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Green coconut shell as energy biomass: a bibliometric and systematic analysis of scientific literature

Abstract

The husk of the green coconut is a widely available and low-cost resource, yet often underutilized, despite carrying considerable potential as a sustainable energy source. This study is a bibliometric and systematic analysis of scientific literature published between the years 2013 and 2022, using the Scopus database as a source, aiming to examine in detail the scientific landscape surrounding the energy potential of this biomaterial. To do so, rigorous inclusion and exclusion criteria were established to select the most pertinent articles on the subject. The compiled data not only encompasses the number of publications but also identifies the most productive authors, the most prominent research areas, predominant keywords, and the geographical origin of scientific contributions. The bibliometric analysis conducted in this study reveals a clear trend of increasing interest in exploring the energy potential of green coconut husk over the years. Such a trend suggests a growing recognition, by the scientific community, of the intrinsic value of this waste as a promising source of renewable energy. Terms like 'biomass,' 'biochar,' and 'pyrolysis' often permeate the publications, outlining the main approaches to the energy utilization of this resource. Furthermore, there is a noticeable increase in participation from various countries, indicating a global interest in exploring this energy potential. This study emphasizes the importance of continuing research in this field and highlights the positive impact that the exploration of green coconut husk can have in the context of transitioning to cleaner and more sustainable energy sources.

Keywords: biochar, biomass, energy utilization, ethanol, green coconut husk

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Introduction

Coconut is a tropical fruit that thrives in sandy soils, particularly in coastal areas and tropical islands. It is widely cultivated in Asia, Latin America, and Africa, benefiting from abundant sunlight and water.[1] There is a growing demand for coconut-based products such as functional foods, functional beverages, nutraceuticals, pharmaceuticals, and cosmeceuticals, among others.[2]

Brazil is among the top 5 largest coconut producers globally. Broadly, Brazil has an approximate production of 2.8 million tons and a harvested area of 257,000 hectares.[3] In 2021, the country produced 2,457,860 tons of coconut husk, covering an area of 186,392 hectares.[4] For the coconut species known as *Cocos nucifera*, Brazil alone produced 1,829,612 tons in 2022, with a harvested area of 189,525 hectares.[5] In the same year, the Northeast region was responsible for approximately 79% of the total production of this species, reaching 1,441,990 tons and covering an area of 156,127 hectares, representing around 82% of the total area.[6]

The high consumption, especially of green coconut water, results in a significant generation of waste, primarily composed of the fruit's husk, which accounts for 62% to 65% of its total weight. The most common disposal methods for green coconut husks are landfills, dumping sites, and open dumps, leading to serious environmental issues such as soil and water contamination. Additionally, it poses risks to public health by promoting the proliferation of insects and disease vectors. Furthermore, these practices have negative impacts on the economy.[3,7]

An effective management of green coconut husks, with a more sustainable approach, brings multiple benefits, including compliance with Federal Law No. 12.305/2010, which establishes the National Solid Waste Policy,[8] and with Decree No. 10.375/2020, which institutes the National Bioinputs Program.[9] Therefore, the increasing production of this waste represents an opportunity to explore its potential, especially in the energy sector. Green coconut husks are a potential agro-industrial waste to be harnessed as an energy source in Brazil, as they constitute a carbon-rich and environmentally friendly solid fuel.[3,7]

An innovative approach for utilizing green coconut husks is their transformation into briquettes and pellets. The compression of this waste into various sizes results in a high-energy-density fuel, which can be used in thermal energy generation, replacing traditional fuels such as wood and coal. This application serves as an energy concentrator and also facilitates the transportation and storage of fuel.[3]

In Singh et al.,[7] it was pointed out that one of the ways to harness green coconut husk is in the production of bioethanol. They state that other researchers also recommend this biomass for bioethanol production. It emphasizes that in some studies, pre-treatments are conducted on the coconut husk to facilitate access to cellulose and optimize conversion into ethanol. By utilizing simultaneous processes of saccharification and fermentation, as well as separate hydrolysis and fermentation, they achieved high ethanol productivity using coconut husk cellulose.

Pyrolysis is a thermochemical conversion route of biomass into hydrocarbons, making its energetic properties more suitable.[10] Biochar is a carbonaceous material obtained through pyrolysis, and it can be used as a fuel source with potentials comparable to high-grade coals. Green coconut husks for biochar production have proven to be a promising, efficient, and sustainable strategy.[11]

The effective and judicious use of energy plays a crucial role in promoting sustainable development, mitigating environmental impact, and enhancing the quality of life for the population. This paradigm is intrinsically linked to a series of Sustainable Development Goals (SDG) in an interconnected sequence, encompassing, in the following

order, SDG 7 - Affordable and Clean Energy, SDG 13 - Climate Action, and SDG 12 - Responsible Consumption and Production. These goals were established by the United Nations (UN) as part of the 2030 Agenda.

