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A evolução da pesquisa do Selênio e Mercúrio de 1700 a 2017 baseada na análise bibliométrica

The evolution of Selenium and Mercury research from 1700 to 2017 based on bibliometric analysis

La evolución de la investigación de Selenio y Mercurio de 1700 a 2017 basada en el análisis bibliométrica

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Pablo Andrei Nogara
ORCID: https://orcid.org/0000-0002-9133-6102
Universidade Federal de Santa Maria, Brazil
E-mail: pbnogara@gmail.com
Gabriela Luisa Schmitz
ORCID: https://orcid.org/0000-0003-2354-496X
Universidade Federal de Santa Maria, Brazil
E-mail: gabrielaluisas@gmail.com
Nayara de Souza da Costa
ORCID: https://orcid.org/0000-0001-6134-9458
Faculdades Pequeno Príncipe, Brazil
E-mail: costasouzanayra@gmail.com
Jean Paul Kamdem
ORCID: https://orcid.org/0000-0003-1730-8602
Universidade Regional do Cariri, Brazil
E-mail: kamdemjeanpaul2005@yahoo.fr
João Batista Teixeira da Rocha
ORCID: https://orcid.org/0000-0003-3829-0595
Universidade Federal de Santa Maria, Brazil
E-mail: jbtrocha@yahoo.com.br
Cláudia Sirlene Oliveira
ORCID: https://orcid.org/0000-0002-2004-5316
Faculdades Pequeno Príncipe, Brazil
E-mail: claudia.bioquimica@yahoo.com.br

Resumo

Selênio e Mercúrio são dois elementos químicos estudados em vários campos do conhecimento devido às suas propriedades e interações químicas. O objetivo deste estudo foi analisar a evolução da atividade de pesquisa de 1700 a 2017 sobre a tendência global desses elementos, realizamos uma análise bibliométrica usando o banco de dados Scopus. Para cada palavra-chave acessada ("selênio", "seleneto", "selenito", "selenato", "organosselênio", "mercúrio", "mercúrio inorgânico", "vapor de mercúrio" e "metilmercúrio"), analisamos o resultado da publicação, e as 5 principais distribuições geográficas de publicações e autores contribuintes, bem como as 5 principais categorias de assuntos do Scopus em que os documentos são indexados. Os resultados demonstraram um aumento no número de publicações ao longo do tempo para todas as palavras-chave. Pesquisas sobre selênio e suas formas químicas inorgânicas e orgânicas e Mercúrio e suas formas químicas inorgânicas e orgânicas foram descritas em aproximadamente 117.000 e 164.000 documentos, respectivamente. Os Estados Unidos foram o país com o maior número de documentos publicados em todas as palavras-chave analisadas. Química, Medicina e Ciência Ambiental foram as categorias de assunto com o maior número de documentos. Pesquisadores dos Estados Unidos, China, Japão, Eslovênia e Brasil estavam no ranking dos autores mais produtivos. Para nosso conhecimento, este é o primeiro estudo bibliométrico sobre Selênio e Mercúrio e pode ser útil para identificar grupos de pesquisa em potencial para colaborações científicas.

Palavras-chave: Mercúrio; Selênio; Produção científica.

Abstract

Selenium and Mercury are two chemical elements studied in several fields of knowledge due to their chemical properties and interactions. The aim of this study was to analyze the evolution of research activity from 1700 to 2017 on the global trend of these elements, we carried out a bibliometric analysis using the Scopus database. For each keyword accessed (“selenium”, “selenide”, “selenite”, “selenate”, “organoselenium”, “mercury”, “inorganic mercury”, “mercury vapor” and “methylmercury”), we analyzed the publication output, and the top 5 geographic distribution of publications and contributing authors, as well as the top 5 Scopus subject categories where the documents are indexed. The results demonstrated an increase in the number of publication over time for all the keywords. Research about Selenium and its inorganic and organic chemical forms, and Mercury and its inorganic and organic chemical forms were described in approximately 117,000 and 164,000 documents,

respectively. United States was the country with the highest number of published documents in all the keywords analyzed. Chemistry, Medicine and Environmental Science were the subject categories with the highest number of documents. Researchers from the United States, China, Japan, Slovenia, and Brazil were in the ranking of the most productive authors. To our knowledge, this is the first bibliometric study on Selenium and Mercury and can be useful to identify potential research groups for scientific collaborations.

Keywords: Mercury; Selenium; Scientific production.

Resumen:

El selenio y el mercurio son dos elementos químicos estudiados en varios campos del conocimiento debido a sus propiedades químicas e interacciones.
El objetivo de este estudio fue analizar la evolución de la actividad de investigación desde 1700 hasta 2017 sobre la tendencia global de estos elementos, llevamos a cabo un análisis bibliométrico utilizando la base de datos Scopus. Para cada palabra clave a la que se accedió ("selenio", "seleniuro", "selenito", "selenato", "organoselenio", "mercurio", "mercurio inorgánico", "vapor de mercurio" y "metilmercurio"), analizamos el resultado de la publicación, y las 5 principales distribuciones geográficas de publicaciones y autores contribuyentes, así como las 5 principales categorías de temas de Scopus donde se indexan los documentos. Los resultados demostraron un aumento en el número de publicaciones a lo largo del tiempo para todas las palabras clave. La investigación sobre el selenio y sus formas químicas inorgánicas y orgánicas, y el mercurio y sus formas químicas inorgánicas y orgánicas se describieron en aproximadamente 117,000 y 164,000 documentos, respectivamente. Estados Unidos fue el país con el mayor número de documentos publicados en todas las palabras clave analizadas. La química, la medicina y la ciencia ambiental fueron las categorías temáticas con el mayor número de documentos. Los investigadores de los Estados Unidos, China, Japón, Eslovenia y Brasil estaban en el ranking de los autores más productivos. Hasta donde sabemos, este es el primer estudio bibliométrico sobre selenio y mercurio y puede ser útil para identificar posibles grupos de investigación para colaboraciones científicas.

Palabras clave: Mercurio; Selenio; Producción científica.

