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Bibliometric Analysis on Biochar Research in the Philippines

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Abstract

This review aimed to analyze the status of biochar research in the Philippines over the past twenty years (2004-2024) in order to provide direction for future research. The bibliometric analysis of 215 publications from Scopus and Google Scholar using Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) showed that the trends in biochar research in the Philippines are increasing for various uses. However, collaborations, the number of researchers, and other problems related to funding, policies, markets, and human factors need to be addressed to advance biochar research in the country. The current thematic clusters include identifying suitable biomass sources for pyrolysis, exploring the adsorptive properties of biochar in the environment, and utilizing it as a carrier for arbuscular mycorrhizal fungi (AMF). However, the limited clusters imply fewer applications, indicating the potential for biochar to expand into various other utilizations. In addition, the economic return has not been thoroughly studied, which affects the adoption of technology by end users. Chronologically, biochar has been observed shifting from identifying potential biomass sources to a more field-specific utilization, which suggests advancements in biochar research, although further exploration is recommended.

Keywords

Biochar review, VOSviewer, visualization, application, Philippines

Introduction

Biochar is a material produced from the pyrolysis of carbon-rich materials derived from plants or animals in an inert environment (Kocsis *et al.*, 2022). It is a well-researched material known for its wide applications in agriculture and the environment (Das *et al.*, 2020). Due to its unique physicochemical properties, it has been utilized in various fields concerning air, soil, water, and organisms (Gorovtsov *et al.*, 2019; Wang & Wang, 2019; Hussain *et al.*, 2020). Moreover, there has been a growing interest in modifying biochar for specific uses (Huang *et al.*, 2020). Modifications through acid and

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alkaline washes, amination, gas purging, steam, thermal treatments, plasma treatments, sulfuration, nitrogenation, and compositing are among the various methods to modify the properties of biochar (Wang & Wang, 2019; Huang *et al.*, 2020). The main reason for modifying biochar is attributed to the improvement of the physicochemical properties of the biochar, such as pH, electrical conductivity (EC), functional groups, porosity, elemental composition, and adsorption capacity (Panwar & Pawar, 2020). These studies have been verified as beneficial in terms of the potential of biochar applications in agriculture, the environment, and energy (Wu *et al.*, 2020). However, understanding the present progress, development trends, and research topics could provide further direction in many other fields (Yan *et al.*, 2020). The global biochar research trends from 2011-2015, 2016-2018, 2019, 2020, and 2021 show extensive and intensive applications, advancing biochar worldwide (Wu *et al.*, 2019; Wu *et al.*, 2020; Wu *et al.*, 2021; Wu *et al.*, 2023). However, the perspective from a local level may be different, affecting the advancement of biochar research in the Philippines.

In the Philippines, biochar has been studied in various fields, benefiting agricultural and environmental systems (Carnaje *et al.*, 2015; Sarong & Orge, 2015; Aggangan *et al.*, 2019a; Jamao-as & Aggangan, 2019; Chiam *et al.*, 2020; Doctolero *et al.*, 2020; Oblepias *et al.*, 2020; Salvacion & Pangga, 2020; Solis *et al.*, 2022; Bulfa *et al.*, 2023; Gonzales *et al.*, 2023). These studies present a growing utilization of biochar in the Philippines. However, due to its increased utilization, understanding the trends within the Philippine context could provide directions for future research to further expand and deepen biochar applications in the country. In addition, although research studies have expanded, the number of published articles from specific fields within the Philippine context remains limited. Thus, a bibliometric analysis of published research articles on biochar conducted in the Philippines within a given time frame can provide insights into the status of biochar applications and future directions. The present review examines the trends, author diversity, biochar feedstock sources, primary utilization focuses, economic returns, and chronological advancement of biochar research in the Philippines.

Bibliometric analysis

Summarizing studies on biochar applications provides insights that can help identify hotspots and present research frontiers, advancing biochar applications (Wu *et al.*, 2021). Performing a bibliometric analysis can assist in identifying research gaps, publication trends, and directions in biochar application (Arfaoui *et al.*, 2019), providing a comprehensive understanding of the topic over a specific period (Abdeljaoued *et al.*, 2020).