To identify the main applications for the energy utilization of green coconut biomass, a bibliometric review proves to be a suitable method that allows for a quantitative survey of the primary scientific works developed on the subject. The bibliometric review method requires a protocol that specifies the systematic search in databases, the determination of the researched period, inclusion and exclusion criteria, and the analysis and format for presenting the results.[12]

The increasing demand for renewable and sustainable energy sources have propelled research on biomass as a viable and promising alternative. In this context, coconut husk emerges as an abundant resource, presenting significant potential for energy utilization. However, despite the growing interest in the field, there is a knowledge gap regarding trends, advancements, and research gaps related to the energy utilization of coconut husk. Therefore, this work proposes a bibliometric and systematic analysis of literature from scientific articles published between 2013 and 2022 in the Scopus database, aiming to provide a comprehensive overview of the topic. Through systematic literature review and the application of bibliometric metrics, it is hoped to identify publication trends, application areas, and research gaps. Thus, this study aims to contribute significantly to the advancement of knowledge on the energy utilization of coconut husk, providing valuable insights for researchers, industry professionals, and policymakers interested in promoting the sustainable utilization of this biomass.

Material and methods

The present study is conducted through a bibliometric literature review regarding the transformation of green coconut biomass (GCB) and its potential for energy generation over the last decade.

The literature search was carried out using the Foundation Coordination for the Improvement of Higher Education Personnel (CAPES) periodicals portal through the Scopus database, as it is one of the most important multidisciplinary databases in the academic context.[13]

The keywords used in the study were: "coconut shell," "energy potential," and "biomass." According to the selected keywords, the following string was created: TITLE-ABS-KEY ((("coconut shell" OR "coconut husk" OR "green coconut" OR "green coconut shell*" OR "green coconut husk") AND ("ethanol" OR "pellets" OR "biochar" OR "briquettes") AND ("biomass"))) AND PUBYEAR > 2013 AND PUBYEAR < 2022 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (PUBSTAGE, "final")). The following inclusion criteria were applied to the obtained results: academic articles and reviews; published between 2013 and 2022; written in English; and in the final stage of publication.

The collected data were analyzed using VOSviewer software version 1.6.8, executed with Java version 9. This tool is commonly employed in scientific research, especially in fields such as bibliometrics and information science. The choice of this software was made because it is an open-source program and accommodates formats from major academically consolidated databases. Through VOSviewer, it was possible to identify patterns of co-occurrence among the keywords in the analyzed publications. In alignment with the application of Zipf's Law, it enabled the identification and classification of trends and gaps in the scientific literature.

For a comprehensive analysis of the data, the RStudio software, an open-source R language platform, was used. With the assistance of Biblioshiny and Bibliometrix data packages, the following analyses were conducted on the data obtained from the Scopus database: analysis of the number of academic productions over the years; assessment of the number of publications by countries, allowing the identification of countries with greater academic influence; determination of the ranking of the most relevant journals; application of Bradford's Law to identify journals with the greatest academic impact on the topic of interest; identification of the most productive affiliations; use of Lotka's Law to identify the most relevant authors in terms of publication volume; and identification of articles that received the highest number of citations, highlighting publications with greater academic dissemination and their contributions to the topic at hand. These analyses were conducted to provide a more comprehensive understanding of the academic and scientific data related to the topic under analysis.

Results and discussion

According to the Food and Agriculture Organization of the United Nations (2021), from 2013 to 2022, the countries with the highest green coconut production in the world were Indonesia, the Philippines, India, Brazil, and Sri Lanka. Throughout these years, coconut production showed fluctuations. Between 2013 and 2017, coconut production experienced a significant decline, dropping from 62.3 million tons in 2013 to 58.8 million tons by the end of 2017. However, in the following year, it reached a record production for the past decade, with 65.3 million tons produced in 2018.

As shown in Figure 1, despite fluctuations in production, when plotting a trend curve, there is an observable growth trend in the production of this raw material worldwide. However, the trendline indicates a variability of 18.4%, meaning low variability, suggesting that analyzing the growth trend solely based on the volume of raw material production is insufficient to ensure a high growth trend in the coming years.

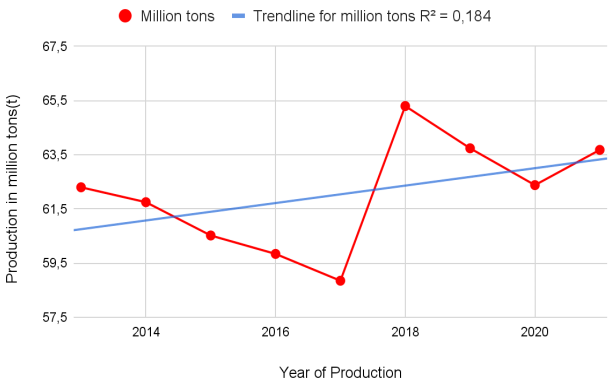

Figure 1 Green coconut production per year.

