ENHANCING BIOFUEL PRODUCTION FROM AGROINDUSTRIAL WASTE: EXPLORING THE POTENTIAL OF STEAM EXPLOSION PRE-TREATMENT

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ABSTRACT

The present study conducted a bibliometric consideration over the past decade, focusing on using steam explosion treatment on agro-industrial waste for sustainable biofuel production. The assessment included the terms "steam explosion, waste, and fuel" within the search criteria. The outcomes of this study suggest that steam explosion treatment is a promising approach for converting lignocellulosic waste into biofuels, including biogas, methane, butanol, and ethanol. Additionally, the bibliometric analysis identified gaps and opportunities for future research in this area. As sustainability concerns continue to grow, steam explosion treatment presents a promising approach to promoting the circular economy and mitigating environmental impacts. Notably, India, the United States, and China are the countries that stand out in this study, with publications mainly in the areas of energy, environmental sciences, and chemical engineering. However, the study also reveals a gap in the literature regarding using more common or less conventional agro-industrial waste, particularly those from small properties or homes. These results highlight the need to explore new sources of lignocellulosic materials to expand the applicability of this technique.

Keywords: Biorefinery. Green technology. Biofuel. Circular economy. Sustainability.

1 INTRODUCTION

Global agroindustry is a considered source of waste generation, which comes from two different industrial processes and comprises a significant part of the waste generated on a global scale, originating in different stages of the production chain, from food production to final consumption. This agricultural waste (AW) includes hulls, seeds, leaves, and other by-products and is generated in billions of tons annually worldwide. The four primary agricultural cultures cultivated worldwide include sugarcane, corn, cereals, and rice. The total amount (by weight) produced from these crops is 16.5 trillion kilograms per year. As agricultural waste comprises 80% of this weight, there are three kilograms of agricultural waste worldwide. Only Europe produces approximately 700 million tons of agricultural waste yearly[1]. For example, Brazil has two world leaders in agroindustrial production. This waste management has enormous proportions, reflecting the force of the country's sector. The improper disposal of AW poses severe environmental risks, contributing to water and air pollution and climate change. However, there is hope in the form of biorefineries, platforms where this waste can be converted into a range of value-added products. This concept is gaining momentum, offering a promising solution and reinforcing the principles of the circular economy. By developing and implementing technologies for the reuse of AW, we can transform it into clean and sustainable energy sources like biogas and hydrogen, thereby mitigating the environmental impact of this waste.

The lignocellulosic composition of agricultural waste, characterized by cellulose, hemicellulose, and lignin, holds potential for various industrial applications, including fermented sugars and biocomposites. Hydrolysis processes are necessary to utilize these fractions effectively to extract fermentable sugars or biocomposites. Steam explosion (SE) is an efficient and environmentally friendly option among the available methods. SE involves exposing lignocellulosic biomass to high-pressure saturated steam, causing rapid pressure release and material explosion, which breaks down the lignocellulosic matrix and improves cellulose accessibility[2,3]. This cost-effective and ecologically sound approach has potential applications across various biomass types. Additionally, SE results in significant sugar recovery and enhances enzymatic digestibility, all while consuming less energy than mechanical or chemical preparations[4].

In the context of a Biorefinery for producing biofuels from fruit and vegetable waste, the waste contains a significant amount of lignocellulosic matter. It is subjected to the steam explosion process. In this process, waste is exposed to saturated steam at high pressure, breaking the lignocellulose structure and making it more accessible for subsequent processes. After steam explosion pretreatment, lignocellulosic waste is subject to enzymatic or chemical hydrolysis. These processes break down cellulose and hemicellulose into fermentable sugars such as glucose and xylose. Microorganisms are then used to ferment these sugars, producing biofuels like ethanol or biogas. By integrating the steam explosion process into a biorefinery, fruit and vegetable waste can be converted into products with commercial value. This creates a closed cycle, where resources are used efficiently and sustainably, following the principles of the circular economy.