A schematic diagram of the bibliometric analysis is presented in **Figure 1**, employing Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Page *et al.*, 2021). The literature data used in this bibliometric analysis were obtained and merged from Scopus and Google Scholar (Abdeljaoued *et al.*, 2020). For the search criteria, the word "Philippines" was combined with "Biochar Production", "Biochar Crops", "Biochar Soil", "Biochar Heavy Metals", "Biochar Carbon Sequestration", "Biochar Gas", "Biochar Environment", "Biochar Water", "Biochar Microorganism", "Biochar Animals", "Biochar Characterization", or "Biochar Modification" to obtain all related research studies on biochar that have been conducted in the Philippines over the past 20 years. This covered the period from January 1, 2004 to December 31, 2024, totaling 215 screened research studies, with 152 indexed in Scopus. After searching, the articles were saved as RefMan RIS files containing all the citations and organized in Mendeley Desktop software version 1.19.8, where individual citations were checked for missing data by inputting the authors' keywords and abstracts from their original papers. Further, duplicated articles and potentially predatory articles were identified and removed, ensuring the credibility of the published papers. Inclusion and exclusion criteria for full reading were followed, resulting in only 51 articles being added as references for the review. However, all 215 articles were

considered in the analysis to generate visualizations. The initial analysis was conducted using Microsoft Excel 2019, resulting in a line graph that covered the past 20 years of biochar research in the Philippines. Then, the RIS file was exported and analyzed based on the database metrics of the search, and the results were visualized in VOSviewer software version 1.6.20 to generate network maps, link strengths, associations, and occurrences of authors and keywords, including abstract word mining (Kumar *et al.*, 2023).

Co-authorship analysis in VOSviewer was conducted using full counting, with a minimum of one document per author to retrieve all data from the RIS file. This ensured that all authors were included, considering the limited publications available for the review. The maximum length was set at 30, allowing for full-size variation and emphasizing the most notable authors. Similarly, an authors' network visualization was conducted, but only the most extensive set of connected authors was considered, as per the software's data analysis prompt, due to the limited connections among Filipino authors.

Keyword analysis on the VOSviewer's co-occurrence analysis was done at full counting, with a minimum of two occurrences. However, to obtain a refined analysis that focused only on the utilization of biochar, the words "biochar" and "Philippines" from the co-occurrence of keywords were excluded. The network visualization, density visualization, and overlay visualization were automatically generated with the keyword analysis. Thematic clustering of the keyword analysis was determined by identifying the strength of associations from the generated visualizations.

Results and Discussion

Trends of biochar research

Biochar is the solid product of heating feedstocks without oxygen (Bolan *et al.*, 2022). The number of published biochar research studies conducted in the Philippines over the past 20 years has grown exponentially (**Figure 2**). From 2004 to 2024, a total of 215 biochar-related research articles were published in the Philippines based on the Scopus and Google Scholar databases. In comparison, China, the United States of America (USA), Australia, the United Kingdom (UK), and Germany contributed the highest numbers of publications on biochar research, ranging from 300 to more than 3000 (Li *et al.*, 2019). From a worldwide perspective, biochar-related literature has reached over 30,000, indicating its global importance (Yang *et al.*, 2023). Interest in biochar research in the Philippines began in 2010, when fewer than five articles related to biochar were published, indicating that pyrolyzed biomass was relatively new at that time. This interest followed the global increase in biochar-related publications in 2010 *(Kumar et al.*, 2023). A surge in published biochar-related articles was recorded between 2016 and 2018,

Figure 1. Schematic diagram of the bibliometric analysis

reaching 30 published each year. A downtrend in the number of published articles was observed from 2020 to 2022, followed by a surge in 2023. However, the number of articles related to biochar was still relatively low compared to other countries. In comparison, the leading countries in biochar research publications in 2017 were China, with 800 articles, and the United States, with 500 articles. In contrast, the Philippines published fewer than five articles on biochar during the same period, when the country had just begun its biochar research (Li *et al.*, 2019). In the 2022 Global Innovation Index (GII), the Philippines ranked 59th, dropping eight places from its position in 2021. Similarly, the country's ranking in innovation inputs fell from 72nd in 2021 to 76th in 2022. Innovation outputs also dropped from 40th in 2021 to 51st in 2022, attributed to weaker knowledge and technology output performance, primarily influenced by knowledge creation, impact, and diffusion. The Department of Science and Technology (DOST) has identified various factors contributing to the low productivity of research output in the Philippines (Philippine Development Plan 2023-2028). The country's gross expenditure for research and development (GERD) was lower than that of Singapore, Vietnam, and Malaysia (UNESCO Institute for Statistics) (UIS, 2024). According to Jandoc *et al.* (2024), there are various attributed problems the Philippines has faced in research and development, which they enumerate as follows: (1) low budgets, (2) rules on procurement are complex, (3) hampered technology transfer due to missing markets, (4) lack of complementarity individuals in human resources, and (5) insufficient clarity and coherence in the vision for harnessing innovation. These can be rooted in the system of governance and policymakers, making it harder to acquire the needed support for research and development that could benefit the nation. Although biochar can fall under the crops research and development agenda under the Harmonized National Research and Development Agenda (HNRDA-AANR 2022-2028) of the DOST under the Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development (PCAARRD), the limited acceptance of research proposals due to low funding hampers the progress of biochar research in the country (DOST-PCAARRD, 2021).