Source: FAOSTAT (2021).

This analysis points to the underlying complexity of coconut production and the need to consider a series of interconnected factors for a comprehensive and accurate understanding of the dynamics of this industry. In addition to fluctuations in production over time, it is crucial to recognize that the performance of this sector is intrinsically linked to multifaceted variables that go far beyond simple production volume. One such factor is the impact of climate change, which can directly influence coconut cultivation conditions, affecting both the

quantity and quality of the harvest. Variations in temperatures, rainfall patterns, and extreme weather events can have significant effects on coconut plantation productivity in different regions of the world.

Furthermore, the adoption and development of innovative agricultural technologies play a crucial role in maximizing yield and the efficiency of coconut cultivation, harvesting, and processing processes. Advances in irrigation techniques and sustainable management practices can contribute to increasing productivity and the resilience of coconut plantations to environmental adversities. Market demand plays a central role in determining coconut production and distribution patterns. Changes in consumption habits, consumer preferences, and global food trends can influence the demand for coconut-based products, directly impacting the economy and the viability of producers.

Therefore, for a more accurate and robust forecast of the future of the coconut industry, it is essential to consider and analyze a wide range of variables together, from climatic and technological factors to market dynamics and consumer demand. This holistic approach will allow for a deeper understanding of the challenges and opportunities shaping the landscape of coconut production and facilitating the formulation of effective strategies to drive sustainable growth in this vital sector of the global economy.

A search conducted in the Scopus database from 2013 to 2022, using the search string and applying pre-determined inclusion criteria, identified 74 publications connecting green coconut husk and its forms of energy utilization. Among these, 72 articles (97.3%) and 2 reviews (2.7%) were identified.

Due to the versatility of the raw material, which not only supports food-related uses but also holds inherent energy potential, the increase in its production has been accompanied by a corresponding rise in scientific research on the subject. According to Figure 2, the production of scientific articles has shown variations over the years, but an analysis of the trend line revealed a growth of 75.9% in article publications between 2013 and 2022. While other factors may influence, the significant increase indicated by the trend line serves as an effective indicator to demonstrate the growth trend in an article production for the coming years.

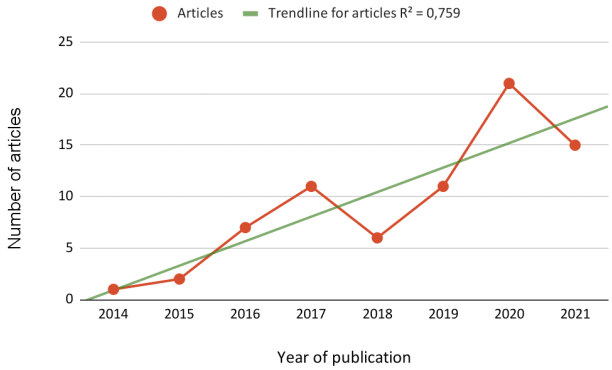

Figure 2 Scientific article production over the years.

Source: Authors (2023).

The growing scientific interest and the increasing publications about coconut husk reflect a series of factors demonstrating its importance and potential in various research areas. Coconut husk exhibits a unique versatility that extends beyond its traditional use as packaging material or agricultural substrate. Its composition rich in fibers, lignin, and other organic compounds makes it a promising source for a variety of applications, from biofuel production to the manufacturing of construction materials and chemicals.

Moreover, the growing awareness of the need for sustainable development drives the search for renewable and environmentally friendly alternatives, making coconut husk a focus of interest for researchers worldwide. The increase in coconut production in many regions also contributes to this interest, as efficient waste management becomes a priority. The inherent interdisciplinarity in the study of coconut husk, involving aspects of Agronomy, Chemistry, Engineering, and other fields, attract a wide range of researchers interested in exploring its potential applications. Thus, the growing scientific production reflects not only the relevance of coconut husk as a valuable resource but also the increasing awareness of the importance of sustainable innovation in addressing global challenges.

The development of scientific research and the volume of publications related to the energy utilization of coconuts have been notably prominent in China (35 publications), Brazil (21 publications), Malaysia (18 publications), India (17 publications), and the United States (13 publications). As evidenced in Figure 3, countries demonstrating a clear academic commitment in this domain are geographically located in the regions of Asia and the Americas. Additionally, according to FAOSTAT data,[4] it is observed that the Asia region holds a majority share of 84.4% in global coconut production, followed by the Americas with 7.8%, Oceania with 4.5%, Africa with 3.4%, and Europe with 0%. This analysis emphasizes that regions with a substantial coconut production volume also stands out for significant investment in scientific research in the field, aligning with the commitment of these countries to UN Sustainable Development Goal 12 (Sustainable Consumption and Production).

