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ANALYSIS OF THE EVOLUTION OF RESEARCH IN POLYMER MATRIX COMPOSITES: A BIBLIOMETRIC STUDY

ANÁLISE DA EVOLUÇÃO DA PESQUISA EM COMPÓSITOS DE MATRIZ POLIMÉRICA: UM ESTUDO BIBLIOMÉTRICO

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Abstract – Composite materials are mixtures of two or more components with distinct compositions, where one component serves as the matrix and the other as the reinforcement. The main types of matrices are ceramics, metals, and polymers. However, the use of polymers presents challenges such as proper waste management and concerns about environmental impacts. Natural-based polymers obtained from renewable sources offer a potential solution to these challenges. This bibliometric study aims to analyze the state of the art in the use of polymer matrix composites with natural reinforcements, providing valuable insights for future research. Data were collected from the

Scopus® database, covering the period from 2014 to 2022 and including only English-written documents, totaling 357 publications. The annual scientific production showed significant variation during the analyzed period. Brazil emerged as the leading country in this field's publications. Composite materials find applications in construction, architecture, packaging, furniture and interior design, toys, and biomedical industries. Bibliometric analysis plays a crucial role in determining research directions, identifying gaps in the discussion, and discovering promising areas for future investigations.

Keywords: Bibliometric analysis; bibliometrix; composites; polymer matrix; natural reinforcement.

Resumo – Materiais compósitos são misturas de dois ou mais componentes com composições distintas, onde um dos componentes atua como matriz e o outro como reforço. Os principais tipos de matrizes são cerâmicas, metais e polímeros. No entanto, o uso de polímeros apresenta desafios como a gestão adequada de resíduos e preocupações com impactos ambientais. Polímeros de base natural obtidos de fontes renováveis, oferecem uma solução potencial para esses desafios. Este estudo bibliométrico tem como objetivo analisar o estado da arte no uso de compósitos de matriz polimérica com reforços naturais, fornecendo insights valiosos para pesquisas futuras. Os dados foram coletados na base de dados Scopus®, abrangendo o período de 2014 a 2022 e incluindo apenas documentos escritos em inglês, totalizando 357 publicações. A produção científica anual apresentou variação significativa durante o período analisado. O Brasil se destacou como o principal país nas publicações nessa área. Materiais compósitos encontram aplicações na construção, arquitetura, embalagens, móveis, design de interiores, brinquedos e indústria biomédica. A análise bibliométrica desempenha um papel crucial na determinação das direções da pesquisa, na identificação de lacunas na discussão e na descoberta de áreas promissoras para futuras investigações.

Palavras-chaves: Análise bibliométrica; bibliometrix; compósitos; matriz polimérica; reforço natural.

1. Introduction

Composite materials are composed of a combination of two or more components with distinct compositions, structures, and properties. These components interact synergistically, where one acts as the matrix, responsible for cohesion and support of the system, while the other, known as reinforcement, provides mechanical and structural strength. Reinforcements play an essential role in conferring structure

to the material and providing the ability to withstand impacts and applied forces. The matrix, on the other hand, typically composed of an adhesive agent, is responsible for keeping all the fibers united, ensuring the integrity and conformation of the composite (Moreira., 2009; Guimarães., 2018).

Matrices can be classified into three types: ceramic, metallic, and polymeric (Väisänen et al., 2016). The polymeric matrix refers to a continuous structure or phase formed by a polymer in a composite material or in a polymer blend. Polymers are macromolecules characterized by their large molecular dimensions, unique chemical structure, and internal and intermolecular interactions. These polymers act as matrices in the mentioned composites. Due to their ability to be easily processed into the final product and the design freedom they offer, polymers have experienced increasing use in industries that were previously dominated by other material classes such as metals and ceramics. This trend has enabled the production of products with specific properties at an affordable cost, satisfying consumer demands (Almeida et al., 2015; Ramires., 2010).

However, it is important to emphasize that, despite the advantages of polymers, there are also challenges associated with their use, such as proper waste management and concerns about environmental impacts. Synthetic polymers exhibit remarkable resistance to natural degradation, especially when disposed of in the environment, such as in landfills or dumpsites, leading to growing concern over the accumulation of these materials. Additionally, the majority of these polymeric compounds are derived from synthetic organic solids containing petrochemical components (Yildizhan et al., 2018). The annual generation of plastic waste amounts to approximately 400 million tons, of which around 150 million tons end up in the oceans (Plastic Market size., 2021).