The biochar trend in the Philippines has been increasing steadily over the past 20 years and is expected to rise further with advancements in technology and growing demand for its applications. Some of the possible drivers that can be correlated with the increase in biochar research include research funding (Mehmood *et al.*, 2017), a global scientific network and author collaboration (Chen *et al.*, 2023), and improvement in technology on characterization (Amin *et al.*, 2016). The rise in biochar research indicates growing interest in its utilization in various fields, most importantly in agricultural and environmental applications. However, the

Figure 2. Publication trends in the Philippines (2004-2024)

problem with published articles related to biochar production and utilization is that 29.3% of published articles have not been Scopus-indexed, impacting their credibility and reliability. In contrast, 70.7% of the articles have been indexed in Scopus, indicating a higher credibility of publications in various journals on biochar research in the Philippines.

Co-authorship analysis on biochar research in the Philippines

Between 2004 and 2024, prominent researchers, including Tan (14), Aggangan (13), and Orge (12), contributed to approximately 15% of the total publications on biochar (**Figure 3a**). While these researchers are among the most prolific in the field, their output over the past two decades has remained relatively modest. One key factor is that biochar research represents only a small fraction of their scholarly work. For instance, despite having 764 published articles listed on Google Scholar, Tan has only contributed 14 articles (or 1.8%) focused explicitly on biochar production, utilization, and characterization. This suggests that, despite growing interest in biochar, there remains a gap in focused, specialized research within the country.

The analysis further examined the strength of associations among researchers, focusing on the number of unique co-authorships and collaborations (**Figure 3b**). Three significant collaboration clusters were identified, with Mark Daniel De Luna, Sergio Capareda, and Catalino Alfafara emerging as key authors within each of these clusters. Surprisingly, the most productive researchers were usually associated with networks within their institutions, or, in some publications, the collaborations were limited to two or three authors. Abramo *et al.* (2017) stated that collaboration benefits an organization's research productivity. The visualization also showed limited collaborations with international researchers on biochar in the country. This finding reiterates the importance of collaborative networks in advancing biochar research productivity in the country.

While the co-authorship's density and network visualizations in biochar research in the Philippines imply positive collaborations, few researchers obtained very high densities **(Figure 3a**). In addition, the network visualization (**Figure 3b**) also shows limited connections among Filipino researchers, indicating fewer collaborations. The reason can be attributed to the growing number of researchers interested in biochar utilization and the expanding scope of its applications, where authors discover other potential uses and modifications of biochar. Similar analyses were conducted by Kumar *et al.* (2023) and Xu *et al.* (2025) from global perspectives, where biochar was found to be multifaceted even under the same utilization category. For instance, Gamboa-Herrera *et al.* (2021) utilized biochar to improve the bioavailability of mercury from mine tailings, attributing the improvement to the adsorption of heavy metals. On the other hand, Sabijon & Gulla (2018) used guano biochar to improve the growth and yield of sweet corn, indicating its application as fertilizer. The two articles were related only in terms of biochar but differed in their application. This leads to fewer co-authorship network associations due to the many fields of application.

Thematic clustering of biochar research in the Philippines

Different materials used for pyrolysis

Cluster 1, presented in **Figure 4a**, was found to be the largest and most diverse cluster of associated topics on biochar research related to the use of different biomass sources for pyrolysis. Biochar research starts with finding biomass from agricultural waste (Enaime & Lübken, 2021), such as wood chips (Yuan *et al.*, 2016), herbaceous biomass and grasses *(Wang et al.*, 2015), and other possible materials. Using various agricultural wastes in the Philippines has been common in producing biochar. In particular, rice hulls as a feedstock for biochar were among the first to be explored during the early stages of biochar research in the Philippines (**Figure 5**). Using waste as a feedstock for biochar production is a potentially productive approach in sustainable waste management (Ahmed *et al.*, 2024). Although variabilities in waste feedstock composition, moisture content, and contaminants pose challenges in optimizing