1. Introduction

Selenium (Se) is a trace element that was discovered in 1817 by Jöns Jacob Berzelius

Rocha et al. (2017a). It is classified on the Periodical Table as a non-metal and belongs to the chalcogens group, with the atomic number of 34. There are two forms of Se: the inorganic selenium that includes selenide (Se^{2-}), selenite (Se^{4+}) and selenate (Se^{6+}) (Sarquis & Mickey, 1980), and the organic selenium, known as organoselenium compounds, that contain selenide (R_2Se) and/or selenol (RSeH) groups (Nogueira et al., 2004; Oliveira et al., 2017; Rocha et al., 2017a). Biologically, Se is found in selenoproteins as the amino acid selenocysteine (Oliveira et al., 2017; Rocha et al., 2017a, 2017b), and plays an essential role in health, development and cancer prevention (Hatfield et al., 2014). Of particular importance, Se has been reported to play a critical role in several neurodegenerative disorders due to its antioxidant activity and its ability to modulate mitochondrial function (Cardoso et al., 2017). The production of Se occurs during sulfuric acid production, via the extraction of selenide from the sulfide ores, generally of Iron, Copper, and Lead. Se can also be produced by some sulfuric acid plants (Sarquis & Mickey, 1980). Moreover, Se possesses several applications, for instance, in the glass production, as a catalyst of chemical reactions, and in the pharmaceutic industry (Rosenfeld & Beath, 1964; Oldfield, 1998).

In contrast to Se, Mercury (Hg) is a transition metal known to be one of the major environmental pollutants (Bjorklnd et al., 2017; Oliveira et al., 2017,2018). Inorganic Hg can be found in three oxidation states (Hg^0, Hg^+, Hg^{2+}), while organic Hg can be obtained by methylation of its inorganic form (e.g., methylmercury) by microorganisms. Hg^0, also known as Hg vapor, has a unique characteristic, in the sense that it is found in a liquid state at room temperature (Menzies, 1919; Iano et al., 2008).

Hg was widely used in the artisanal mining of gold and silver once it can form amalgams with these metals (Conteras, 1999; Malehase et al., 2017). In industries, Hg is used as a catalyst for chemical reactions such as synthesis of acetic acid and derivatives, vinyl chloride and chlor-alkali (Yasuda et al., 2004). In addition, Hg is used as antiseptic and conservative of medicines (for instance vaccines) (Baker, 2008) and in the production of fluorescent lamps and laboratory instruments, such as thermometers, electrodes, and barometers (Horowitz et al., 2014). There are reports of Hg uses since ancient China (Clarkson et al., 2007; Oliveira et al., 2017). However, to our knowledge the first scientific document published with the word mercury (registered in the Scopus database) was in 1798, describing the use of Hg in a barometer (Keith, 1798). Human exposure to all forms of Hg has been found to cause neurological disturbances, cerebral palsy, impairment in vision, walking, speech, among others (Park & Zheng, 2012; Dos Santos et al., 2016; Gao et al., 2017; Oliveira et al., 2017,2018).

In the past decades, the number of published papers related to organic and inorganic forms of both selenium and mercury has dramatically increased. Particularly, selenium compounds have emerged as therapeutic candidates not only against mercury toxicity (Glaser et al., 2013; Gajdosechova et al., 2018) but also against cancer (Rocha et al., 2017b). Currently, in the scientific literature, the vast amount of information about selenium and mercury are related to their chemical forms, toxicology or pharmacology effects, as well as their industrial application.

Brazilian publications in indexed Journals are increasing as a result of personnel qualification, collaborative relationships, improvement of the infrastructure, investment of the public sector, increasing in the number of Brazilian PhDs and masters, and the addition of Brazilian Journals in the databases (Coura & Willocox, 2003; Regalado, 2010; Leta, 2012; Leta et al., 2013; Santin et al., 2016). According to Vasconcelos et al. (2015), the universities have a central role in fostering of research, and the Brazilian universities and governmental funding agencies are collaborating on this way. In a period of 20 years (1991–2011), Brazil moved from the 23rd to the 13th position in the world ranking of publications and is the country with the highest number of publications in Latin America. However, these publications still present a modest citation impact (Leta et al., 2013). From 1997 to 2017, the Brazilian publications with the word “mercury” were practically the same, 2.7%–2.8% of the total world publication, transferring Brazil from the 13th to 12th position in the ranking of publications by country. On the other hand, publications with the word “selenium” increased from 0.4% to 3.7% of the total world publication, transferring Brazil from 34rd to the 10th position (data from Scopus). These observations indicate the importance of the research about these elements, both in national and international levels.

To our knowledge there is no bibliometric study related with those chemical elements. Thus, this study can be of utmost importance for the researchers working in these areas taking into account the fact that it portrays the global trend of these elements and their scientific production. Bibliometric tools are used to investigate research trends in a specific research field (Cao et al., 2012; Canas-Guerrero et al., 2013) and the scientific outputs of researchers (Kamdem et al., 2016, 2017), countries, journals, and institutions (Abramo et al., 2011). For instance, recently, Kamdem et al. (2018) used bibliometrics tool to compare the scientific productivity of Brazilian researchers from different fields in Biomedical Sciences and highlighted the need for objective bibliometric parameters that can be considered in grant allocation.

Although there are some important studies analyzing the scientific production related

to chemical elements (Schummer, 1997; Magnone, 2012), for example, the study performed by Schummer (1997) where the author analyzed the growth in the publication of chemical substances during the period of 1800 to 1995. Considering the lack of information on the trend of selenium and mercury in scientific literature, the present study was designed to quantitatively and qualitatively investigate research trends on Se and Hg within the past decades using Scopus database in order to reveal the well performing countries, the Scopus subject categories where they are indexed and the most contributing authors.

2. Materials and methods

2.1 Data source

The data were collected from May to June 2017 using Scopus database which is one of the widely used databases that covers chemistry, health and life science, environmental science among other areas (Jacso, 2005; Leydesdorff et al. 2015).

2.2. Search strategies

For bibliometric analysis, “selenium”, “selenide”, “selenite”, “selenate”, “organoselenium”, “mercury”, “inorganic mercury”, “mercury vapor” and “methylmercury” were used as keywords to search all documents (articles, reviews, and book chapters) available since 1700 to 2017, that containing these words in the abstract, keyword list and/or title. It should be stressed that each keyword was entered individually for data collection. Moreover, the Boolean “and” was used to search the documents that containing selenium and mercury.