Therefore, the growing global concern over the depletion of fossil fuel resources and the exponential increase in plastic waste, which does not naturally degrade in the ecosystem and has a high carbon footprint, has spurred greater interest in the development of eco-friendly alternatives (Righetti et al., 2019; Kumar et al., 2020). Thus, the prioritization of developing composites based on natural components is considered crucial.

Biocomposites, also known as polymers of natural origin, are derived from renewable sources and have the potential to act as viable alternatives to non-renewable polymers derived from petrochemicals (Das et al., 2018; Sundarakannan et al., 2019; Das et al., 2019). These materials have significant potential for technological applications and also contribute to reducing the environmental impacts resulting from their use.

Bibliometric analysis is the application of statistical and mathematical methods to describe and evaluate scientific production and academic communication (Aksnes., 2006). It is a useful tool for understanding and addressing the environmental issues caused by polymer matrix products. Through this analysis, it is possible to map and evaluate the existing scientific production on the subject, identify knowledge gaps, research trends, and areas of greater impact. This can help direct research and development efforts to address these issues more efficiently and sustainably.

The aim of this article is to conduct bibliometric analyses and assess the state of the art in studies related to the use of natural reinforcements in polymer matrix composites, aiming to gather advancements in this field and provide informative support for future research. The specific objectives of this work were: i) to quantitatively assess the growth of publications over the years; ii) to identify the authors, as well as the most relevant journals in the area, and iii) to identify the direction of scientific research associated with the use of composites.

2. Materials and Methods

The technique used for the present study is bibliographic research, a quantitative and statistical approach aimed at measuring the indices of production and dissemination of scientific knowledge, as well as the relevance of the studied area (Araújo., 2006).

Data for this research were collected through the Scopus® database from Elsevier, which is considered the largest abstract and citation database of academic literature, comprising over 22,000 titles from more than 5,000 publishers worldwide,

including scientific journals, books, and conference proceedings in various fields (Elsevier., 2020).

The analyzed publications were identified using the Scopus search engine, employing three sets of keywords as search terms (Figure 1).

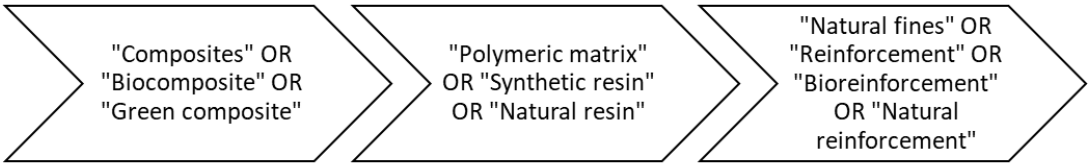

Figure 1 - Keywords for the bibliometric analysis.

The combination "OR" was chosen between the keywords to merge all results related to the topic. Based on this interaction, the "AND" combination of keyword sets was performed to obtain only the works that deal with composites using polymer matrix and reinforced with natural fibers.

The search was delimited to the period from 2014 to 2022 and only for documents written in the English language. The results were combined, totaling 357 documents. All bibliometric information from Scopus was exported in CSV (comma-separated-values) format. Microsoft Excel for Windows® 2016 was used for tabulating the statistical data. After the article selection, the "biblioshiny" function in the "bibliometrix" package of the R software (R Core Team., 2021) was employed to generate a unified table, from which graphs and tables were created. Figure 2 schematically presents the steps for obtaining the data.

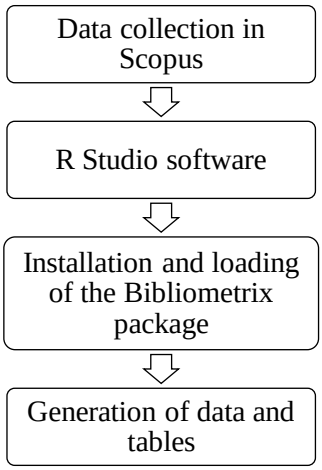

Figure 2 - Flowchart of Data Acquisition.