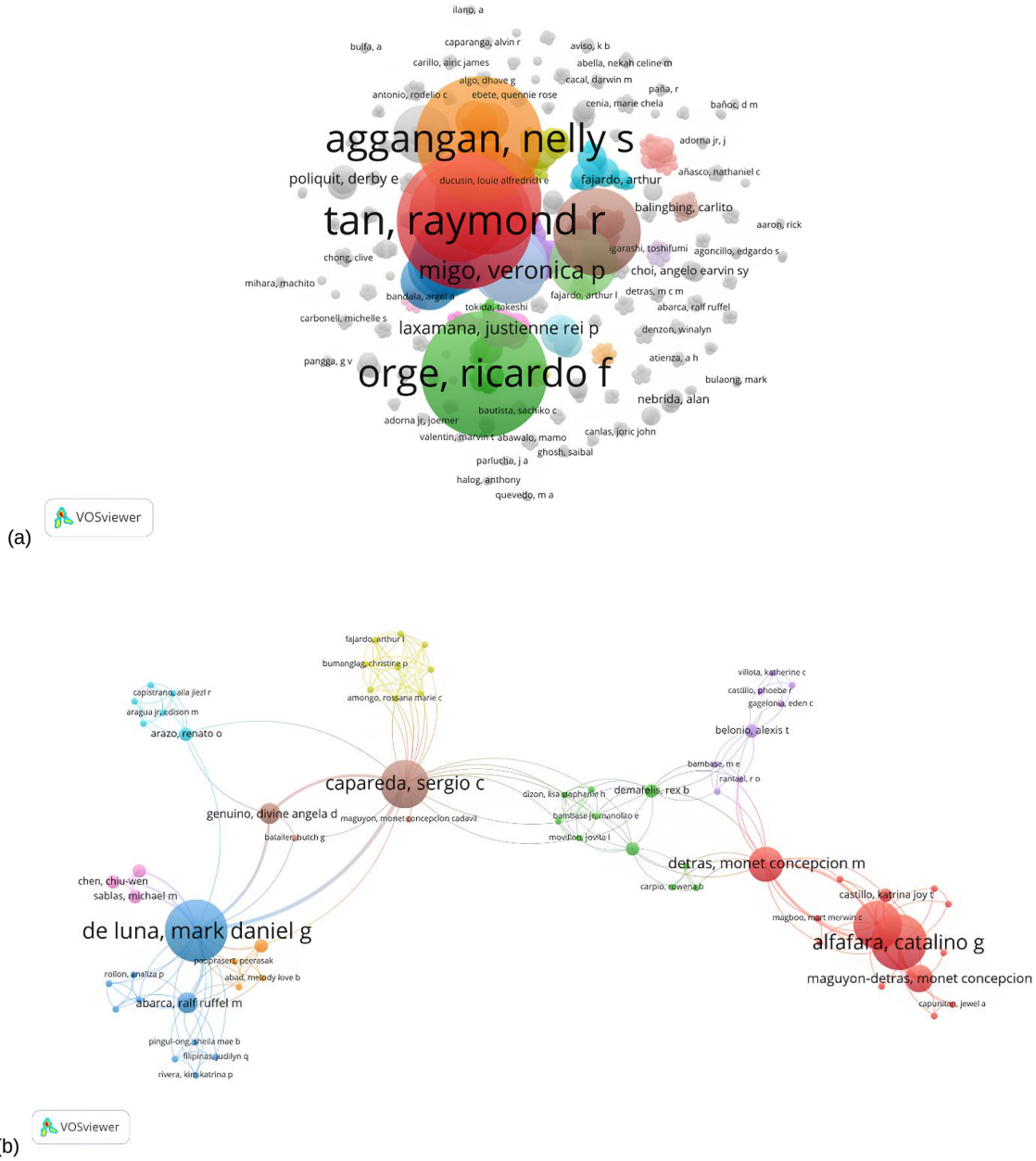

Figure 3. Co-authorship analysis of biochar research in the Philippines: (a) density visualization and (b) network visualization of association strengths

biochar research, they have led to the exploration of various materials as feedstocks for efficient biochar production in the country. In more recent years, new research avenues have emerged, such as the use of biochar as a composite material and the exploration of alternative biochar feedstocks, extending beyond the commonly used rice and coconut husks (Salvacion & Pangga, 2020; Martin *et al.*, 2022; Solis *et al.*, 2022; Nebrida & Rodolfo, 2024). The popularization of biochar among researchers has resulted in the production of biochar derived from various materials, including sawdust, dried banana leaves, cacao pods, tobacco stalks, coconut shells, and banana peels (Vicente *et al.*, 2014; Martin *et al.*, 2022). Other locally sourced materials from native and invasive plant species could also be potential feedstocks, however, no research on locally sourced biomass made from native or invasive plants has been published, leaving room for potentially new biomass sources in biochar research.