2.3. Data collection

The following information was manually collected for each keyword: publication output per decade, total number of published documents, year of the first indexed document, year with the highest number of indexed documents, top 5 contributing countries, top 5 Scopus subject categories where the documents were indexed, top 5 authors that have the highest number of indexed documents and their citations. The top 5 contributing countries, Scopus subject categories where the documents were indexed, and authors that have the highest number of indexed documents and their citations were chosen because they represent more than 50 %of the published documents.

3. Results and discussion

3.1 Published documents related to Selenium, Mercury and their inorganic and organic forms

Different chemical forms of selenium (Se) and mercury (Hg) have been tested for their pharmacological and toxicological activities in various models, and used as catalysts for the synthesis of new compounds (Yasuda et al. 2004; Clarkson et al. 2007; Rocha & Nogueira 2010; Bjorklund et al. 2017; Oliveira et al. 2017). Table 1 shows that since the first publication of a document with the word "selenium" in 1818, almost 82,000 documents have been published, with the highest number of publications in 2015 (5%). However, studies with the inorganic forms of selenium began almost five decades later with the maximum number of publications in 2013 for selenide (5%), 2014 for selenite (4%) and 2012 for selenite (4%). The organic form of selenium, organoselenium, emerged in 1939 as promising pharmaceutical agents (Nogueira & Rocha, 2011), and steadily increased to reach its maximum number of documents in 2011, with 6% of its total documents (Table 1). On the other hand, the first scientific document with the word "mercury" found in Scopus database was published in 1798, 19 years before the discovery of Se (Table 1). The highest number of documents published with the word "mercury" was in 2016, representing 4% of the total indexed documents (Table 1). This finding indicates that mercury poisoning still emerged in the past years. In this context, Ori et al. (2018) recently reported mercury poisoning in a toddler from home contamination due to skin-lightening cream. Although the first indexed paper with the organic form of mercury (i.e., methylmercury) is relatively recent (1960) in comparison to its inorganic forms, inorganic mercury (1923) and mercury vapor (1873), the number of documents with methylmercury was higher than that of others, with the highest number of indexed documents in 2012 (4%) (Table 1). It also can be noted that the first documents related to the organic forms of both selenium (organoselenium, 1939) and mercury (methylmercury, 1960) were published more than a hundred years after the first selenium (1818) and mercury (1798) publication (Table 1).

Table 1 - Total number of published documents from 1700 to 2017, year of the first publication and year with the highest number of publications. In parenthesis is highlighting the percentage of publication in relation to the total number of published documents.

	Total number	**Year of the**	**Year with the**

	of published documents	first publication	highest number of publications
Selenium	81,903	1818	2015 (5%)
Selenide	17,619	1885	2013 (5%)
Selenite	9,299	1866	2014 (4%)
Selenate	3,928	1877	2012 (4%)
Organoselenium	3,445	1939	2011 (6%)
Mercury	145,901	1798	2016 (4%)
Inorganic mercury	2,572	1923	2015 (3%)
Mercury vapor	4,633	1873	2004 (3%)
Methylmercury	10,489	1960	2012 (4%)
Selenium and Mercury	4,965	1913	2015 (5%)

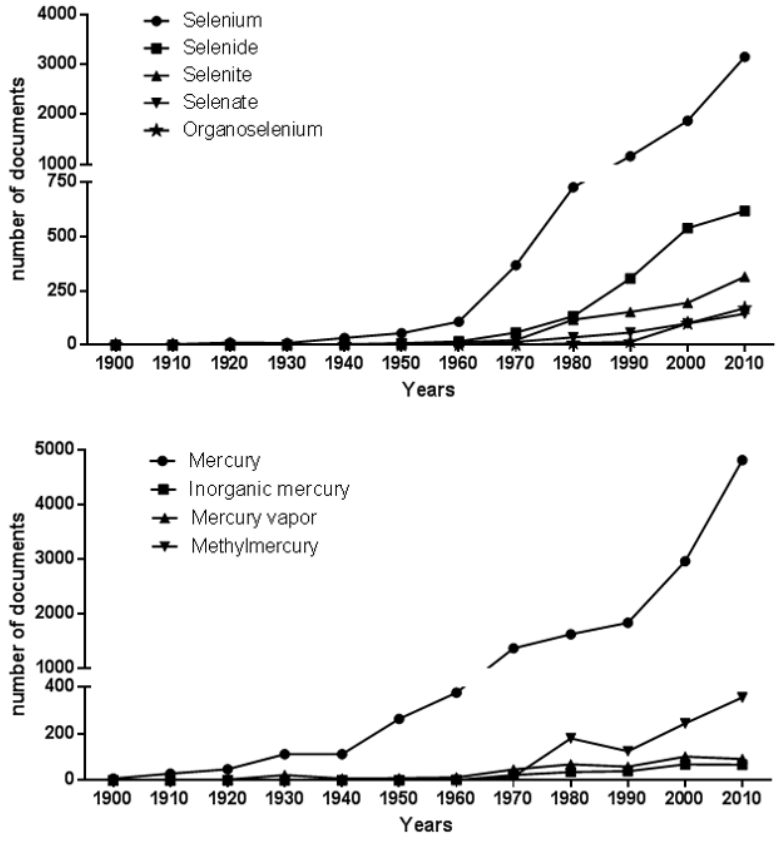
Source: The authors.

Moreover, when we searched documents with the keywords selenium and mercury the first indexed document was published in 1913 and the year with the highest publication was 2015 (5%) (Table 1).

3.2 Global evolution of publication output per decade with “Selenium”, “Mercury” and their organic and inorganic forms

The distribution of publication output per decade with the word “selenium” and its organic and inorganic is depicted in the Figure 1A. Although the publications with mercury and selenium started in the XVIII and XIX centuries, respectively, the “boom” of published documents started in the 60's and 70's decades. The number of indexed documents with the word “selenium” increased dramatically from 1960 to 2010 followed by that published with the word “Selenide” (from 1970-2010), both representing ~85% of the total number of documents (Figure 1A).

Figure 1 - Number of documents published per decade from 1700 to 2010. **(A)** “Selenium” and its organic and inorganic forms; (B) “Mercury” and its organic and inorganic forms.



Source: The authors.

In contrast to Selenium, there was an increasing number of published documents with the keyword “mercury” during two periods: from 1940 to 1970 and from 1990 to 2010. The "methylmercury" documents presented an increase in the number of documents mainly from 1990 to 2010 (Figure 1B). The number of documents with the keywords “mercury” and “methylmercury” represented ~95% of the total documents (Figure 1B).