3. Results and Discussion

After data collection, the identified documents were accessed through indexing portals, and only those that met the selection criteria were included in this research. A total of 357 documents met the selection criteria, and from there, surveys and analyses of bibliometric indicators were conducted to gain a better understanding of the topic addressed in the study.

The number of publications within a specific time period is an important indicator of trends related to the research topic (Velez et al., 2023). The annual scientific production showed significant variation during the analyzed period (2014 to 2022), as illustrated in Figure 3. In 2014, there were only a few publications (20). From 2015 to 2022, a growing and non-linear trend in the number of publications was observed, reaching its peak in 2021 (58), indicating an increased interest in the topic. The continuous increase in publications over the years highlights the importance of the subject matter.

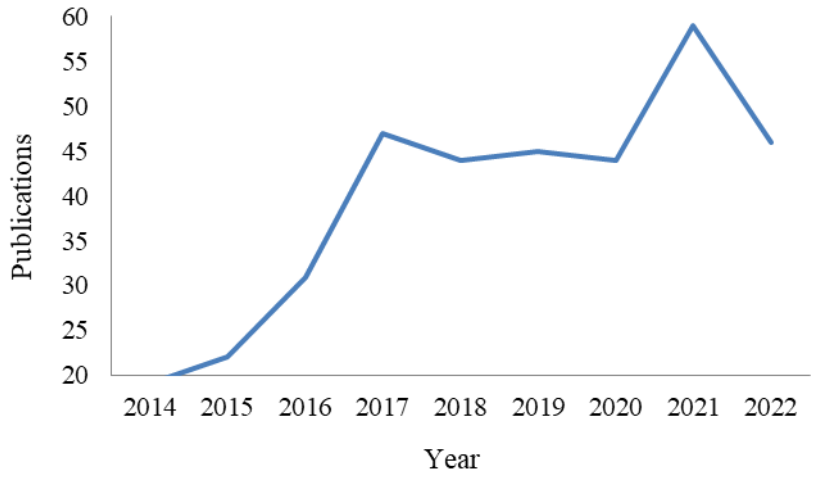

Figure 3 - Annual scientific production.

Figure 4 presents a map with the distribution of publications by territory, represented by a color scale, where darker shades indicate a higher number of publications. The territories that stood out in terms of scientific production were South America, North America, Europe, and Asia.

These regions boast an extensive history of scientific progress, dating back to the pre-modern era. Such areas make substantial investments in scientific research and technological development. Endowed with a highly qualified population that benefits from access to high-quality education and training, these regions stand out as hubs of innovation, housing companies and institutions in a constant process of developing new technologies. The convergence of these elements has contributed to the establishment of a robust scientific infrastructure in these territories, enabling them to generate a remarkable volume of high quality scientific research.

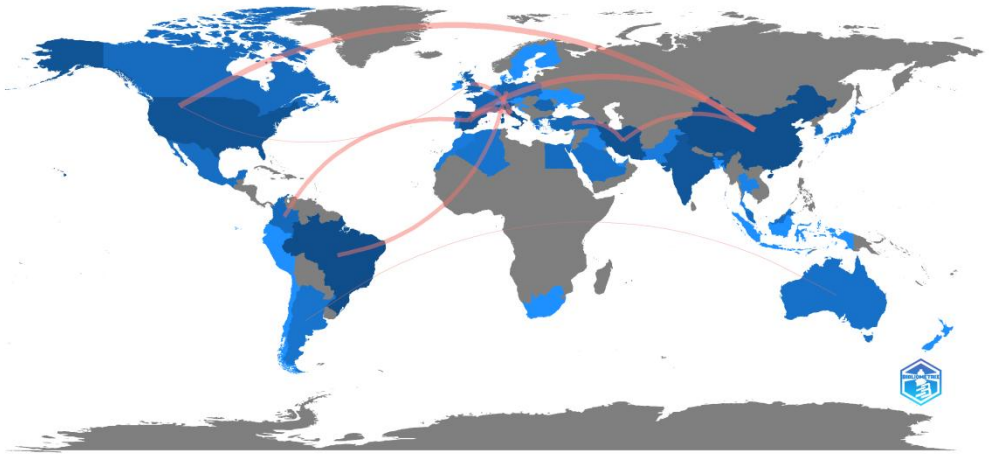

Figure 4 - National scientific production.