This review aims to investigate the use of steam explosion treatment on various AW reported in the scientific literature to evaluate its effectiveness and viability as a pre-treatment method for producing biofuels from these lignocellulosic materials. It is expected to advance knowledge in this area and promote more sustainable practices in managing AW, aligned with the circular economy principles.

2 MATERIAL & METHODS

This study used bibliometric techniques to analyze scientific production, focusing on publications dealing with the application of steam explosion in AW. A bibliometric analysis was conducted using searches in the Scopus database, exploring a collection of information on the topic. The keywords used were refined for the search, resulting in 2,003 articles for “steam explosion,” 353 articles for “steam explosion,” and “waste,” and finally, 44 articles for “steam explosion” and “fuel.” The search was limited to document types "article" and "review," covering the period from 2014 to 2024. From this analysis, trends in research in this sector were also identified within the analyzed time frame, as well as the leading journals for publication, authors, and most cited articles, among other pertinent information for understanding the topic. The selected articles were exported and analyzed using VOSviewer© (version 1.6.20) and applied to form maps of the network of journals, countries, institutions, authors, and most published and cited keywords in the field.

3 RESULTS & DISCUSSION

SE pretreatments are becoming more attractive than conventional pretreatment techniques, such as using acids or bases, as they are simple, with low capital investment, high scalability, and reduced chemical risks (Figure 1). The waste cited in the selected articles that used SE technology addressed pasture biomass, corn straw, orange peel, municipal solid waste, corn stubble, seed cake, and palm waste to obtain biofuels, such as biogas, methane, butanol, and ethanol. However, there is still a gap in the literature regarding using the most commonly discarded AW in agro-industry and residential homes.

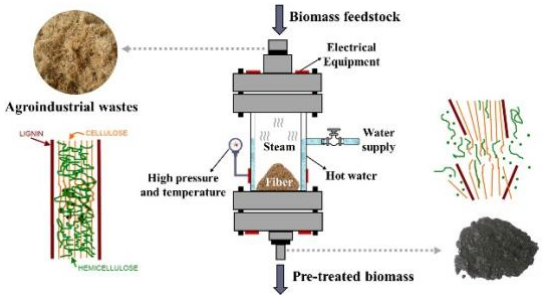

Figure 1 Schematic representation of steam explosion technology for pre-treatment of lignocellulosic biomass.

The research findings show that in recent years, India, the United States, and China have stood out in the study of using waste from SE black treatment to produce biofuels (Fig. 2A). Articles have been published, especially in the areas of energy, environmental sciences, and chemical engineering (Fig. 2B), sectors that are increasingly concerned with sustainability and clean energy production. Figure 2. Analysis of the countries where research into technologies that use steam explosion for pre-binding waste is concentrated (A) and the primary publication areas (Data based on the search on the Scopus platform “Steam Explosion,” “Waste,” and “Fuel).

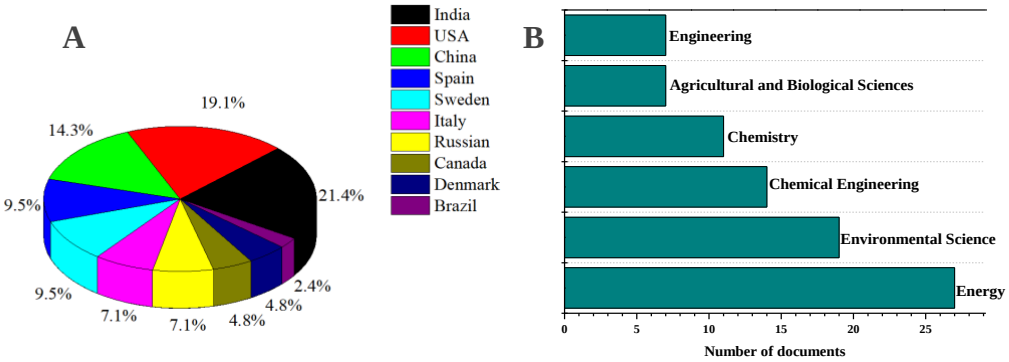

Figure 2 Analysis of the countries where research into technologies that use steam explosion for pre-binding waste is concentrated (A) and the primary publication areas (Data based on the search on the Scopus platform “Steam Explosion,” “Waste,” and “Fuel).