3.3. The top 5 productive countries in research on Selenium, Mercury and their organic and inorganic forms

The contribution of the countries to science is of extreme importance. Here, the top 5 countries were ranked based on their number of scientific productivity. Table 2 shows that the United States with approximately 23-28% and 24-37% of total publications in Selenium and Mercury, respectively, stands out far above the other countries. Twenty-five (25) to 30% of the published documents with these keywords were from authors affiliated in American universities (data not shown).

Table 2 - Percentage of papers published by the top 5 countries from 1700 to 2017.

	1st	2nd	3rd	4th	5th
Selenium	USA (25%)	CHN (9%)	GER (7%)	JPN (6%)	UK (5%)
Selenide	USA (23%)	CHN (11%)	JPN (10%)	GER (8%)	IND (8%)
Selenite	USA (26%)	CHN (11%)	JPN (6%)	GER (6%)	IND (5%)
Selenate	USA (28%)	JPN (7%)	GER (6%)	POL (5%)	FRA (5%)
Organoselenium	USA (28%)	BRA (11%)	JPN (11%)	CHN (10%)	IND (7%)
Mercury	USA (24%)	CHN (9%)	JPN (5%)	UK (5%)	GER (5%)
Inorganic mercury	USA (26%)	JPN (11%)	CHN (7%)	CAN (7%)	SWE (6%)
Mercury vapor	USA (25%)	JPN (9%)	UK (5%)	GER (4%)	CAN (3%)
Methylmercury	USA (37%)	JPN (11%)	CAN (11%)	CHN (6%)	BRA (4%)
Selenium and Mercury	USA (28%)	CAN (8%)	JPN (7%)	CHN (6%)	GER (5%)

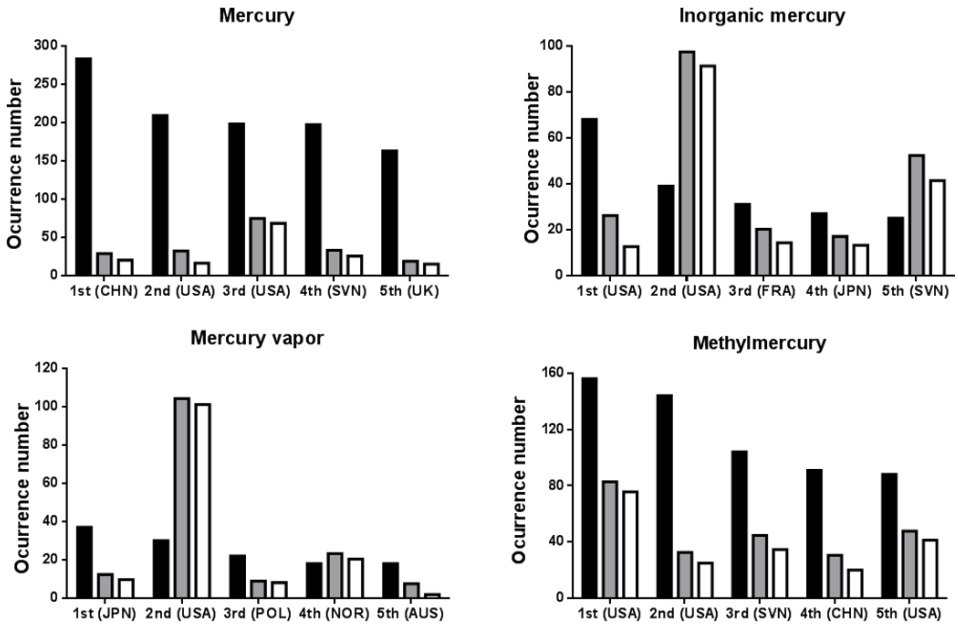
BRA: Brazil; CAN: Canada; CHN: China; FRA: France; GER: Germany; IND: India; JPN: Japan; POL: Poland; SWE: Sweden; UK: United Kingdom; USA: United States.

Source: The authors.

So far behind the USA, we find China (CHN) at the second position for selenium, selenide, selenite, and mercury; Japan (JNP) for selenate, methylmercury, inorganic mercury, and mercury vapor; and Brazil (BRA) for organoselenium. In fact, China is a big country and we assume that its position is explained, at least in part, by the fact that several researchers are working with these chemical elements. In agreement with this, only one Chinese researcher appeared on the top 5 authors when the keyword “Mercury” was entered (Figure 3). On the other hand, Brazil is also a big country but research on organoselenium compounds is concentrated in the Southeast region. Four Brazilian authors appeared in the rank of the top 5 authors (Figure 2). It is also important to note that Brazil is the only country in Latin America that appears in the top 5 countries that contributed to the selected keywords of this work. This might be due in part to the financial support from the Brazilian funding agencies, mainly, CAPES (Coordination for the Improvement of Higher Education Personnel) and CNPq (National Council for Scientific and Technological Development) (Kamdem et al., 2017). The presence of Japan in the second position for the keyword “mercury” may be attributed to the case of Minamata outbreak (a case of organic mercury contamination in Japan) in the 50-70 decades (Ekino et al., 2007). After it, the number of published documents about mercury