The analysis of scientific production by country, as shown in Figure 5, reveals that Brazil is the country with the highest number of publications, totaling 256 documents. Following Brazil, we have China with 181 publications, Italy with 139, Spain with 114, and India with 102.

The high number of studies in Brazil is believed to be largely due to the availability of vast natural resources such as wood, natural fibers, and minerals, which can be used in composite manufacturing. This creates a favorable environment for research development in this area. Additionally, another possible explanation is the fact that the country has a diversified industrial sector, including aerospace, automotive, construction, and wind energy industries, which demand advanced materials, including composites, thus driving research in this field.

These combined factors contribute to Brazil's leadership in terms of scientific production in the field of composites.

However, in the realm of research on natural fiber-based biocomposites, countries such as India, Malaysia, France, China, Italy, the United States, and Canada have emerged as leaders in recent times, fostering a significant increase in the number of articles published in this domain.

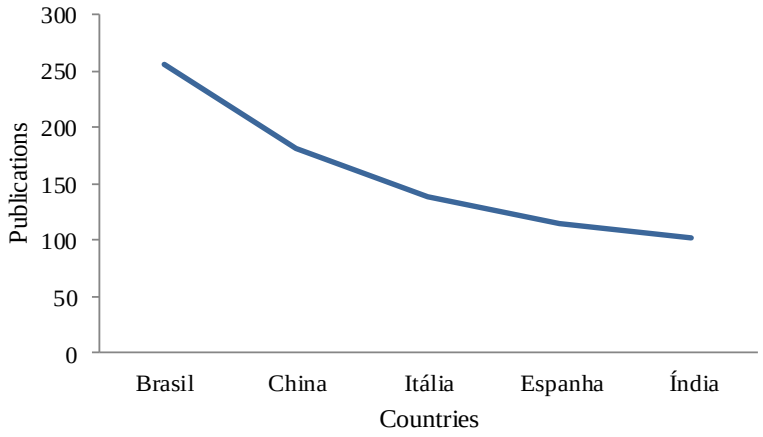

Figure 5 - Production of countries over time.

The main research sources on the topic can be observed in Table 1. Through the graph, it can be noted that the three primary sources of works are Polymers (26 documents), Composites Part B: Engineering (15 documents), and Composite Structures (14 documents).

Feldens et al., 2021 conducted a bibliometric study on the analysis of the evolution of research on fiber reinforcement in civil engineering and found similar results, with their main sources of works in the field being the journals Construction and Building Materials, Composites Part B: Engineering, and Composite Structures.

These sources are recognized as important scientific journals in the field of composites and polymers. The publication of research in these journals indicates the interest and relevance of these publications in the field of composite materials.

Table 1 - Most Relevant Sources.

Sources	Number of documents
Polymers	26
Composites Part B: Engineering	15
Composite Structures	14
Journal of applied polymer science	10
Journal of composite materials	10
Polymer composites	10
Polymer testing	7
Composites science and technology	6
Composites: Mechanics, computations, applications	5
Journal of materials research and technology	5

The first journal focuses on the fields of polymerization methods, theory, simulation, and modeling, understanding new physical phenomena, advancements in characterization techniques, and leveraging biological and self-assembly strategies for producing complex multifunctional structures (Santa et al., 2021).

On the other hand, the second journal emphasizes impactful, high-quality research on composite materials, supported by fundamental mechanics and materials science approaches. It covers aspects related to manufacturing, design, validation, characterization/testing, performance, application, and sustainability of composite materials, including functional and smart composites, new composite material concepts, as well as biomimetic and bio-based composites (MDPI., 2023).

The third journal contributes to knowledge regarding the use of composite materials in engineering structures. The articles address design, research and development studies, experimental investigations, theoretical analysis, and relevant manufacturing techniques for the application of composites in load-bearing components for assemblies, from individual components such as plates and shells to complete composite structures (Elsevier., 2023).

The most productive authors in the field of polymer matrix composites reinforced with natural fibers were identified based on the number of publications for each author Kiani Y and Venkatachalam G are the most prolific authors with seven publications each, followed by Cinelli P, Lazzeri A, and Monteiro SN with five publications each,

and finally, Balaji A and Benavente R with three publications each.

Table 2 - The most relevant authors.