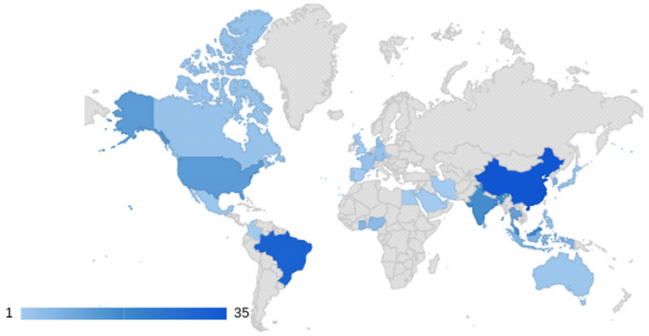

Figure 3 Number of articles published per country.

Source: Authors (2023).

Asia and the Americas are home to some of the largest coconuts producers in the world, with a long tradition in coconut production and use, which naturally sparks scientific interest in exploring its potential, including its energy utilization. Furthermore, the abundance of coconut resources in these regions provides a conducive environment for research and development of technologies related to its energy utilization. Another important factor is the increasing demand for renewable and sustainable energy sources in developing and emerging countries, where many of these nations are located.

In this regard, coconut stands out as a promising alternative due to its availability, low cost, and energy potential. Therefore, the combination of a solid coconut production base, increasing demand for sustainable energy solutions, and tradition in the use of this raw material favors the growth of scientific research on its energy utilization in the Asian and American continents.

The VOSviewer software creates keyword co-occurrence maps based on the concept of clusters. Keywords are grouped into color-coded clusters, where keywords share similarities or common characteristics are represented in the same color cluster. Additionally, the size of the nodes allows the identification of keywords that occur more frequently, which, combined with additional data, helps highlight the most common keywords, those with lower impact, and identify gaps in the research.

According to the conducted mapping, the standout keywords were: 'biochar,' 'biomass,' 'pyrolysis,' and 'coconut.' Given that the coconut biomass is the focus of the research, it is possible to identify that the pyrolysis method, which involves converting biomass into useful products such as biofuels, charcoal, combustible gases, and chemicals, was the most widespread among publications. On the other hand, 'biochar,' which is a carbonized material produced through the pyrolysis of biomass, was the most utilized form of energy utilization in the authors research.

To contribute to the keyword analysis, Zipf's Law is a statistical principle describing the distribution of ke ywords in a body of text or dataset, stating that few keywords are very common, while the majority of keywords are rare.[14] Applying Zipf's Law identified other keywords in the publications and their repetition frequencies. They are: biomass (56), charcoal (42), biochar (40), coconut (20), adsorption (19), ethanol (19), pyrolysis (19), hydrolysis (16), soil (15), and fermentation (14). Thus, it was possible to identify other forms of energy utilization and methods mentioned in the analyzed works, such as 'charcoal' and 'hydrolysis' for biofuel production, like the mentioned 'ethanol'.

The observation of the map, combined with the application of Zipf's Law, allowed us to identify some gaps, such as the absence of publications applying the pellet method and the low occurrence of publications working with briquets. This observation demonstrates that, within the literature produced in recent years, these are methods that lack further studies.

The Law of Scattering of Scientific Knowledge by Bradford (1934) enables the assessment of the significance level of scientific journals in a specific field of knowledge. Journals that have a higher production of articles on a particular topic are identified as the core journals, presumably representing higher quality or relevance within that specific area.[14] By applying the Bradford Methodology to the data extracted from the database, journals were categorized based on ranking, frequency, cumulative frequency, and zones. The ranking classification involves arranging journals according to the most significant number of publications on the topic in consideration. Cumulative frequency, on the other hand, represents the cumulative sum of the publication frequencies of all journals up to a certain point in the ranking. With the journals arranged in descending order, they are distributed into three zones, each comprising one-third of the total publications. The first zone encompasses a small number of highly productive journals. The second zone includes a larger number of journals but with lower productivity. Finally, the third zone encompasses an even greater number of journals, although each of these is characterized by even lower productivity Figure 4.[15]

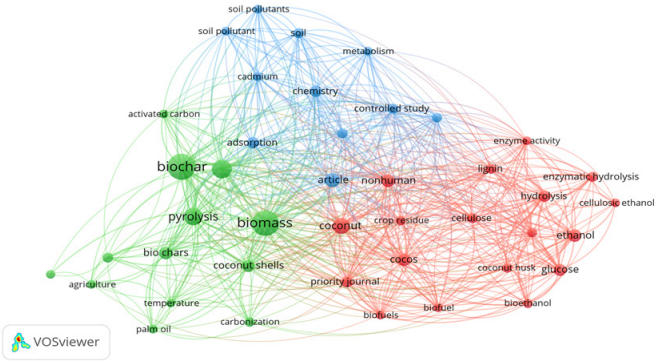

Figure 4 Keyword co-occurrence.

Source: VOSviewer (2023).