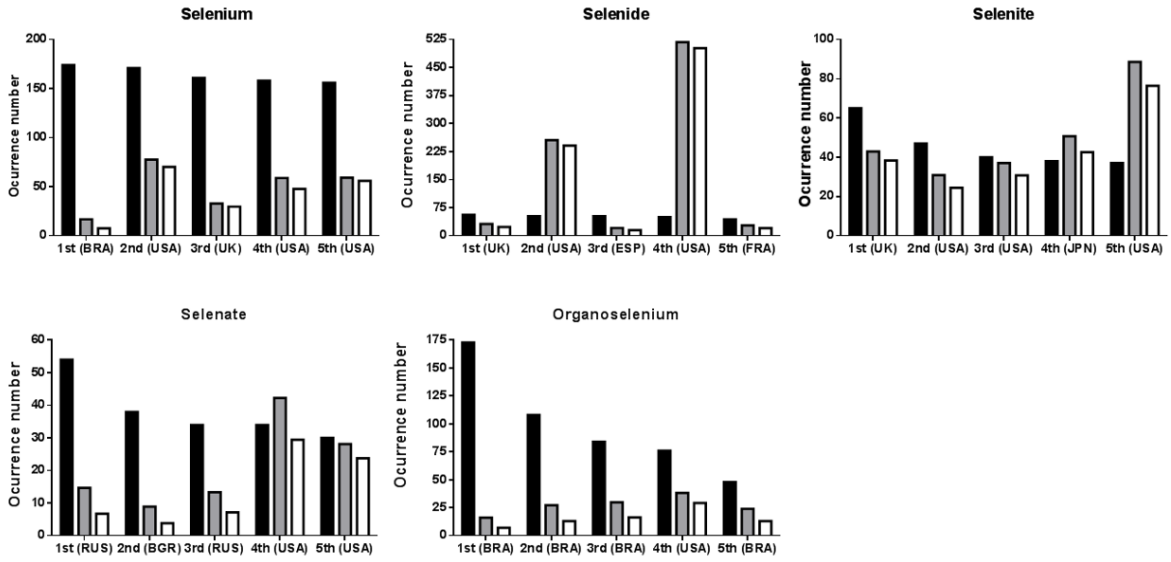
intoxication increased considerably and it is plausible to think that Japan has been improving its research in this area.

Figure 2 - Top 5 authors with the highest publication from 1700-2017 with the keyword "mercury", "inorganic mercury", "mercury vapor" or "methylmercury". The black bar represents the number of published documents, the grey bar represents the number of citations per document with self-citations and the white bar represents the number of citations per document without self-citations. AUS= Australia, CHN= China, FRA= France, JNP= Japan, NOR= Noruega, POL= Polonia UK= United Kingdom, USA= United States, SVN= Slovenia.



Source: The authors.

Figure 3 - Top 5 first authors with the highest publication from 1700-2017 with the keyword "selenium", "selenide", "selenite", "selenate" or "organoselenium". The black bar represents the number of published documents, the grey bar represents the number of citations per document with self-citations and the white bar represents the number of citations per document without self-citations. BGR= Bulgaria, BRA= Brazil, ESP= Spain, FRA= France, JNP= Japan, RUS= Russian Federation, UK= United Kingdom, USA= United States.



Source: The authors.

The USA is also in the first position when we searched documents with selenium and mercury owning 28% of the indexed documents.

3.4. Top 5 Scopus subject categories where research on Selenium, Mercury and their organic and inorganic forms are indexed

Unlike the countries, the classification of the keywords by Scopus subject categories was diverse, indicating that research on these keywords has emerged in other subject categories. Table 3 shows the top 5 Scopus subject categories for each keyword. They were classified based on the number of documents per category. It can be observed that the Scopus subject category, Medicine (MED) was in the first place to the keywords “selenium” (28%) and “selenite” (35%) (Table 3). Similarly, Physics and Astronomy (PA) category was in the first position for the keyword “selenide” (46%), Chemistry (CHE) for “selenate” (31%), and Biochemistry, Genetics and Molecular Biology (BGMB) for the keyword “organoselenium” (48%) (Table 3). The most represented category in comparison to the others was BGMB (48%) which can be explained at least in part, by the use of selenium in cancer therapy among others (Rocha et al, 2017a,b; Ju et al. 2017). In addition, the number of papers where selenium is used for the synthesis of new molecules is high, and this justifies the strongest of Chemistry (CHE) area in the field of selenium.

Table 3 - Distribution of the documents published by area (5 first areas) from 1700 to 2017.

	1st	2nd	3rd	4th	5th
Selenium	MED (28%)	CHE (27%)	BGMB (21%)	MS (17%)	PA (16%)
Selenide	PA (46%)	MS (43%)	CHE (37%)	ENG (27%)	CE (11%)
Selenite	MED (35%)	BGMB (32%)	CHE (21%)	ABS (17%)	ES (13%)
Selenate	CHE (31%)	BGMB (23%)	ABS (20%)	ES (18%)	MED (15%)
Organoselenium	BGMB (48%)	CHE (47%)	PTP (28%)	MED (22%)	CE (8%)
Mercury	CHE (27%)	ES (19%)	MED (19%)	PA (15%)	ENG (15%)
Inorganic mercury	ES (36%)	MED (27%)	CHE (25%)	PTP (24%)	BGMB (17%)
Mercury vapor	PA (25%)	ENG (22%)	MED (20%)	CHE (16%)	ES (15%)
Methylmercury	ES (42%)	PTP (28%)	MED (28%)	BGMG (16%)	CHE (16%)
Selenium and Mercury	ES (45%)	MED (25%)	CHE (23%)	PTP (16%)	BGMB (15%)

ABS: Agricultural and Biological Sciences; BGMB: Biochemistry, Genetics and Molecular Biology; CE: Chemical Engineering; CHE: Chemistry; ENG: Engineering; ES: Environmental Science; MED: Medicine; MS: Material Science; PA: Physics and Astronomy; PTP: Pharmacology, Toxicology and Pharmaceutics. Source: The authors.

In relation to Mercury and its derivatives keywords, Chemistry (CHE), Environmental Science (ES) and Physics and Astronomy (PA) are the top subject categories for "mercury" (27%), "methylmercury" (42%) and "inorganic mercury" (36%), and "mercury vapor" (25%), respectively. The position of the Chemistry area in the first place when the keyword "mercury" was entered may be explained not only by the use of Hg in the synthesis of new molecules, but also by the several papers that study Hg-Se interactions (Jensen et al., 1992; Yasuda et al., 2004; Tirloni et al., 2013; Yurkerwich et al., 2016). The strongest presence of the Environmental Science area in the majority of Mercury related keywords is due to the fact that all the Hg forms are environmental contaminants and several studies are carried out to increase our understanding on Hg toxicity in order to minimize their effects in the environment. It should be stressed however that a single paper (document) can be found in more than one category. In the same context, Environmental Science (45%), Medicine (25%) and Chemistry (23%) are the areas that represent the majority of the documents indexed with selenium and mercury.

