific work produced there and the formation of new researchers.^[8] Brazil has a graduate system which contributes significantly to the socioeconomic development of the country and is a reference for all Latin America countries. According to the latest National Plan of Graduate Studies (2005-2010), in all areas of knowledge, graduate courses have shown a significant growth over the years, with a rising trend, observed by the data obtained from the number of courses and scientific production.^[9]

Moreover, an important factor is the importance given to publication in mainstream journals, as well as the internationalization of Brazilian journals, in the Brazilian graduate programs assessment, in the last decade, motivating the selection of international recognized journals by Brazilian researchers and search for greater inclusion of Brazilian journals in international databases such as Scopus.^[10] These facts combined result in the consolidation of Brazil in the international scientific scenario.

Due to the expansion in scientific production, it has become an object of research in many areas of scientific knowledge, given the need for studies to analyze, assess the new constituted knowledge, and evidence areas and issues, highlight institutions as well as their needs among other characteristics, once this information contributes to

visualize the science state of development - a structural dimension of the social development of a country - and provide indicators that make it possible to evaluate and rethink goals and needs, informing decision making that enable the redesign for growth strategies.

In this context, scientometric indicators based on disseminated scientific production in international databases such as Scopus, have proven adequate for analyzing production in Science and Technology (S and T). In this research, this database was used because it is the largest multidisciplinary references database with the largest number of journals indexed in non-English language, which allows better visualization of Brazilian science, and it is also internationally visible.

In this research, bibliometric indicators of production, citation and scientific collaboration were used for identification, visualization, and better understanding of the current scenario of Brazilian scientific production in mathematics indexed in Scopus.

The production of a researcher, institution or country on a specific theme, subject or area of knowledge can be measured by the number of research papers published in a given period of time. Indicators based on the production of authors contribute to evidence, among other characteristics, researchers, institutions, themes, journals, countries in evidence in a scientific community, enabling the identification of their producers and respective scientific elite. When working with production indicators, papers have become the most popular basic unit for bibliometric analysis once they present original research results, are submitted by a review system based on evaluation rules, and compose broad access literature.

Among the relative production indicators, the annual growth rate shows the time evolution of scientific production variation tendencies of an institution, country or area. This rate is obtained by the difference between the current year's production and the previous year's divided by the previous year's production.^[10] Therefore, the annual growth rate is calculated as:

$$T_c(X_t) = \frac{X_t - X_{t-1}}{X_{t-1}} * 100$$

where $T_c(X)$ is the scientific production growth rate in the year t ; X_t is the scientific production in the year t ; X_{t-1} is the scientific production in the year $t-1$, that is, in the previous year.

The citation indicators show the scientific literature impact, the influence and visibility of an author, institution, journal or country within their scientific community and are the most recognized means of assigning credit to an author. Among the citation indicators used for evaluating a researcher, institution, journal or country, the number of citations per paper (average citations) is emphasized.

The scientific collaboration analysis contributes to the understanding of a complex social phenomenon which is characteristic of contemporary scientific research (Glänzel and Schubert, 2004).^[11] Collaboration leverages the scientific production of authors, institutions or countries once they join efforts to promote a network of collaborators and provide better researching conditions for the group involved, offering support, exchange, information, and resource sharing. It also contributes to expand possibilities of approaches and instruments to meet the proposed objective.^[12]

According to Glänzel and Schubert (2004),^[11] co-authorship is an objective and well-documented type of scientific collaboration, and co-authorship bibliometric indicators enable reliable analysis of almost all aspects of scientific collaboration networks. Glänzel^[13] considers that for studies on collaborative analysis at the macro level, such as those among countries, scientific collaboration is well portrayed by co-authorships of published papers.

These indicators are used as indirect measures of scientific research activity and contribute to the understanding of the research objectives, the scientific community structure, the particular research objective or its social, political, and economic impact.^[14]

METHODOLOGICAL PROCEDURES

The collection of articles was conducted in Scopus, in October 2012, using the following terms on "Advanced search": "SUBJAREA (MATH) AND AFFILCOUNTRY (BRASIL OR BRAZIL) AND PUBYEAR > 2001 AND PUBYEAR < 2012 AND DOCTYPE (AR)" in order to retrieve all articles in mathematics area, with at least one author with Brazilian affiliation, published from 2002 to 2011. As a result of the search, 12,240 articles were retrieved.