The journals that boast a high publication index, along with constant relevance and consistency over several years, were classified in the category called 'Zone 1' 'Zone 1,' that as shown in Table 1, encompasses a total of nine journals, including those ranked from 1 to 9 in the relevance ranking. In contrast, other journals that recorded a the comparatively lower impact was allocated in the categories 'Zone 2' (with 19 journals) and 'Zone 3' (with 24 journals). According to the Bradford approach, the journals identified in the 'Zone 1' category, such as Bioresource Technology, Environmental Science and Pollution Research, and Chemosphere, are those that make up the core and maintain a more intense and direct connection with the theme. On the other hand, the other journals classified in the 'Zone 2' and 'Zone 3' categories are considered part of the periphery, encompassing those with lower interconnection with the analyzed theme.

Table 1 Ranking of the most relevant sources according to Bradford's Law

Journals	Ranking	Frequency	Cumulative Frequency	Zone
Bioresource Technology	1	5	5	Zone 1
Environmental Science and Pollution Research	2	4	9	Zone 1
Chemosphere	3	3	12	Zone 1
Energy Sources, Part A: Recovery, Utilization and Environmental Effects	4	3	15	Zone 1
Waste and Biomass Valorization	5	3	18	Zone 1
Biochar	6	2	20	Zone 1
Chemistryselect	7	2	22	Zone 1
Energies	8	2	24	Zone 1
Fuel Processing Technology	9	2	26	Zone 1
Industrial Crops and Products	10	2	28	Zone 2
Journal of Environmental Management	11	2	30	Zone 2

Source: Authors (2023).

By Identifying the main affiliations involved, it is possible to understand the most important institutions in terms of publication volume, recognizing centers of excellence and academic collaborations, identifying the most involved countries and regions in research, trends in collaboration between institutions, and detecting potential research partners with similar interests and specialties, which can promote effective academic collaborations.

Brazil has proven to be an influential country not only in the production of raw materials but also in scientific production, with four Brazilian institutions among the top affiliations. As shown in Figure 5, the number of publications over the years makes the country the most represented on the list of top affiliations, namely: Federal University of Sergipe, Federal University of Alagoas, Federal University of Espírito Santo, and Federal University of Rio Grande do Norte. Although no collaborations were detected between Brazilian affiliations and foreign institutions, there is a clear collaboration among Brazilian institutions over the years.

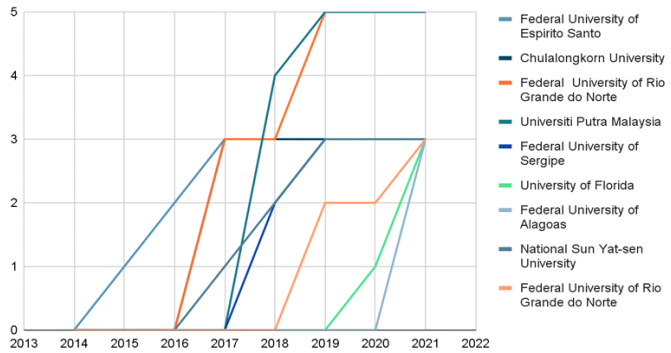

Figure 5 Principal affiliations and publica tion over the years.

Source: Authors (2023).

To assess the authors' productivity over time, the application of Lotka's Law is essential. This law asserts that the correlation between the number of authors and the number of articles published by them, in any scientific domain, adheres to the Inverse Square Law, represented by the formula $1/n^2$. In other words, during a specific period of time and when examining n articles, the number of scientists contributing to three articles would be equivalent to 1/9 of the number of scientists contributing to a single article.[15]

For the application of Lotka's Law, the identification of the number of articles and authors was conducted, followed by the use of the Inverse Square Law to obtain the publication frequency. In accordance with Lotka's principle, the results reveal that 92% of authors, corresponding to 325 individuals, published a single article, while 7% of authors, representing 25 individuals, contributed to two articles. Additionally, only 0.56% of authors, comprising 2 individuals, published three articles, and an extremely small portion of 0.85% of authors, equivalent to 3 individuals, produced four articles on the analyzed topic. These findings demonstrate that while the vast majority of authors limit themselves to a restricted number of publications, on average, only 1.5% of authors exhibit high productivity Table 2.

Table 2 Application of Lotka's Law

Number of Articles	Number of Authors	Frequency
1	325	0,9155
2	25	0,0704
3	2	0,0056
4	3	0,0085

Source: Authors (2023).

After identifying high-productivity authors, Figure 6 reveals the identity of these five researchers. All of them are Brazilian and collaborated jointly in their respective academic works. Such collaboration highlights the relevance of Brazil and its valuable contribution to the advancement of scientific research in the field. Additionally, the results demonstrate the significant interaction among researchers at the national level. However, since these researchers are the most prominent in terms of scientific production, a potential gap between research conducted in the country and collaborations with foreign institutions is also evident.