3.5. Top 5 contributing authors in Selenium, Mercury and their organic and inorganic forms

Generally, research groups are specialized in a determined field of study, and the same was observed in relation to the subjects of this paper. When we searched for the top 5 publishing authors in the Selenium area, it was possible to see that the Brazilian researcher, Dr. Nogueira, appears in the first position followed by researchers from United States (Dr. Burk, Dr. Gladyshev, and Dr. Combs) and United Kingdom (Dr. Whanger) (Figure 2 and Table 4). All of them have almost the same number of published documents (approximately 170 documents) indexed in the Scopus database (Figure 2). Although the number of citations per paper of Dr. Nogueira is lower than the other authors (Figure 2), when compared to the other authors, Dr. Nogueira is young in the selenium research field. Her first paper with the keyword selenium was published in the Brazilian Journal of Medical and Biological Research in 2002 (see Farina et al., 2002) (Table 4). Thus, she still has much to contribute in the selenium and organoselenium (discussion above) fields.

Table 4 - Top 5 publishing authors' information in Selenium from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	Nogueira, C.W. (BRA)	Year: 2002 Citation: 47	Year: 2017 Citation: 0	Year: 2004 Citation: 988
2nd	Burk, R.F. (USA)	Year: 1967 Citation: 64	Year: 2015 Citation: 5	Year: 1976 Citation: 2405
3th	Whanger, P.D. (UK)	Year: 1969 Citation: 9	Year: 2016 Citation: 3	Year: 2004 Citation: 420
4th	Gladyshev, V.N. (USA)	Year: 1994 Citation: 52	Year: 2017 Citation: 0	Year: 2003 Citation: 1236
5th	Combs, G.F. (USA)	Year: 1973 Citation: 18	Year: 2017 Citation: 1	Year: 1996 Citation: 2281

Source: The authors.

The top 5 authors with the highest number of documents in the "selenide" keyword are presented in Figure 2 and their information in Table 5. The number of published documents is similar among the authors (approximately 60). Two of the five authors presented a great number of citations per paper, Dr. Bawendi and Dr. Alivisatos. Dr. Bawendi is affiliated in an American institution and his highest cited paper was published in 1997 in the Journal of Physical Chemistry B (see Dabbousi et al., 1997); Dr. Alivisatos is also affiliated in an American institution and his highest cited paper was published in 1998 in Science (see Bruchez et al., 1998). Both have been contributing to the field of quantum dots and nanocrystals.

Table 5 - Top 5 publishing authors' information in Selenide from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	O'Brien, P. (UK)	Year: 1996 Citation: 57	Year: 2016 Citation: 2	Year: 1998 Citation: 193
2nd	Bawendi, M.G. (USA)	Year: 1990 Citation: 1	Year: 2015 Citation: 0	Year: 1997 Citation: 3075
3th	Segura, A. (ESP)	Year: 1993 Citation: 162	Year: 2014 Citation: 35	Year: 1983 Citation: 137
4th	Alivisatos, A.P. (USA)	Year: 1994 Citation: 52	Year: 2016 Citation: 5	Year: 1998 Citation: 6986
5th	Chevy, A. (FRA)	Year: 1978 Citation: 152	Year: 2007 Citation: 8	Year: 1978 Citation: 152

Source: The authors.

When the keyword "selenite" was searched, four (Dr. Shearer, Dr. Ganther, Dr. Suzuki and Dr. Ip) of the top 5 authors apparently stopped their scientific carrier, since their last indexed publication with the keyword "selenite" was in the last decade (Table 6). On the other hand, when the keyword "selenate" was searched, two of the top 5 authors with the highest number of publications were from Russian Federation (Dr. Krivovichev and Dr. Tananaev), one from Bulgaria (Dr. Stoilova), and two from United States (Dr. Pilon-Smits and Dr. Frankenberger). As it can be shown in Table 7, it is possible to conclude that, Dr. Frankenberger is not more academically active since its last published paper was in 2008. The other four authors are still publishing (Table 7) and will probably increase their contribution to the field of Material Science (Dr. Krivovichev and Dr. Tananaev), classic Chemistry (Dr. Stoilova) and Agricultural and Biological Sciences (Dr. Pilon-Smits).

Table 6 - Top 5 publishing authors' information in Selenite from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	Whanger, P.D. (UK)	Year: 1972 Citation: 32	Year: 2016 Citation: 3	Year: 2004 Citation: 420
2nd	Shearer, T.R. (USA)	Year: 1975 Citation: 12	Year: 2006 Citation: 6	Year: 1997 Citation: 126
3th	Ganther, H.E. (USA)	Year: 1966 Citation: 87	Year: 2004 Citation: 24	Year: 1968 Citation: 274
4th	Suzuki, K.T. (JPN)	Year: 1995 Citation: 4	Year: 2009 Citation: 18	Year: 2002 Citation:171
5th	Ip, C. (USA)	Year: 1981 Citation: 2	Year: 2005 Citation: 61	Year: 1998 Citation: 554

Source: The authors.

Table 7 - Top 5 publishing authors' information in Selenate from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	Krivovichev, S.V. (RUS)	Year: 2004 Citation: 70	Year: 2017 Citation: 0	Year: 2005 Citation: 119
2nd	Stoilova, D. (BGR)	Year: 1992 Citation: 10	Year: 2016 Citation: 1	Year: 2009 Citation: 24
3th	Tananaev, I.G. (RUS)	Year: 2005 Citation: 119	Year: 2017 Citation: 0	Year: 2005 Citation: 119
4th	Pilon-Smits, E.A.H. (USA)	Year: 1998 Citation: 43	Year: 2017 Citation: 3	Year: 1999 Citation:242
5th	Frankenberger, W.T. (USA)	Year: 1986 Citation: 21	Year: 2008 Citation: 31	Year: 1997 Citation: 146

Source: The authors.

Among the top 5 authors of the keyword "organoselenium", four are from Brazil (Dr. Nogueira, Dr. Rocha, Dr. Zeni, and Dr. Braga) and one is from United States (Dr. El-Bayoumy) (Table 8). The three first authors are affiliated to the same Brazilian institution, Universidade Federal de Santa Maria, and their highest cited paper is titled "Organoselenium and organotellurium compounds: Toxicology and Pharmacology", published in Chemical Review (see Nogueira et al., 2004). In the same line, Dr. El-Bayoumy is affiliated to an American institution and has published several papers studying the effects of the organoselenium compound, 1,4-phenylene-bis(methylene)selenocyanate (p-XSC), in tumorigenic cells (for example, see EL-Bayoumy, 1997; EL-Bayoumy et al., 2003; EL-Bayoumy and Sinha, 2004).

