Periódico Eletrônico
Fórum Ambiental da Alta Paulista
ISSN 1980-0827 – Volume 19, número 1, 2023

Use of natural fibers in alternative wastewater treatment technologies, aiming at a more sustainable production: A review

Eduarda Bertoletti Duarte
Graduate student (Master's degree) in Clean Technologies, Unicesumar, Brazil.
eduardabertoletti@gmail.com

Luciana Cristina Soto Herek Rezende
Professor, Unicesumar, Ph.D. researcher at the Cesumar Institute of Science, Technology, and Innovation, Brazil
lucianarezende17@gmail.com

Periódico Eletrônico
Fórum Ambiental da Alta Paulista
ISSN 1980-0827 – Volume 19, número 1, 2023

SUMMARY

The most worrisome issues today are the excessive production of solids in wastewater and the discharge of wastewater containing toxic components. Despite current environmental legislation, there are still difficulties in treating wastewater and properly disposing of the waste generated in the various stages of the production process to avoid inadequate and premature disposal that may pollute the environment. As a result, techniques are being developed to reuse wastewater differently, and in this scenario, natural fibers can be used to treat wastewater through an adsorption-based technique. Thus, this research has been developed from an exploratory bibliographic survey carried out according to scientific papers that used natural fibers as bioadsorbents in Scopus, ScienceDirect, Web of Science, and Capes databases. VOSviewer® software was used to create a cluster map to analyze the correlation between citations of selected papers. It was observed an increase in the number of research on the above topic over the years, especially in 2021. The most used natural fibers were plant-based, mostly cellulose. When evaluating the scientific contribution by country, Malaysia, India, and China were the most relevant. Brazil ranked fourth. Therefore, even with legislation on wastewater disposal and targets for the 2030 wastewater treatment plan, some countries are lagging in alternative techniques for the use of natural fibers in adsorption processes.

Keywords: Cleaner technologies. Solids waste. Plant fibers.

1. INTRODUCTION

Industrial development has led to significant urban growth, resulting in changes in consumption patterns. However, as a consequence of these changes, there was a growing proportion and dimension of environmental impacts (GONÇALVES; NOVELLO; PEREIRA JUNIOR, 2022; MARTINS; RIBEIRO, 2021). Among the environmental impacts, it is worth highlighting the significant generation of waste, which is inherent in any process and results from high production (LIMA, 2015).

The 2021 "*Panorama de resíduos sólidos"* presented an increase in waste generation in 2020, with an average of more than 1 kg per capita per day. Moreover, this figure was high due to the Covid-19 pandemic, which resulted in high production of household waste (ABRELPE, 2021). According to the Brazilian Association of Public Cleaning Companies and Special Waste, in 2020, the annual production of solid waste will exceed 80 million tons (ABRELPE, 2021). This association carries out annual reports on solid waste, and in 2019, the annual production was 79.1 million tons, a significant increase in 2 years (ALBRELPE, 2020).

Another problem that occurs in Brazil is the production of agroindustrial waste since Brazil's effective participation in agribusiness is known. However, the characteristics of this waste are different depending on the crops produced (COSTA FILHO et al., 2017). Nevertheless, the concern is not only in terms of the production of solids in wastewater but also in the way it is disposed of and treated properly since improper disposal can cause environmental contamination (DEUS, 2015; MAIELLO et al., 2018; LIMA, 2015; SOUSA, 2016).

An effective waste management system is needed. It must cover all stages from production to disposal or reuse, in addition to appropriate treatments to reduce the contaminating effect on the environment (MERSONI; REICHERT, 2017). The National Solid Waste Policy regulates this management, implemented from Federal Law 12.305 in 2010, which establishes the adequacy of all processes, from collection to treatment and environmentally correct destination, in addition to promoting reduction, reuse, and recycling (BRASIL, 2010).

This same sustainable management is one of the goals of Agenda 2030, an international document between the countries of the United Nations that considers an action

plan with 17 goals for sustainable development and 169 targets, with topics ranging from waste and wastewater management, water quality, sanitation, and gender equality (UN, 2015). Goal 12 aims to ensure sustainable production and consumption patterns, and one of its objectives is to reduce waste generation through prevention, reduction, recycling, and reuse (UN, 2015).