This study considered the largest institutions producing researches in mathematics: Those responsible for more than 1.5% of published articles. This criterion is justified because there is a wide dispersion of production below this number,

that is, many institutions responsible for a very low number of articles, considered unrepresentative of the scientific elite in the area in Brazil. Based on the same rationale, the threshold of 1.5% of production was also used to analyze the variables: Journal and collaborator country.

For the diachronic analysis of Brazilian publication in mathematics during the studied period, the total number of publications was also searched in Scopus database using the search expression mentioned above, removing the term related to Brazilian affiliation in order to obtain the relative presence of Brazilian production, year by year, in the period. For each year, the annual growth rate of Brazilian scientific production in the area was also calculated. Furthermore, the total number of citations received by articles with Brazilian authors was obtained, per year. From this data, it was possible to calculate the mean number of citations per article per year.

In order to obtain the visualization of scientific collaboration network in Brazil with the main collaborators, a 12×12 country symmetric matrix with the co-authorship frequency among these countries was built. The network of international scientific collaboration in mathematics, in which Brazil participates, was generated using Ucinet for Windows: Software for Social Network Analysis. Harvard, MA, USA: Analytic Technologies..

RESULTS PRESENTATION AND ANALYSIS

Table 1 shows the diachronic distribution of production and citation indicators of articles published in the field of mathematics with the presence of Brazilian authors in the period from 2002 to 2011. It is observed that, except in 2005, the annual growth rate is always positive, more significantly in 2004, 2008 and 2009 and other years, not as significant such as in 2010, 2007, and 2011. In the accumulated period, Brazilian scientific production in the area of mathematics more than doubled presenting accumulated growth rate of 104.9%.

However, despite this growth, it is observed that the Brazilian participation in the area, as measured by the percentage of the production [Table 1, third indicator] remained around 2% throughout the period, slightly above this percentage in the 1st year and below this percentage at the end of the period. It is highlighted that 2004 was the one presenting the highest annual growth rate (35.4%), placing Brazil that year as responsible for approximately 2.3% of the international scientific production in mathematics, indexed in Scopus.

Some hypotheses can be raised to explain the increase of Brazilian research internationalization: (1) Greater access to mainstream science, leveraged by the use of the Brazil's journal portal, made available from November 2000 and currently consolidated as one of the largest virtual libraries in the world, providing vital content for Brazilian research, ensuring density to Brazilian science; (2) greater inclusion of Brazilian scientific production in internationally indexed journals; (3) greater inclusion and openness to Brazilian journals by mainstream science, which are now indexed in greater numbers, motivated by Brazilian assessment criteria of graduate courses, which has strongly valued the scientific production disseminated in journals with higher impact factors, measured by international databases.^[15]

Regarding citations, a decreasing trend was observed in the period: The most cited articles were published in 2002 and 2003, with an average of 11.6 and 8.6 citations per paper, respectively, whereas in recent years - 2009, 2010, and 2011 - the articles received fewer than five citations on average. This behavior indicates the period of time that Brazilian production takes to be assimilated and incorporated by the scientific by mainstream science.

Table 2 shows the six major journals where the Brazilian scientific production has been disseminated - responsible for 3,195 (26.1%) of the 12,240 articles published in the period. It is observed that none of these journals is Brazilian, four are European and three are North American, indicating that the Brazilian scientific production in mainstream science has been disseminated primarily in foreign journals. It should be added that, based on a search carried out in SCImagoJR portal, out of 878 journals

Table 1: Diachronic distribution of Brazilian articles in mathematics, annual growth rate, production percentage, and total of citations

Year	No. of articles	Annual growth rate	% production in the field	Citations	Average of citation per article
2002	843	-	2.2	9804	11.6
2003	939	11.4	2.0	8030	8.6
2004	1271	35.4	2.3	8700	6.8
2005	929	-26.9	2.0	7741	8.3
2006	1060	14.1	2.0	7937	7.5
2007	1121	5.8	1.9	7934	7.1
2008	1336	19.2	1.9	7581	5.7
2009	1590	19.0	1.8	6083	3.8
2010	1604	0.9	1.9	3906	2.4
2011	1727	7.7	1.9	1719	1.0
Total	12,420	104.9	2.0	69,435	5.6

classified in the area of mathematics by Scopus, only 3 (0.3%) of them are Brazilian and have been indexed in this database more recently, one in 2008, another in 2010 and the third one in 2011.