Table 8: Top 5 publishing authors' information in Organoselenium from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	Nogueira, C.W. (BRA)	Year: 2002 Citation: 47	Year: 2017 Citation: 0	Year: 2004 Citation: 988
2nd	Rocha, J.B.T. (BRA)	Year: 2000 Citation: 124	Year: 2017 Citation: 0	Year: 2004 Citation: 988
3th	Zeni, G. (BRA)	Year: 2002 Citation: 47	Year: 2017 Citation: 0	Year: 2004 Citation: 988
4th	El-Bayoumy, K. (USA)	Year: 1985 Citation: 41	Year: 2012 Citation: 13	Year: 2004 Citation:171
5th	Braga, A.L. (BRA)	Year: 1994 Citation: 3	Year: 2016 Citation: 4	Year: 2000 Citation: 124

Source: The authors.

With regard to mercury keywords, Dr. Clarkson stands up in all of them (Figure 3, Tables 9, 10, 11, and 12). He is/was affiliated to an American institution, and has dedicated his life to the toxicology of mercury. Scopus database revealed that Dr. Clarkson has published fourteen reviews articles about the toxicology of mercury, three of them with more than 900 citations (see Bakir et al. 1973; Clarkson et al. 2003; Clarkson and Magos, 2006). When we searched for the keyword "mercury", one of the top contributing authors was from China (Dr. Feng.), two from United States (Dr. Solomon and Dr. Clarkson), one from Slovenia (Dr. Horvat) and one from United Kingdom (Dr. Bond) (Figure 3 and Table 9). Dr. Feng published more documents than the other authors (Figure 3). On the other hand, when we considered the number of citations per paper, it was similar among the authors, excepted Dr. Clarkson (Figure 3).

Table 9 - Top 5 publishing authors' information in Mercury from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	Feng, X. (CHN)	Year: 1997 Citation: 3	Year: 2017 Citation: 0	Year: 2010 Citation: 536
2nd	Solomon, S.C. (USA)	Year: 1974 Citation: 85	Year: 2016 Citation: 4	Year: 2001 Citation: 251
3th	Clarkson, T.W. (USA)	Year: 1961 Citation: 0	Year: 2013 Citation: 6	Year: 1973 Citation: 970
4th	Horvat, M. (SVN)	Year: 1987 Citation: 24	Year: 2017 Citation: 1	Year: 1993 Citation:350
5th	Bond, A.M. (UK)	Year: 1970 Citation: 17	Year: 2017 Citation: 1	Year: 1986 Citation: 117

Source: The authors.

Table 10: Top 5 publishing authors' information in Inorganic mercury from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	Zalups, R.K. (USA)	Year: 1987 Citation: 32	Year: 2017 Citation: 3	Year: 2010 Citation: 81
2nd	Clarkson, T.W. (USA)	Year: 1970 Citation: 96	Year: 2010 Citation: 66	Year: 2006 Citation: 909
3th	Amouroux, D. (FRA)	Year: 1997 Citation: 162	Year: 2017 Citation: 0	Year: 1997 Citation:162
4th	Suzuki, T. (JPN)	Year: 1970 Citation: 28	Year: 1997 Citation: 61	Year: 1997 Citation: 61
5th	Horvat, M. (SVN)	Year: 1994 Citation: 12	Year: 2017 Citation: 2	Year: 1994 Citation: 308

Source: The authors.

Table 11 - Top 5 publishing authors' information in Mercury vapor from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	Yoshida, M. (JPN)	Year: 1973 Citation: 1	Year: 2014 Citation: 2	Year: 2002 Citation: 46
2nd	Clarkson, T.W. (USA)	Year: 1973 Citation: 35	Year: 2011 Citation: 17	Year: 2006 Citation: 909
3th	Moszczynski, P. (POL)	Year: 1989 Citation: 0	Year: 2006 Citation: 0	Year: 2005 Citation:48
4th	Ellingsen, D.G. (NOR)	Year: 1993 Citation: 28	Year: 2006 Citation: 7	Year: 1993 Citation: 46
5th	Bhargava, S.K. (AUS)	Year: 2008 Citation: 7	Year: 2017 Citation: 0	Year: 2009 Citation: 27

Source: The authors.

Table 12 - Top 5 publishing authors' information in Methylmercury from 1700 to 2017.

Position	Authors' name	First publication	Last publication	Highest cited publication
1st	Clarkson, T.W. (USA)	Year: 1970 Citation: 96	Year: 2012 Citation: 25	Year: 1973 Citation: 970
2nd	Aschner, M. (USA)	Year: 1984 Citation: 43	Year: 2017 Citation: 0	Year: 2003 Citation: 254
3th	Horvat, M. (SVN)	Year: 1987 Citation: 24	Year: 2017 Citation: 1	Year: 1993 Citation:350
4th	Feng, X. (CHN)	Year: 2001 Citation: 92	Year: 2017 Citation: 0	Year: 2008 Citation: 180
5th	Grandjean, P. (USA)	Year: 2001 Citation: 31	Year: 2017 Citation: 0	Year: 2006 Citation: 882

Source: The authors.

In relation to inorganic mercury, two of the top contributing authors were from USA (Dr. Zalups and Dr. Clarkson), one from France (Dr. Amouroux), one from Japan (Dr. Suzuki), and one from Slovenia (Dr. Horvat) (Figure 3 and Table 10). Dr. Zalups, the author with the highest number of published documents (Figure 3), has a great expertise in the study of nephrotoxicity of inorganic mercury, and has published several important original and review articles (for more information, see Bridges and Zalups, 2010 and Zalups, 1991, 1995, 1997, 1998, 2000).