Thus, studies on alternative techniques and processes in which the raw material becomes the by-product are increasing, evaluating the waste and making the chains more sustainable (BALLA et al., 2019; FICO et al., 2022). Another environmental concern is directly related to the increase in studies evaluating pollutants and contaminant loads in water bodies, mainly at the expense of inadequate treatment of industrial effluents (OTHMANI, 2022; RAHMAN et al., 2018). Proper treatment requires efficient treatment techniques, and adsorption stands out as an advanced and highly efficient technique for the removal of environmental pollutants (OTHMANI, 2022; YAASHIKAA; KUMAR; KARISHMA, 2022; YEO et al., 2021).

Adsorption is a technique that uses a solid to remove substances in liquid or gaseous solutions by the attraction of the surface, adsorbents most used are synthetic materials, mainly activated carbon and membranes (OTHMANI, 2022; YEO et al., 2021). Since the matrix of the adsorbents is synthetic, there is a high cost in its production, besides a high energy demand (CANDIDO; PIRES; OLIVEIRA, 2021). Therefore, new studies are looking for low-cost natural materials, such as waste, which are available in the environment and have a high adsorption efficiency to replace synthetic materials and make wastewater treatment with biosorbents eco-efficient (CANDIDO; PIRES; OLIVEIRA, 2021; RAHMAN et al., 2018). Thus, it is possible to verify the need for alternative technologies and more sustainable adsorbents in this scenario.

This study aims to evaluate, through a literature review, the inclusion of natural fibers as adsorbents natural.

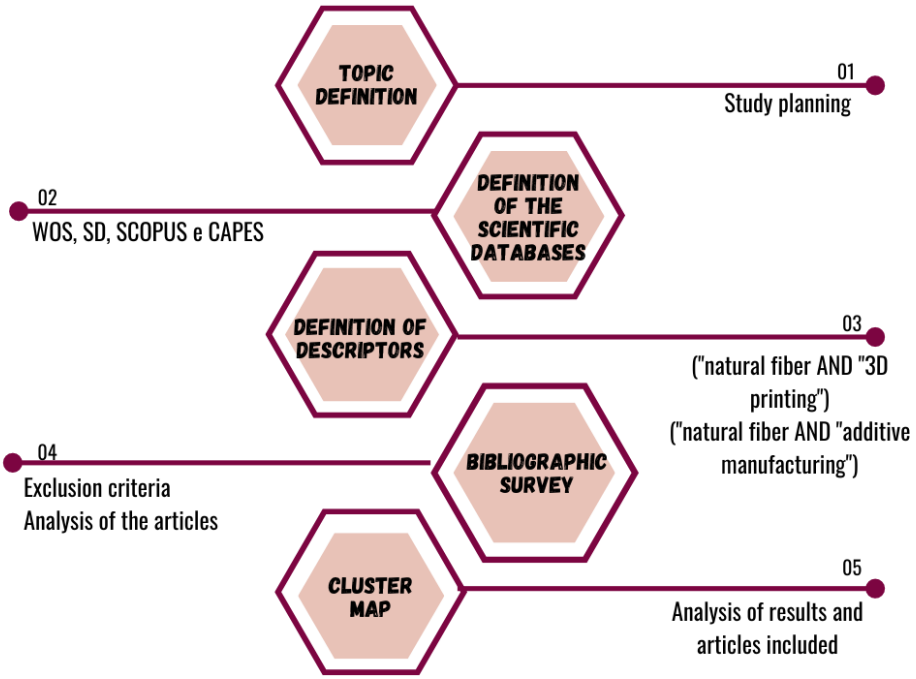
2. OBJECTIVES

This paper aims to evaluate the inclusion of natural fibers in alternative adsorption techniques in the treatment of wastewater, through a careful bibliographic survey and search for sustainable and efficient processes and waste valorization. A specific objective is to explore the evolution over the years of research on the subject, evaluate the most commonly used fibers and analyze the scientific contribution of countries.

3. METHODOLOGY

This work began with a systematic review of the feasibility of incorporating fibers into alternative processes in the search for cleaner production, as shown in Figure 1.

Figure 1: Methodology flowchart



Source: Created by authors, 2022

The inclusion criteria allowed the inclusion of articles that dealt with topics such as the addition of natural fibers in the adsorption of wastewater and excluded those without adherence to the topic, duplicates, and with more than ten years of publication.