It is noted that, except from the Journal of Mathematical: Analysis and applications, rated only in the field of mathematics, the other five journals have interdisciplinary nature, four of them particularly in physics, mathematics and statistics and the other between mathematics and computer science, indicating the interface area with several other areas of knowledge. It is highlighted that, except for periodic *Physica A: Statistical Mechanics and its applications* and lecture notes in computer science, the other four journals are in the first quartile of the journals ranking according to 2011 SCImagoJR rank, indicating that the Brazilian scientific production in the field of mathematics has been inserted into high visibility channels in the area.

Table 3 presents the 21 most productive Brazilian institutions in the area from 2002 to 2011. Initially, it is emphasized that all institutions most productive have graduate programs, and almost all (18) of them have graduate programs in mathematics, one has a specific program in subarea statistics (Universidade de Brasília), another in the specific area of physics (Centro Brasileiro de Pesquisas Físicas [CBPF]) and another in the subarea Computer Science (Universidade do Estado do Rio de Janeiro), in accordance with Witter^[8] and Brazil^[9] that scientific production is strongly associated with graduate courses in Brazil. Moreover, the areas in which these graduate programs perform explain the choice for major journals for the dissemination of new knowledge produced.

It is highlighted that the graduate programs from University of São Paulo (USP), Universidade Estadual de Campinas (UNICAMP), Universidade Federal do Rio de Janeiro (UFRJ), Instituto Nacional de Matemática Pura e Aplicada (IMPA) and Universidade Federal de Minas Gerais (UFMG) have equivalent performance in comparison with international centers of excellence, have a highly differentiated level of performance and national leadership compared to other programs in the area, according to Brazilian coordination for the improvement of higher level personnel.

It is also observed that only three institutions are not universities - IMPA, CBPF and Laboratório Nacional de Computação Científica - being, however, public institutions

Table 2: Major journals with Brazilian presence (2002-2011)

Journal (country)	No. of articles	Percentage
Physical Review E-Statistical, Nonlinear, and Soft Matter Physics (USA)	915	7.5
Physical A: Statistical Mechanics and its Applications (Netherlands)	620	5.1
Physical Review D: Particles, Fields, Gravitation and Cosmology (USA)	568	4.6
Lecture Notes in Computer Science (Germany)	497	4.1
Journal of Physics A: Mathematical and Theoretical (United Kingdom)	396*	3.2
Journal of Mathematical: Analysis and Applications (USA)	199	1.6

*The total of articles include the articles from journal of physics A: Mathematical and general, formerly named journal of physics A: Mathematical and theoretical

Table 3: Most productive Brazilian institutions in mathematics (2002-2011)

Institution (abbreviation)	No. of articles	Percentage
Universidade de São Paulo (USP)	2759	22.5
Universidade Estadual de Campinas (UNICAMP)	1329	10.9
Universidade Federal do Rio de Janeiro (UFRJ)	1182	9.7
Universidade Estadual Paulista (UNESP)	714	5.8
Instituto Nacional de Matemática Pura e Aplicada (IMPA)	631	5.2
Universidade Federal de Minas Gerais (UFMG)	613	5.0
Universidade Federal de Pernambuco (UFPE)	534	4.4
Universidade Federal do Rio Grande do Sul (UFRGS)	500	4.1
Universidade Federal Fluminense (UFF)	488	4.0
Universidade de Brasília (UnB)	482	3.9
Centro Brasileiro de Pesquisas Físicas (CBPF)	404	3.1
Universidade Federal do Ceara (UFC)	375	3.1
Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio)	342	2.8
Universidade Federal de São Carlos (UFSCAR)	320	2.6
Universidade Federal da Paraíba (UFPB)	303	2.5
Universidade Federal de Santa Catarina (UFSC)	300	2.5
Universidade do Estado do Rio de Janeiro (UERJ)	289	2.4
Universidade Estadual de Maringá (UEM)	288	2.4
Universidade Federal do Paraná (UFPR)	275	2.2
Laboratório Nacional de Computação Científica (LNCC)	244	2.0
Universidade Federal do Rio Grande do Norte (UFRN)	197	1.6

of national reference in the field of Mathematics, Physics and Computer Science. In addition, researchers at the National Institute of Pure and Applied Mathematics (IMPA) have received several international awards in recognition of relevance in developed research, among them Srinivasa Ramanujan prize, created by the International Center for Theoretical Physics, Trieste science prize and Balzan prize for exact sciences.