Cluster 1 also includes studies on determining the optimal pyrolysis temperature, residence time, and inert environment, which can affect the quality of the resulting biochar, especially its physicochemical properties (Zhao *et al.*, 2018). Aside from the challenges posed by the variable properties of feedstocks, the energy demands of biochar production and the logistical challenges in waste collection hinder consistent biochar quality and production efficiency, affecting biochar productivity in the country. With the given studies primarily focusing on biochar production for the pyrolysis process, biochar research in the Philippines is still relatively new. While it was found that this cluster had the largest density from the total published articles (**Figure 5b**), the continuous search for potential biomass sources for biochar production is still relevant since the studies in the country are still fewer compared with other countries worldwide (Laghari *et al.*, 2016; Tripathi *et al.*, 2016; Wang *et al.*, 2020). In the review by Márquez *et al.* (2024), the Philippines was far below the top 15 productive countries in pyrolysis research. Meanwhile, China held the top spot from 2017 to 2022, while the neighboring country of Malaysia secured the seventh rank globally.

In **Figure 4b**, a notably low density is observed in the application of biochar for improving soil fertility, biorefinery, and carbon management networks. This indicates potential research focuses that benefit soil productivity, carbon sequestration, and biofuel production. However, these are only a few topics, considering the wide possible applications of biochar in various fields, which have steadily grown over the years. In comparison to other countries, biochar has been used for microplastic reduction (Seetasang *et al.*, 2025) and antibiotic degradation (Jian *et al.*, 2025). Moreover, the density visualization analyzed a total of 215 publications only, indicating that although there are already research hotspots, the number of publications under the three identified clusters remains low. This suggests that the topics could be further explored and expanded to reveal additional potential benefits.

Using biochar for the adsorption of various elements and compounds

Biochar has a sorptive characteristic, which has been a research topic in the Philippines as indicated in cluster 2 in Figure 4a. The sorptive capacity of biochar is primarily attributed to its physicochemical properties, especially the presence of a porous structure, high surface area, and oxygen-containing functional groups (Panwar & Pawar, 2022). Notably, the application of biochar for the adsorption of various chemicals has gained interest in the Philippines (**Figure 4a**). In total, 39 publications were related to using biochar for adsorption. This indicates that this field is steadily gaining more interest among researchers. The second largest cluster indicates that biochar research in the country has increased due to its application in chemical adsorption. Understanding the properties of biochar can provide insights into its potential applications and offer benefits in finding answers and solutions. Possibly the most important aspect in its characterization is attributing the changes in soil, water, and air to the physicochemical properties of biochar (Gwenzi *et al.*, 2021; Kumar *et al.*, 2022; Qiu *et al.*, 2022). With this unique property of biochar, research studies on heavy metal adsorption (Papa, 2017; Canlas *et al.*, 2019; Oblepias *et al.*, 2020), carbon dioxide sequestration (Peñaflor *et al.*, 2019), methylene blue (Parlucha & Razal, 2022; Gonzales *et al.*, 2024), pesticides (Cruz *et al.*, 2023), and even ibuprofen removal (Capistrano *et al.*, 2023) have become the focus of various biochar research in the Philippines. Given biochar's role in sequestering heavy metals, carbon dioxide, and other pollutants, the demand for potential environmental remediation is also timely and necessary (Bulfa & Pangga, 2017; Sabijon *et al.*, 2019; De Luna *et al.*, 2020; Jose *et al.*, 2021; Verdida *et al.*, 2023; Alfonso *et al.*, 2024).