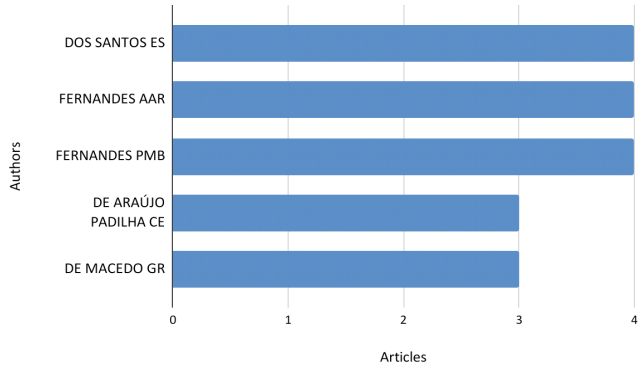

Figure 6 Most important authors and number of publications.

Source: Authors (2023).

The application of Lotka's Law contributes to the identification of researchers with high productivity, but the assessment of the impact of their contributions is conducted through other indicators, with one of the most essential being the analysis of the number of received citations. Recognizing the most cited articles allows for identifying the diffusion and recognition of a scientist by their peers, establishing intellectual property rights, and representing significant sources of information.[15] In Table 3, the most widely cited articles are listed along with the total number of citations received. The article that recorded the fifth-highest number of citations was titled *Algal Biodiesel Production with Engineered Biochar as a Heterogeneous Solid Acid Catalyst. This article* accumulated a total of 83 citations, averaging 20.7 citations per year, and was written by authors affiliated with the National Institute of Technology Rourkela in India. Reinforcing that, in addition to India ranking fourth in the countries with the highest the volume of publications, the presence of one of its publications among the top five most cited further strengthens the country's importance in expanding scientific knowledge. According to Bunushree Behera et al.,[20] acidified peanut shell biochar acts as an efficient catalyst in biodiesel production from algae oil, allowing the acidified biochar catalyst to reduce processing costs and minimize environmental impacts associated with corrosive chemicals.

The fourth most-cited article was *Porous Coconut Shell Carbon Offering High Retention and Deep Lithiation of Sulfur for Lithium-Sulfur batteries*. It received a total of 104 citations, equivalent to 14.5 citations per year, and was written in collaboration between authors affiliated with Hefei University of Technology, P. R. China, and Materials Science and Engineering Program & Texas Materials Institute, United States. The United States and China are countries that appeared in the ranking of the highest number of publications, and having a collaboratively cited article establishes the importance of countries that already have a strong research relationship with the topic establishing a connection between them. According to Chen ZH et al.,[19] the biochar produced from coconut shell carbon (CSC), used

as a cathode material for lithium-sulfur (Li-S) batteries after sulfur encapsulation in micro/mesopores, showed superior discharge-charge performance due to high sulfur retention in micro/mesopores and deep lithiation of sulfur confined in CSC. According to the authors, it is possible to produce CSC powder on a large scale in a factory through a simple carbonization-activation process, without the need for precise control of operational conditions, making it a viable option given its abundance as a plant resource worldwide. The collaboration of several countries resulted in the article *Conversion of Biological Solid Wasteto Graphene-containing Biochar for Water Remediation: A Critical Review*. The article ranked third among the most cited, receiving a total of 105 citations and 26.5 citations per year. This article was developed in collaboration between researchers from China, Australia, Germany, Saudi Arabia, Egypt, and the Republic of Korea.

Table 3 Most cited articles

Title	Total Citations	Reference
A novel modified method for the efficient removal of Pb and Cd from wastewater by biochar: Enhanced the ion exchange and recipitation capacity	221	WU, Jiawen et al.[16]
Microwave induced synthesis of magnetic biochar from agricultural biomass for removal of lead and cadmium from wastewater	162	YAP MW et al.[17]
Conversion of biological solid waste to graphene-containing biochar for water remediation: A critical review	105	Fang Zheng et al.[18]
Porous Coconut Shell Carbon Offering High Retention and Deep Lithiation of Sulfur for Lithium-Sulfur batteries	104	CHEN, ZH. et al.[19]
Algal biodiesel production with engineered biochar as a heterogeneous solid acid catalyst	83	Bunushree Behera et al.[20]

Source: Authors (2023).

The collaboration between countries with greater prominence and countries with less representation in terms of academic publications on the topic provides an opportunity for the diffusion and contribution of research by nations with a smaller presence in the scientific landscape, thus contributing to the development of the field. The article addresses the use of graphene-containing biochar as an adsorbent and catalyst, and according to Fang, Zheng et al.,[18] this is an effective and low-cost solution for the removal of toxic pollutants in contaminated environments. The article presented a highly promising economic and performance analysis of the material. The authors also emphasized the need for future research, including the regeneration of spent graphene-containing biochar and the exploration of different methods for degrading pollutants.