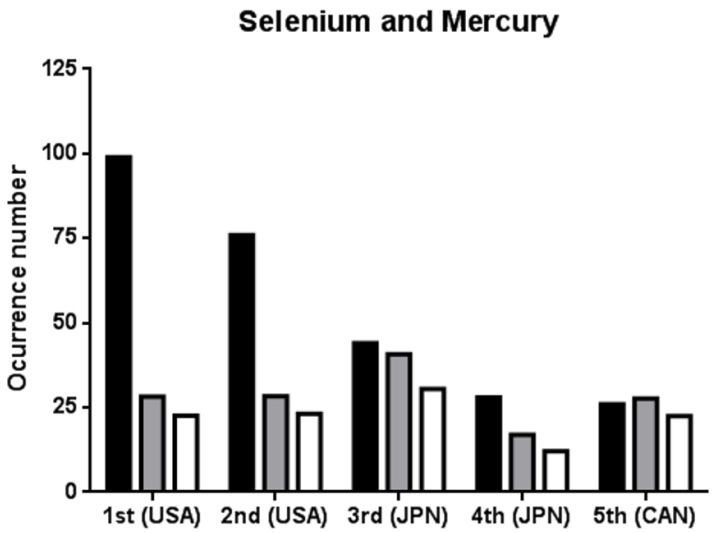
When the keyword "mercury vapor" was searched, we observed that the number of published documents is lower when compared to the other mercury keywords. It was possible to observe a diversity in the affiliation of the top 5 contributing authors. The first contributing author, Dr. Yoshida, is from Japan, the second, Dr. Clarkson, from United States, the third, Dr. Moszczynski, from Poland, the fourth, Dr. Ellingsen, from Norway and Dr. Bhargava, from Australia (Table 11 and Figure 3). The number of citations is also relatively low, with exception of Dr. Clarkson (Figure 3 and Table 11). In relation to "methylmercury" keyword, three authors are affiliated to American institutions (Dr. Clarkson, Dr. Aschner, and Dr.

Grandjean), one from China (Dr. Feng, the same from the “mercury” keyword) and one from Slovenia (Dr. Horvat, the same from “mercury” and “inorganic mercury” keywords). Dr. Aschner has been working with the neurotoxic effects of methylmercury and has made important contributions to the understanding on how methylmercury is handled by the cells (for example, see Rodier, 1984; Aschner & Clarkson, 1988; Aschner & ASCHNER, 1990; Shanker & Aschner, 2003; Farina et al., 2011). Dr. Feng has several publications studying the mercury content in rice and fish as well as its emission in China (for example see Qiu et al., 2005, 2006; Feng & Qiu, 2008; Liu et al., 2014). Dr. Horvat has an expertise in analytical techniques to determine different chemical forms of mercury and has been contributing to this field (for examples see Horvat et al., 1990, 1993, 2003; Liang et al., 1994, 1996). Still, Dr. Grandjean has several papers studying the pre and postnatal exposure to methylmercury as well as he has been following the development of the Faroese and Seychelles Island population, which have fish as main source of protein and unfortunately as methylmercury (Murata et al., 2004; Grandjean et al., 2004, 2005; Debes et al., 2006).

Interestingly, the top 5 authors from the selenium and mercury in the same documents were not the same from the documents published with selenium or mercury keywords separately (Figure 4 and Table 13). Two of the 5 authors are affiliated to American institutions (Dr. Burger and Dr. Gochefeld), two are from Japan (Dr. Tanabe and Dr. Imura), and one is from Canada (Dr. Chan). Dr. Burger and Dr. Gochfeld have been working together determining selenium and mercury in the sea animals, as well as studying the interaction between these elements (for examples see, Burguer et al., 1992, 2017; Burguer & Gochfeld, 2005). In the same line, Dr. Tanabe also works evaluating the selenium and mercury levels in sea animals (for examples see, Kim et al., 1996; Ikemoto et al., 2004; Horai et al., 2014). On the other hand, Dr. Imura studied the selenium and mercury interactions in the mammalian body (for examples see, Imura & Nafamuna, 1978; Nagamuna & Imura, 1980; Urano et al., 1997). Dr. Chan has contributed to increasing the knowledge about the protective effects of selenium against mercury intoxication (for example, see Chapman & Chan, 2000; Sakamoto et al., 2013; Hu et al., 2017).

Figure 4 - Top 5 authors with the highest publication from 1700-2017 with the keyword “selenium and mercury”. The black bar represents the number of published documents, the grey bar represents the number of citations per document with self-citations and the white bar

represents the number of citations per document without self-citations. CAN= Canada, JNP= Japan, USA= United States.



Source: The authors.

Table 13 - Top 5 publishing authors' information in Selenium and Mercury from 1700 to 2017.

Position	Authors' name	First	Last	Highest cited

		publication	**publication**	**publication**
1st	Burger, J. (USA)	Year: 1992 Citation: 28	Year: 2017 Citation: 1	Year: 2005 Citation: 181
2nd	Gochfeld, M. (USA)	Year: 1992 Citation: 28	Year: 2017 Citation: 1	Year: 2005 Citation: 181
3th	Tanabe, S. (JPN)	Year: 1996 Citation: 57	Year: 2014 Citation: 11	Year: 2004 Citation: 133
4th	Imura, N. (JPN)	Year: 1978 Citation: 25	Year: 1997 Citation: 17	Year: 1980 Citation: 72
5th	Chan, H.M. (CAN)	Year: 2000 Citation: 128	Year: 2017 Citation: 4	Year: 2000 Citation: 128

Source: The authors.

In addition, in this study, we found that the great Brazilian authors' contribution occurs mainly in the area of "organoselenium" acting in the organic synthesis, pharmacology or toxicology lines. Here, we would like to highlight the great importance of the organoselenium research of Brazil, once Brazil is in the first position of published documents and the first organoselenium Brazilian document was recently published (see Lang & Comasseto et al., (1988)). In addition, we can say that the presence of Brazil in the research is "youthful", once the first masters and PhDs courses of this country started 65 years ago (Bianchetti & Fávero 2005; Cirani et al., 2015; Nobre & Freitas, 2017). This indicates the importance of the academies in the investigation and the positive evolution of the Brazilian research.

5. Final Considerations

This is the first bibliometric study about the chemical elements Selenium and Mercury. Here, it was possible to observe the increase in the interest of the researches about these elements since their first publication. Although the United States is the country with the highest number of publications in all the keywords used in this study, followed mainly by China, Japan, Germany, United Kingdom and Canadian, it is important to highlight the

presence of Brazil in the second position when the keyword “organoselenium” was searched. This study can become an important tool to find areas of knowledge with the high number of publications, the top scientists in those areas, as well as shown the interest of their respective countries in the research.

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Porcentagem de contribuição de cada autor no manuscrito

Pablo Andrei Nogara – 20%

Gabriela Luisa Schmitz – 20 %

Nayara de Souza da Costa – 15%

Jean Paul Kamdem – 15%

João Batista Teixeira da Rocha – 15%

Cláudia Sirlene de Oliveira – 15%