Table 1 and Figure 3 present a set of clusters of keywords related to the use of the steam explosion technique in the pre-treatment of AW for the production of biofuels. SE is a technique that involves the use of water vapor at high pressure and temperature to break down the complex structure of lignocellulosic biomass, making it more accessible for subsequent steps of conversion into biofuels. Cluster 4, which is directly related to the topic in question, includes terms such as "Agricultural Waste," "Bioethanol," and "Biofuels," indicating a specific focus on the application of AW in the production of biofuels. The presence of "Steam Explosion" in this cluster suggests that steam explosion is one of the techniques considered for pre-treatment of this waste. Including terms such as "Enzymatic hydrolysis" and "Ethanol" in this cluster also indicates the importance of biochemical conversion processes in producing biofuels from treated waste. Furthermore, the table highlights the relevance of other clusters, such as Cluster 1, which addresses environmental and safety issues associated with biomass, and Cluster 3, which deals with anaerobic conversion processes, complementing the general context of biofuel production from agro-industrial waste.

Table 1 Keyword co-occurrence clustering map for the period of 2014-2024

N°	Cluster 1	Cluster 2	Cluster 3	Cluster 4
1	Biomass	Ammonia	Anaerobic digestion	Agricultural wastes
2	Carbon dioxide	Biofuel	Cellulose	Bioethanol
3	Environmental impact	Biofuel production	Lignin	Biofuels
4	Explosions	Fermentation	Lignocellulose biomass	Crop residue
5	Fossil Fuels	Hemicellulose	Methane	Enzymatic hydrolysis
6	Greenhouse gases	Hydrolysis	Pre-treatments	Ethanol
7	Steam explosion	Lignocellulose	Refining	
8	Straw	Water vapor		

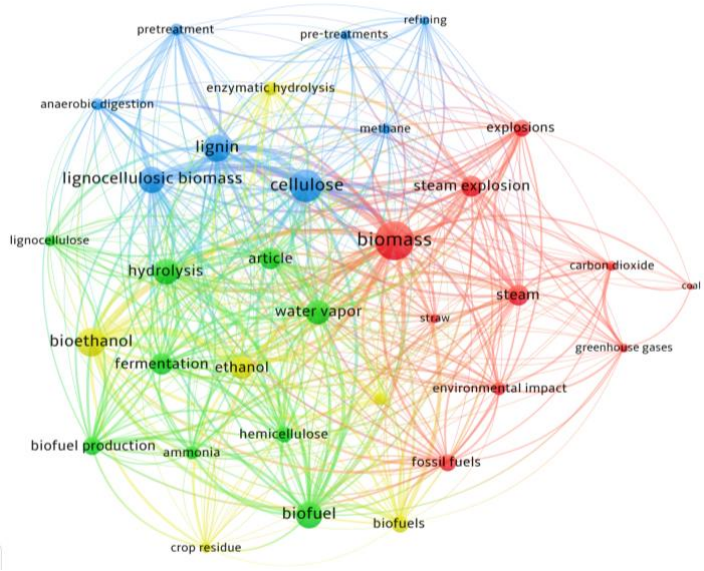

Figure 3 Keyword co-occurrence clustering map for 2014–2024 (Data based on the search on the Scopus platform “Steam Explosion,” “Waste,” and “Fuel)

4 CONCLUSION

This study investigated the use of steam explosion on agro-industrial waste to produce sustainable biofuels. The results highlighted the promising potential of this technique in efficiently converting lignocellulosic waste into valuable products. Furthermore, the bibliometric analysis identified gaps and opportunities for future research. In a growing concern about sustainability and reducing carbon emissions, applying this treatment represents a promising approach to promoting the circular economy and mitigating environmental impacts. One gap identified was the lack of studies on more common or less conventional agro-industrial waste, especially those from small properties or homes. This suggests a need to explore new sources of lignocellulosic materials to expand the technique's applicability.

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