The article *Microwave induced synthesis of magnetic biochar from agricultural biomass for removal of lead and cadmium from wastewater* was the second most cited, receiving 162 citations and 23.14 citations per year. This publication was developed in collaboration with the Faculty of Engineering and Malaysia-Japan International Institute of Technology in Malaysia, and the Department for Management of Science and Technology Development and Faculty of Applied Sciences in Vietnam. Malaysia is among the top five countries publishing on the topic, and both Malaysia and Vietnam are among the countries with the highest coconut production in recent years. This reinforces the interest of these countries not only in being major producers but also in enhancing their production and the energy utilization of their raw materials and the impact of their contribution to scientific research.

Lastly, the article *A novel modified method for the efficient removal of Pb and Cd from wastewater by biochar: Enhanced the ion exchange and precipitation capacity* received the highest volume of citations, proving to be the most widely disseminated within the topic. It garnered 221 citations and 73.6 citations per year, a significantly higher value than other publications. According to Wu, Jiawen et al.,[16] coconut shell biochar modified with magnesium as an adsorbent was 20 to 30 times more efficient in removing heavy metals such as Pb and Cd from wastewater than the original biochar, providing a significant potential solution for the decontamination of water polluted by heavy metals.

After applying filters to the results presented by the mentioned search string, a total of 74 publications were obtained. All of their titles and abstracts were read. Subsequently, 19 articles addressing methods of energy utilization for green coconut biomass were selected. These 19 articles were read in full for a qualitative assessment of the methods employed: Hwangdee et al.,[21–39]

Among the selected publications, the following applications were identified: biochar (7 articles), ethanol (7 articles), bio-oil (1 article), production of furfural and 5-hydroxymethylfurfural (1 article), biocoke (1 article), and enhancement in lithium batteries (2 articles). No applications of pellet or briquette methods were found among the selected publications. As shown in Figure 7, the primary methods among the selected publications were ethanol (36.8%) and biochar (36.8%).

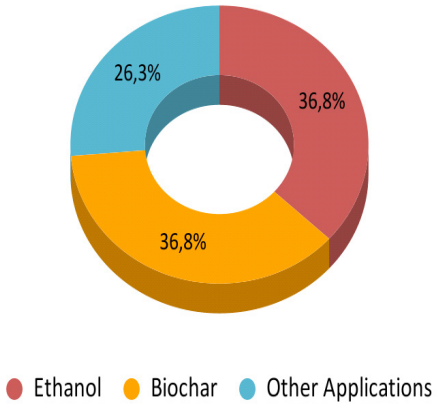

Figure 7 Methods of utilization applied in the included articles.

Source: Authors (2023).

The studies analyzed regarding biochar derived from coconut husk not only promotes environmental sustainability but also drives the economic and energy development of abundant regions in this resource. Some studies equate its energy potential to that of high-grade coal, revealing it as an efficient biofuel that can be used as a promising energy strategy in the contemporary scenario.

The production of ethanol from coconut husk represents a notable example of how agricultural residues can be transformed into renewable energy sources. Through processes of hydrolysis, fermentation, and distillation, the sugars present in coconut husk can be converted into ethanol, providing a way to harness a resource once considered waste. Studies aim to develop alternatives that bring economic viability to this application, more efficiently and productively.

The absence of publications using GCV for the production of briquettes and pellets directly related to energy purposes show that current studies are focused on developing applications and methods aimed at replacing fossil fuels, offering a sustainable and less polluting solution. Additionally, specific applications were found, such as bio-oil produced from the pyrolysis of different biomasses, the use of hydroxymethylfurfural through the catalytic conversion of sugars and biomass, the production of biocoke by the coal blending method, and the improvement of lithium batteries with carbon derived from coconut shell biomass.

Martinelli et al.[40] analyzed a very specific application: the incorporation of coconut fiber into cement-based materials. Coconut fiber, derived from coconut husk, is known for its strength, durability, and low specific weight, characteristics that make it a valuable addition to construction materials. By integrating coconut fiber into cement, it is possible to improve the mechanical properties of the material, such as tensile strength, flexibility, and toughness. Additionally, coconut fiber acts as a natural reinforcement, reducing crack propagation and increasing the durability of the final product. This approach also offers significant environmental benefits as it utilizes a renewable and biodegradable resources, reducing reliance on unsustainable materials and minimizing the environmental impacts associated with construction. Therefore, the use of coconut fiber in cement-based materials not only promote innovation in Civil Engineering but also contributes to the promotion of ecological sustainability in infrastructure and building projects.

The non-energetic use of green coconut husk represents a multifaceted and potentially transformative approach in the co ntext of waste utilization. The analysis of 55 articles revealed a diversified range of purposes for this often underestimated biomass, uncovering a surprising potential that extends beyond its simple application as an energy source, encompassing an impressive variety of uses in different sectors. The purposes found in the articles are presented in Figure 8.