The search included articles published in English and was conducted in the scientific databases Scopus, Science Direct (SD), Web of Science (WOS), and Capes.

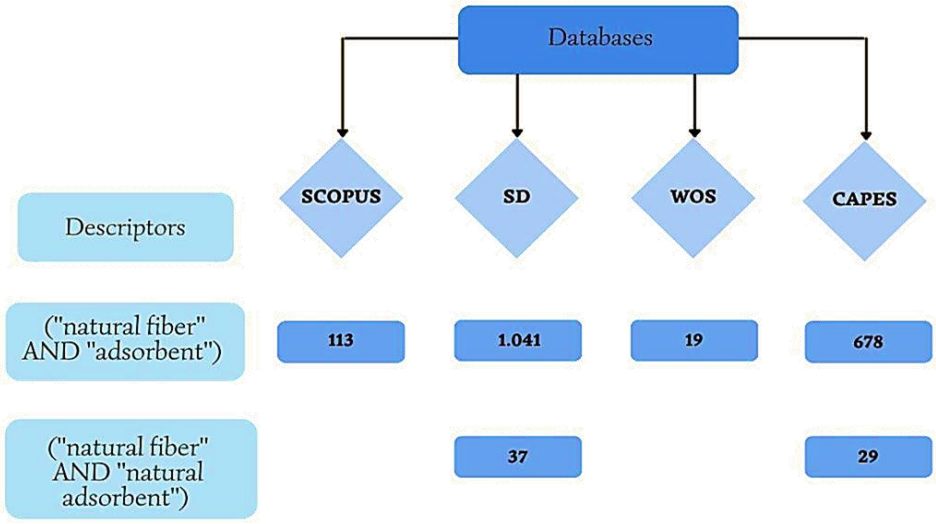
To evaluate the articles, tables were created in Excel and those studies with topics not suitable for the paper were excluded. The cluster map was generated from the data collected from the scientific base Web of Science to verify the correlation between the citations present in the articles from the VOSviewer® software.

After careful analysis of the data obtained, it was possible to build the study on the analysis of the feasibility of natural fibers in alternative processes.

4. RESULTS

From the bibliographic survey, it was possible to analyze the relationship between the articles found and the descriptors used, Figure 2. It is possible to see the significant collection of articles from ScienceDirect compared to the other databases.

Figure 2: Descriptor Flowchart



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The SD and Capes databases provided a collection with a high number of results, which would make it difficult to read the abstracts of all the papers found. To refine the search, it was decided to use the descriptor ("natural fiber" AND "natural adsorbent"). However, when using this descriptor in the other two bases, it was not adhered to, opting to use it only in Capes and Science Direct.

These results went through the exclusion criteria, analysis of duplicate results, and verification of adherence to the topic. Articles with non-adherent themes were excluded. In the end, it was possible to find 70 selected studies.

Another analysis was the co-citation of authors using the VOSviewer® software via the Web of Science database. It was possible to analyze the bibliographic references between the indexed papers and the connection between the cited ones (PINTO, 2022).

Figure 3 shows the co-citation relationship between the papers found from the descriptor ("natural fiber" AND "adsorbent"). Initially, 1110 authors were found, but with the filter minimum of two citations per author, the result counted 20.