Authors	Number of documents
Kiani. Y	7
Venkatachalam. G	7
Cinelli. P	5
Lazzeri. A	5
Monteiro. SN	5
Botelho. EC	4
Karthikeyan. B	4
Righetti. MC	4
Balaji. A	3
Benavente. R	3

It is evident that despite the increase in the number of publications over time, the productivity is still low.

The collaboration relationships among the authors were analyzed and expressed in Table 6. The relationship of each author with the others was studied, taking into account the size of the circle, which represents the number of publications of each author. The larger the circle, the greater the author's contribution to the subject under study. The lines connecting the circles represent the cooperation between the authors, and different colors were used to distinguish the eleven identified clusters.

When observing the figure, it can be noted that authors with the highest number of publications are clustered in the same collaboration network, identified by the color green. Additionally, it can be noted that there is no significant connection between different clusters, indicating that each cluster works independently without direct cooperation among them. This lack of interconnection may impact the exchange of knowledge and the joint development of research in the area under study.

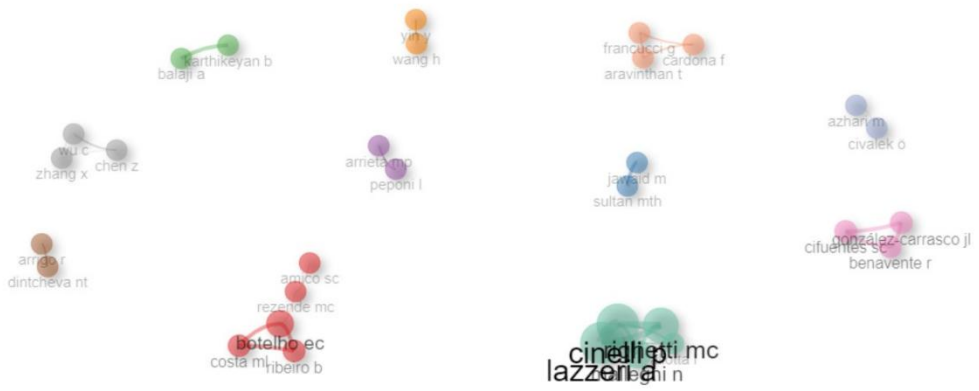

Figure 6 - Authors' collaboration network.

Analyses of the terms used in the titles and abstracts of the publications were conducted to identify trends and obtain detailed information about the subject under study. A total of 3,164 relevant keywords were identified for the research area. The research covers a broad theme related to composite materials and reinforced polymers. Among the most frequent keywords, the concept of "reinforcement" (Figure 7) stands out, involving the enhancement of mechanical properties by adding other components. Polymer matrix composites are mentioned, indicating the use of polymers as matrices and the incorporation of fibers or particles as reinforcement agents.

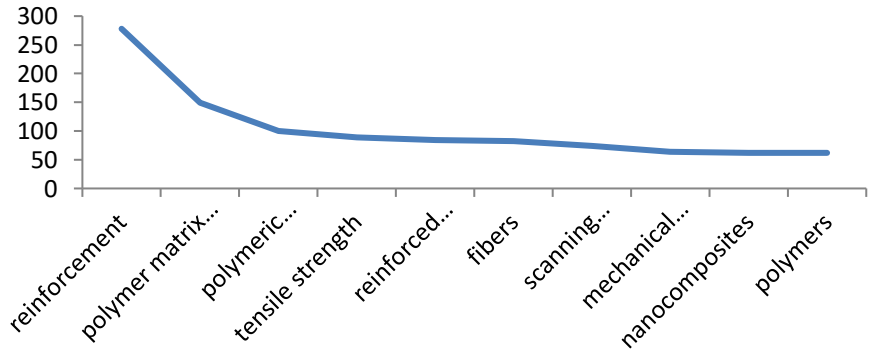

Figure 7 - The most frequently used keywords.

Among the mentioned polymer matrices, polypropylene is the most common due to its widespread availability and popularity in global-scale productions. Tensile

strength is also addressed, being an important parameter to assess a material's ability to withstand tensile forces without breaking. Additionally, analysis techniques such as scanning electron microscopy are mentioned, allowing the observation of microstructure and failure analysis.

These keywords provide a solid foundation for exploring the topic of reinforced materials and their application in various industrial areas.