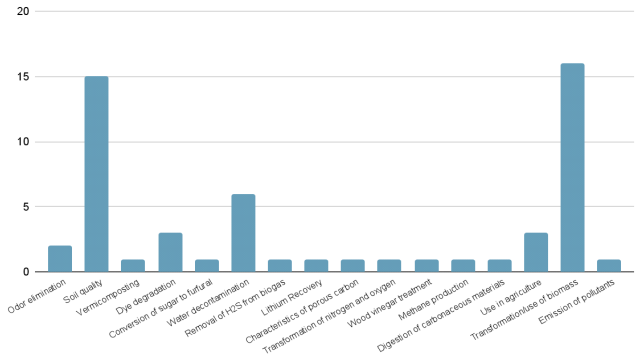

Figure 8 Number of articles by purpose.

Source: Authors (2023).

The ability of green coconut husk to contribute to the elimination of undesirable odors is one of the most notable aspects. Studies demonstrate its efficiency in absorbing and neutralizing compounds that cause bad smells, presenting itself as a practical and affordable solution to mitigate odor problems in various situations, from waste treatment to domestic and industrial environments.

Furthermore, its application in improving soil quality and in the vermicomposting process is of great significance. The nutrient richness and fibrous structure of green coconut husk make it a valuable supplement for poor soils, assisting in soil enrichment and stimulating microbiological activity, crucial for the decomposition of organic matter and ecosystem sustainability.

The ability to degrade dyes and convert sugar into furfural also stands out as an important purpose. These characteristics highlight the potential of green coconut husk in the industry, providing environmentally friendly alternatives for chemical processes and effluent treatment, thereby reducing the pollutant load released into the environment.

Another noteworthy application is assisting in the removal of compounds such as H_2S from biogas. The adsorption and purification capabilities make this biomass a valuable ally in gas treatment technologies, contributing to the reduction of atmospheric pollutants.

The green coconut husk has shown potential as a component in water filtration and purification processes. Studies highlight its ability to adsorb organic and inorganic contaminants, making it a viable option in water treatment technologies, especially in regions with limited resources.

Another relevant point is its application in Agriculture, acting as a substrate for plant cultivation. The green coconut husk can be processed into agricultural substrates, providing a favorable environment for the development of seedlings and plants. This use not only adds value to the waste but also offers a sustainable alternative to conventional substrates, often derived from non-renewable resources.

The potential of green coconut husk is not limited to these areas. Its utility in lithium recovery, transformation of dissolved nitrogen and oxygen in wetlands, treatment of wood vinegar, and even in the digestion of carbonaceous materials demonstrates its versatility, adaptability, and broad application across multiple contexts.

The detailed analysis of the articles reveals the importance of exploring and promoting the non-energy use of green coconut husk. Its physical, chemical, and structural properties pave the way for a range of innovative and sustainable applications across different sectors. The multifunctionality of green coconut husks emerges as a hidden treasure, providing an impressive diversity of uses beyond its initially conceived function. This biomass demonstrates remarkable versatility, adapting to a wide range of purposes, revealing significant potential for innovation in various sectors, promoting more sustainable practices, and offering ecologically viable solutions to diverse contemporary challenges.

Conclusion

In the analysis of publications obtained from the Scopus database related to the energetic utilization of green coconut biomass in the period between 2013 and 2022, a growing trend in academic publications were observed. This increase is particularly notable in Asian and American countries, strengthening their positions as major producers of coconut raw material and prolific contributors to scientific research on the subject. The impact of academic production from these regions is significantly manifested by holding prominent positions in the affiliation ranking and the number of publications, with Brazil standing out as the most influential country in terms of publication volume.

Citation: de Araújo APF, do Nascimento MA, Bezerra JCS, et al. Green coconut shell as energy biomass: a bibliometric and systematic analysis of scientific literature. *Int J Hydro.* 2024;8(3):106–114. DOI: 10.15406/ijh.2024.08.00381

Despite Brazil standing out as one of the largest producers of green coconut, with a significant presence in major affiliations and a high number of publications in the field, none of its publications were among the top five most cited. This indicates that, despite Brazil's substantial contribution to the research field in question, its findings have not yet gained widespread dissemination among researchers from other locations.

Among the analyzed publications, the main methods of energy utilization were identified, including the production of biochar and charcoal through pyrolysis processes, as well as ethanol production through the hydrolysis process. Other methods, such as briquette production, had limited presence, while methods like pellet production were not identified. These results suggest a need for additional studies and greater emphasis on less-explored areas in the context of energy utilization of green coconut biomass.

From the analysis of the non-energy purposes of green coconut husk, it became evident that this biomass represents a valuable and multifunctional resource. Encouraging research and the development of technologies that make the most of the properties of this biomass is crucial not only for innovation in industrial processes but also for promoting more sustainable and environmentally friendly practices in various sectors.

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Conflicts of interest

The author declares there is no conflcit of interest.

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