Periódico Eletrônico
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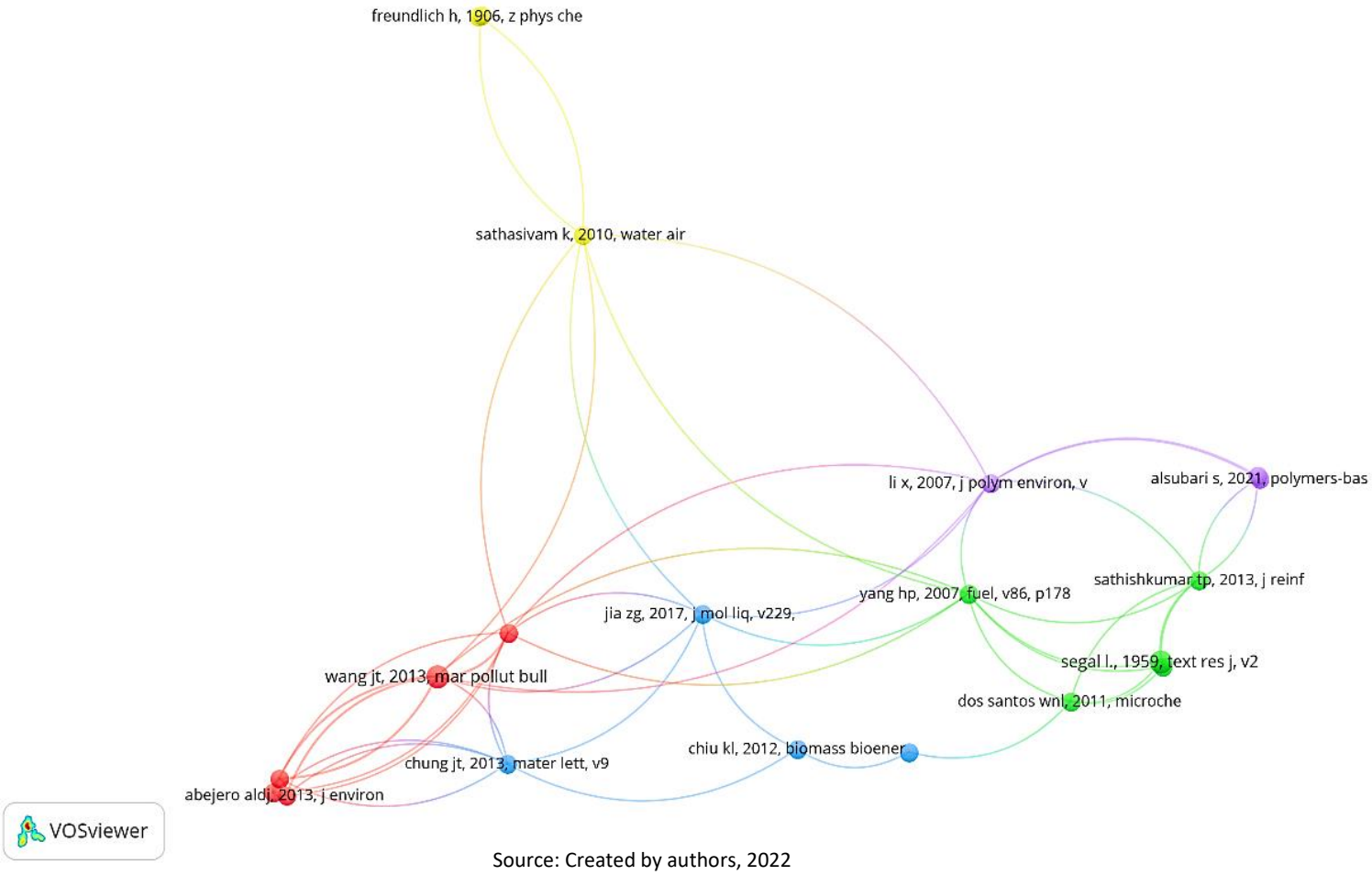
ISSN 1980-0827 – Volume 19, número 1, 2023

Figure 3: Co-citation network of authors by descriptor ("natural fibers" AND "adsorbent")



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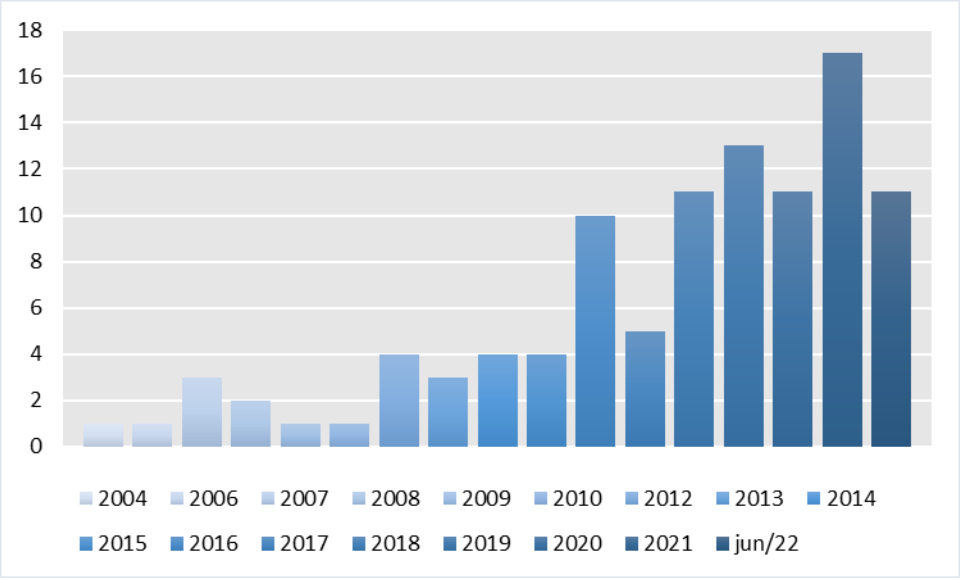
In this figure, there is the presence of five groups (clusters), each group represented by a different color. Red and green have five articles, blue has four, and yellow and purple have three. It is possible to see the interconnected flow among the authors of different clusters, which is an interdisciplinary theme.