It is also noteworthy that, except from Pontifícia Universidade Católica do Rio de Janeiro, a private nonprofit Catholic university, the most productive institutions are public: 15 federal institutions and five state ones from the southeast region of the country (three from São Paulo state, one from Rio de Janeiro state and one from Paraná state). São Paulo state is responsible for over 50% of the investment in S and T in Brazil and according to a report by United Nations Educational, Scientific, and Cultural Organization related to science in 2010, 60% of all Brazilian papers are from 7 universities in the country, four of them from São Paulo state.^[16] In this sense, it is also noted that The Times Higher Education World University Rankings, 2012-2013 edition, only two Brazilian universities from São Paulo are ranked: USP (158th) and UNICAMP (251-275^o). Furthermore, in the Academic Ranking of World Universities (ARWU), 2012 edition, six Brazilian universities are ranked: USP (101-150), UNICAMP (201-300), UFMG, UFRJ, UNESP (301-400) and UFRGS (401-500), three of them are from São Paulo (USP, UNICAMP and UNESP).

Among the mentioned reasons for the outstanding performance of the three São Paulo public universities, there is another significant reason: Sponsorship by São Paulo Research Foundation (Fundação de Amparo à Pesquisa do Estado de São Paulo), through grants and scholarships. This foundation has achieved an international reputation and made agreements with research councils in several countries, including Holland, France, USA, Canada, Germany, and the UK.^[16]

University of São Paulo is the largest producer of scientific papers in mathematics, with a significant percentage (22.5%) of articles, equivalent to more than the sum of the two following universities: UNICAMP and UFRJ. USP is the oldest university in Brazil, it is on the top of Latin-American rank in Times Higher Education World University Rankings-158th position^[16] and is the only Brazilian university ranked among the top 150 institutions, in mathematics, by ARWU.

Table 4 presents the 11 (13%) main countries cooperating with Brazil in mathematics scientific production, among the 85 countries that published co-authored research from 2002 to 2011. It is noteworthy that out of the 12,240 analyzed articles, 7,476 were authored solely by Brazilian and 4,764 (38.9%) were published by Brazilian authorship with at least one foreign author, thus indicating that a very significant part of Brazilian production in the area has been developed internationally.

It is observed that, except from Chile, Portugal and Argentina, major collaborating countries to Brazil are among the top 10 producers in the area of mathematics in Scopus, especially the United States, ranking first place, as seen in SCImagoJR portal with scientometric indicators from Scopus. The United States was the main Brazilian collaborator, participating in approximately 10% of total Brazilian production. The Brazilian collaboration with Latin American countries (Argentina and Chile) and the partnership with Portugal, Portuguese-speaking country are also observed. Out of the 11 major partners of Brazil in mathematics: Seven are European, two are North Americans and two are South Americans.

In order to better visualize, the scientific collaboration network in which Brazil participates, as shown in Figure 1. Being an egocentric network, it has only one component and is a fully connected network (100% density), featuring an intense scientific collaboration among all studied countries. Due to the numbers shown in Table 4, the stronger ties between Brazil are the following countries: USA, France, Germany, United Kingdom and Spain.

This collaboration network also shows significant ties between USA and France and between Germany and USA.