In Figure 8, four distinct clusters of keywords are revealed, identified by the colors green, red, purple, and blue. The lines in the figure represent connections between the terms, with the thickness of the lines indicating the strength of the relationship between the terms. Thicker lines signify stronger connections between the items. Thus, the most prominent terms exhibit more robust interconnections.

This analysis of the keywords used in the publications provides insights into the most relevant keywords and their interconnections, contributing to a deeper understanding of the topic and identifying areas of focus in research on polymer matrix composites and reinforcements.

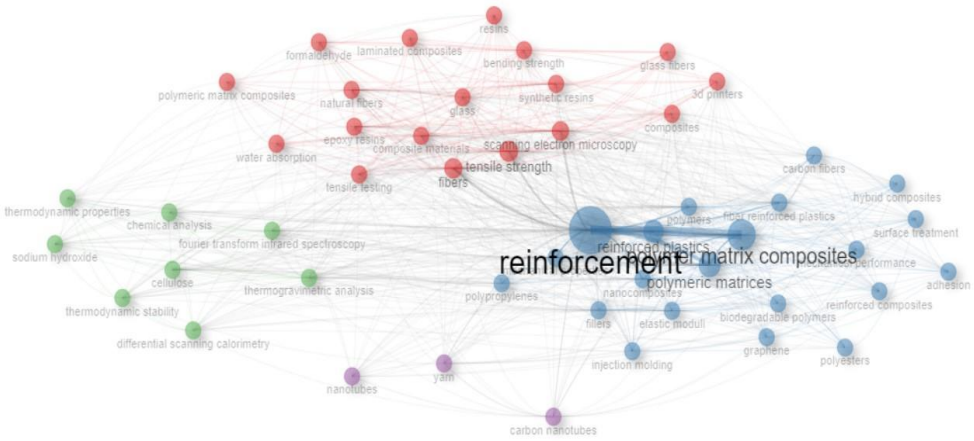

Figure 8 - Keywords interaction network.

After screening the retrieved documents, it was possible to identify the main applications of composite materials in various fields, including: Construction and architecture; packaging industry; furniture and interior design industry; toy industry; biomedical applications. Their versatility, combined with favorable mechanical and chemical properties, makes them an attractive choice in diverse industrial sectors.

In addition to having applications in different industries, the documents also revealed that natural fiber-reinforced composites can serve various purposes, such as:

- Improvement of mechanical properties: These materials enhance the strength, stiffness, and toughness of polymers, enabling the production of products with greater structural strength and the ability to withstand high loads.
- Weight reduction: They are lighter materials compared to conventional ones, resulting in energy savings and increased efficiency.
- Sustainability and lower environmental impact: The use of natural reinforcements reduces reliance on synthetic materials, such as fiberglass, which have a high environmental impact. Additionally, natural fiber-reinforced composites are biodegradable, making them more environmentally friendly.
- Thermal and acoustic insulation: They exhibit improved thermal and acoustic insulation properties, which is beneficial in construction applications, noise isolation, and the manufacturing of electronic components.

Therefore, the bibliometric analysis has provided the opportunity to trace the evolution of publication trends over time, while also highlighting the most relevant terms. Such analysis plays a pivotal role in determining research directions, identifying gaps in the discussion of the subject, and uncovering promising areas for future investigations (Glãnzel et al., 2002).

4. Conclusion

The bibliometric analysis identified the key studies on natural fiber-reinforced polymer matrix composites. There was a significant growth in publications from 2014 to 2021, indicating an increasing demand for these materials over time. However, the total number of publications is still considered low.

Authors Kiani Y and Venkatachalam G were the most prolific with seven papers each. Brazil stood out as the leading country in publications on the topic, demonstrating significant interest and potential for future research in this area.

These composite materials have been applied in various sectors, such as construction, packaging industry, furniture, toys, and biomedical applications. The use of natural reinforcements shows promise, providing improvements in mechanical properties and reducing environmental impacts compared to conventional materials.

In summary, the bibliometric analysis highlights the importance of natural fiber-reinforced polymer matrix composites, with a growth in publications over the years. The results indicate global interest in this research field, with Brazil being particularly prominent, and the potential of these materials to replace conventional materials with more sustainable alternatives.

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