It is possible to evaluate that Wang J.T., Stasia K., Jia Z.G., Yang H.P., and Chung J.T. presented the highest number of linkages. The co-citation analysis made it possible to observe the links between studies through the relationship shown in the figures, in addition to the analysis of the most relevant authors, such as those mentioned prominently in the text. In terms of scientific production, the survey shows that there has been an increase in the amount of research on natural fibers as adsorbents over the years (Figure 4).

Figure 4: How Natural Adsorption Research Developed Over the Years



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It is possible to infer that the concern for environmental pollution, especially industrial pollution and water pollution, is the fuel for scientific research using natural fibers in the adsorption of elements, which has grown in recent years and has proven its efficiency (NERIS et al., 2019; OTHMANI et al., 2022).

Although not uniform, it is clear to see the growth of studies over the observed period. Until 2020, the graph shows an oscillation between scientific productions, with an increase in 2021 compared to the other years. Moreover, the number of articles already published until July 2022 presents a value close to that of 2020.

Adsorption is one of the most efficient techniques for wastewater treatment (COSTA, 2020; OTHMANI et al., 2022). However, it is expensive due to the material used, activated carbon, with high production and reactivation costs, and its disposal, when impregnated with contaminants is a challenge (COSTA, 2020; OTHMANI et al., 2022).

Therefore, it is possible to verify the need for new adsorbents, such as natural fibers, available in the environment, low cost, and as efficient as commercial activated carbon, justifying the growth of studies in the reduction of a pollutant or contaminant load of the water body (CÂNDIDO; PIRES; OLIVEIRA, 2021; OTHMANI et al., 2022; RAHMAN et al., 2018).

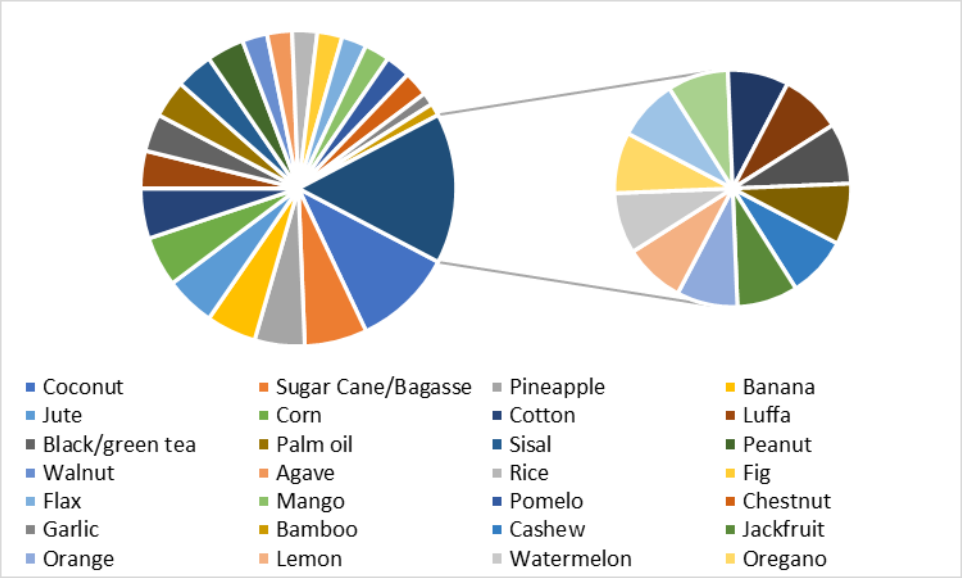
In addition, the use of wastes, mainly agroindustrial, as adsorbent material also stands out because they are by-products of other processes, with a lower cost and large quantities available, since the country has participated in the agroindustrial sector, they are not toxic, and their use makes the adsorption process more sustainable by giving a new purpose to the waste, avoiding early disposal (CÂNDIDO; PIRES; OLIVEIRA, 2021; OTHMANI et al., 2022; RAHMAN et al., 2018; RUSSO et al., 2021).