Table 4: Major Brazilian collaborators in mathematics (2002-2011)

Countries	No. of articles	Percentage
United states	1240	10.1
France	811	6.6
Germany	472	3.9
United kingdom	447	3.7
Spain	439	3.6
Italy	410	3.3
Chile	293	2.4
Russian federation	288	2.4
Canada	286	2.3
Portugal	263	2.1
Argentina	217	1.8

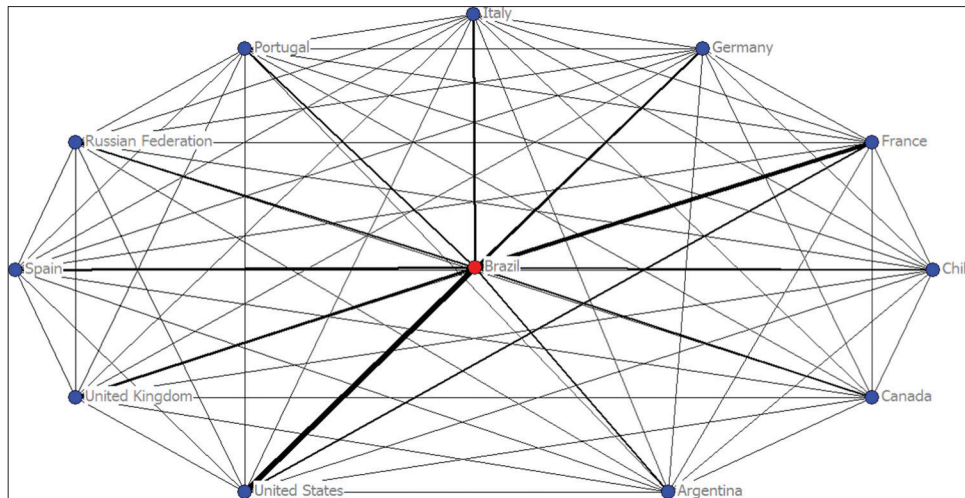


Figure 1: Scientific collaboration network among Brazil and the main countries (2002-2011)

FINAL CONSIDERATIONS

This research proposed to analyze the contribution of Brazilian scientific production in Mathematics for mainstream science, through articles published in journals indexed in Scopus database, in the period from 2002 to 2011. It was possible to observe that the amount of Brazilian scientific production in Mathematics has more than doubled, showing, in general, a positive annual growth rate. In terms of percentage of total production in mathematics, Brazilian participation in the area remained approximately constant, around 2% throughout the period. Regarding the impact of Brazilian scientific production in the area, it was observed that the articles published in the first 2 years of the period, on average, were cited 4-10 times more than those published in the last 2 years of the period.

It was observed that the main six journals that disseminate Brazilian scientific production in mathematics, accounting for a quarter of the analyzed articles - are foreigners, mostly Europeans. Still, except from a journal, exclusively in the area of mathematics, the journals present interdisciplinary nature, particularly among physics, mathematics, statistics and computer science, indicating that Brazilian science in mathematics has an important interface with other areas of knowledge. Most of these journals are in the first quartile of the ranking of journals in mathematics, which suggests that the Brazilian scientific production has been inserted into channels of great international visibility in the area.

Regarding the most productive Brazilian institutions in the area in the period from 2002 to 2011, all of them have graduate programs, and almost all in mathematics and some of them are considered, depending on their scientific

work, equivalent to international centers of excellence, with a highly differentiated level of performance and national leadership according to Brazilian assessment system. The most productive institutions are public universities.

It was also noted that a very significant part of Brazilian production in the area of Mathematics has been developed in international scientific collaboration with 11 countries considered as major Brazilian contributors in the area. Most of these countries are among the top 10 producers in mathematics in Scopus database, especially the United States, ranking first place, as seen in the SCImagoJR portal. There was also a significant Brazilian collaboration with two Latin American countries and Portugal, which has the same official language of Brazil.

Finally, it is considered that the results presented in this study, although limited by the period of the ten most recent years, contribute to visualize the Brazilian performance in the area of mathematics in mainstream science, allowing to highlight the major institutions working in the area, the main formal channels of scientific production dissemination in Brazil, as well as the countries that contribute the most to Brazilian mathematics, indicators that support the national science policy for the area. It is also important to emphasize the fundamental role of bibliometric indicators for the assessment of science by providing data for assessing its results and for planning scientific policies, since they are indirect measures of scientific research activity that contribute to better understanding its dynamic behavior, the structure of the scientific community, its goals and its social, political, and economic impact.

As a recommendation, policies that promote scientific and academic researchers to publish in journals indexed in international databases in order to internationalize Brazilian science are strongly suggested.

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