Batool and Valiyaveettil (2021) and Sathasivam et al. (2021) developed an eco-friendly, non-toxic adsorbent for water treatment from banana fiber, one study with the removal of polymer nanoparticles and the other with the removal of oil in aqueous environment,

respectively. Silva et al. (2021) developed an efficient activated carbon from pineapple crown as an adsorbent for methylene blue dye. Asim et al. (2021) also used a by-product as an adsorbent for methylene blue dye and coconut fiber.

Other works have evaluated the removal of metals in an aqueous environment by natural fibers, such as the use of Pequi shell, cotton fiber, and coconut fiber in the removal of Cr(II) ions, bamboo fibers, banana pseudo-stem, and vegetable dowel in the removal of Cr(VI), Jute and coconut fiber in the removal of Hg2+ and Pb2+, coconut fiber in the removal of arsenic, proving the importance of adsorption of metals with a high power of contamination of water and its biota (ANIRUDHAN; UNNITHAN, 2007; HASSAN; ZOHDY, 2018; MENEZES et al.. , 2021; NWOSU-OBIEOGU; OKOLO, 2020; PARAMASIVAM, 2020; QUEK; DURI, 2007; XUE et al., 2021; ZANG, 2016). Regarding the types of natural fibers used in the adsorption articles found, the result is shown in Figure 5

Figure 5: Natural fibers used in the adsorption process



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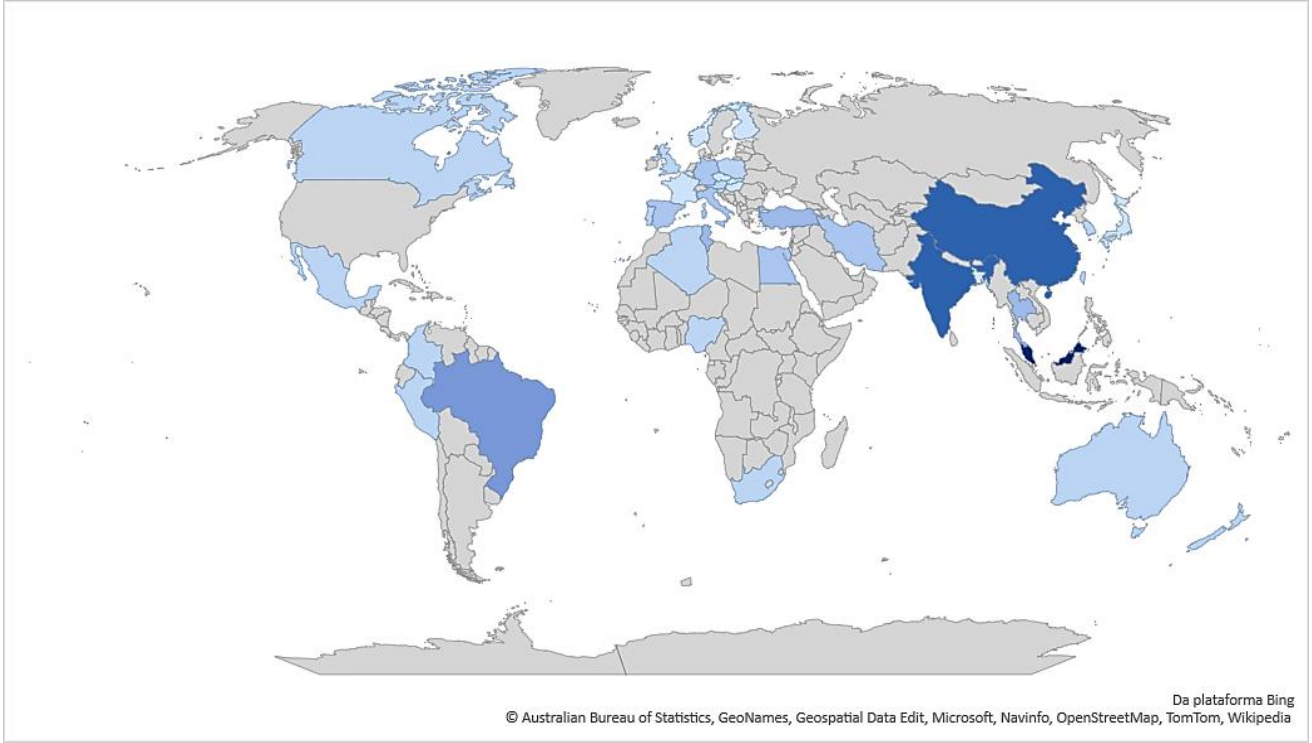
The classification of natural fibers considers their origin as animal organic, vegetable organic, and mineral inorganic (BECKMAN et al., 2021). It is possible to see the majority participation of plant fibers, composed mainly of cellulose, a long-chain polymer of glucose molecules (FICO et al., 2022). In total, 35 different fibers were present. They were classified as natural, of plant origin, and composed of cellulose (BECKMAN et al., 2021; GANGULY et al., 2022).

The fibers with higher frequency were coconut fiber, sugarcane bagasse fiber, almond, pineapple, banana fiber, jute, and corn, accounting for more than 40% of the total. Therefore, the most studied and used fibers in adsorption articles are those mentioned above.

Plant fibers can have different origins, such as seed, stem, leaf, and bark (BECKMAN et al., 2021; GANGULY et al., 2022). Jute is a stem fiber, coconut is a bark fiber, almond, and maize are seed fibers, and pineapple and banana fibers are leaf fibers (BECKMAN et al., 2021; GANGULY et al., 2022; ILYAS et al., 2021).

Another point evaluated in the study was the contribution of countries to the scientific community with studies of more sustainable processes and destinations for natural fibers for bioadsorption (Figure 6).

Figure 6: Country contribution of articles



Source: Created by authors, 2022

Twenty-nine countries contributed articles dealing with natural fiber adsorption, as shown in Figure 6, where the blue coloring darkens as the number of articles in the country increases.

Malaysia, China, and India were the countries with the highest number of articles, as indicated by the darker coloring in the figure. These three countries together accounted for almost 50% of the total contribution, demonstrating a strong power in this area of research. In recent years, China has increased its support to areas of science and technology for the sustainable development of rural areas. Malaysia and India are tropical countries that allow a variety of plantation crops and thus lead to the generation of natural fibers used in studies, some of the reasons for the active participation of these countries (CONTINI; SEIXAS, 2018; MONTE; LOPES; CONTINI, 2017; SEIXAS; CONTINI; SOARES, 2018).

Brazil entered as the fourth country with the highest contribution, with a significant difference from the first three, justified by the search in English. However, although the national language is Portuguese, science is widely disseminated through English, which shows this gap in Brazilian research in this area among the bases searched. It can be observed that even with Agenda 2030, a global agreement, many countries still obtained a low contribution, distancing themselves from the waste reuse targets. In the case of Brazil, there was a relatively low contribution compared to the countries with the highest frequency, despite the National Solid Waste Policy.

The use of natural fibers as adsorbents proved to be a less expensive and more environmentally sound technique compared to the use of synthetic materials. In addition, the inclusion of natural fibers in the process is in line with the goals of Agenda 2030

CONCLUSION

The significant generation of waste is an environmental impact caused by consumption and, therefore, by the excessive production that is present in the present time.

The concern is clear when analyzing the legislation and international agreements that seek a reduction and more sustainable management. In this scenario, it is possible to observe a growth of studies over the years, especially concerning agro-industrial waste. When checking the increase of studies on bioadsorption, there is uneven growth, but on an evolutionary scale, 2021 shows an increase in studies.

Vegetable fibers were the most studied and the most mentioned were coconut, sugarcane bagasse, almond, pineapple, banana fiber, jute, and corn. Looking at the relationship between countries, Malaysia, China, and India emerged as the countries with the highest contribution to the studies in the field. Brazil occupied the fourth place, with a lower scientific production compared to the three countries.

It can be seen that, despite international agreements and environmental legislation, many countries still have little research in this area. Thus, new studies are still needed, with the reuse of vegetable fibers and wastes for the treatment of wastewater from adsorption, in search of environmentally correct and economically viable processes.

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