It should be noted that adsorption is one of the country's primary focuses of biochar research (**Figure 4a**). This can refer to soil, water, and air contaminants, which have been investigated in various biochar studies in the Philippines. For instance, Genuino *et al.* (2018) examined the adsorptive capacity of biochar on municipal solid

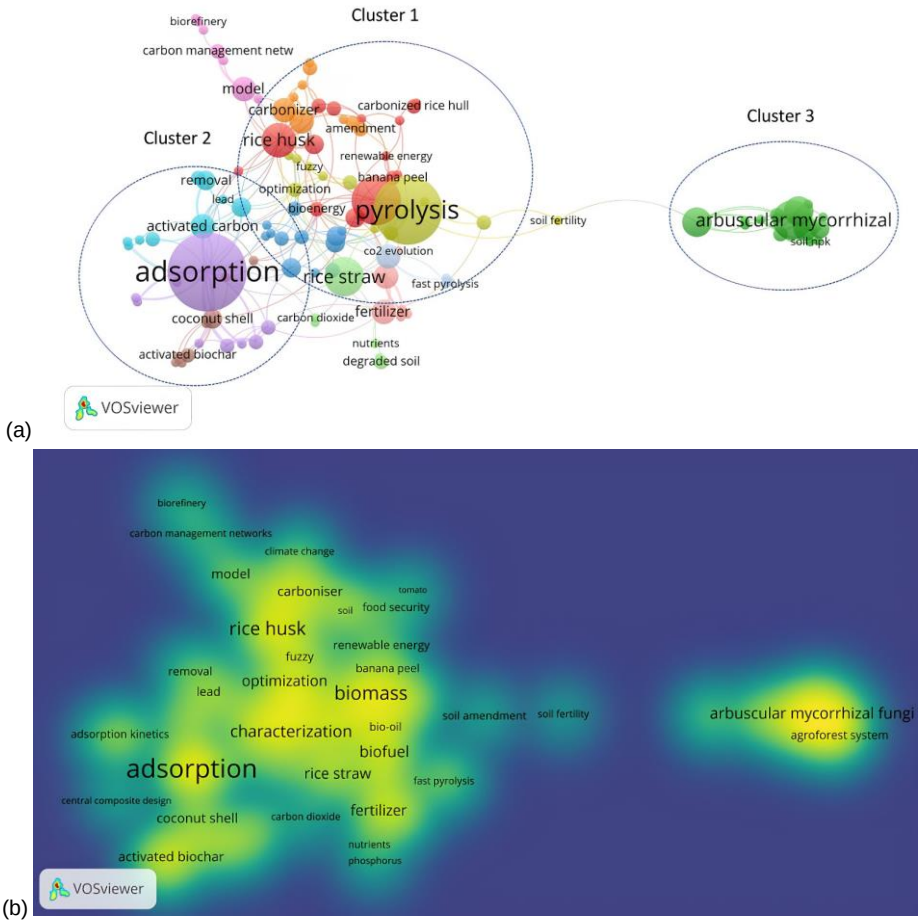

Figure 4. Research trends in the Philippines: (a) network visualization and (b) density visualization of biochar research

waste, leading to the removal of chemical contaminants. In another study, Sacdalan *et al.* (2023) utilized biochar to sequester CO_2 in cement, increasing sequestration as determined by a gas sensor test. Heavy metal adsorption is another important use of biochar for environmental improvement. In the study of Ignacio *et al.* (2024), biochars from different biomass sources were used to adsorb excess phosphates in water, reducing levels by more than 90%. Given the results of published articles on the applications of biochar in the environment, it has become a hot topic among researchers who aim to reduce or slow down the impacts of environmental degradation.

Biochar as a carrier for arbuscular mycorrhizal fungi

The application of biochar as a carrier for arbuscular mycorrhizal fungi (AMF) has gained interest in the Philippines, as indicated in cluster 3 in **Figure 4a**. The cluster of research studies on arbuscular mycorrhizal fungi particularly focused on the growth response and nutrient uptake of crops such as cacao (Aggangan *et al.*, 2019a; b; Cortes *et al.*, 2020; Cortes *et al.*, 2021), falcata (Rollon *et al.*, 2018), sorghum *(Rollon et al.*, 2017), and bahiagrass (Aggangan & Iringan, 2019). The use of biochar as a carrier for AMF can be attributed to its ability to enhance the abundance and infection rate by modifying the activities of microorganisms and soil properties, thereby increasing plant nutrient uptake (Jatuwong *et al.*, 2024).

There is a high density of associated published articles related to biochar as an AMF carrier, as presented in **Figure 4b**, which implies a great importance of this topic in biochar research in the Philippines over the past 20 years. This indicates that interest in biochar as a carrier

for AMF to improve crop growth is gaining popularity in the Philippines and suggests the potential for growth in research and development. However, accounting for the number of published articles related to AMF, limitations such as using a few test crops could still result in less adoption of the technology at the farmers' level due to the influence of social networks and firsthand knowledge (Benami *et al.*, 2020). While it is acknowledged that the number of test crops has been limited, in comparison with some neighboring countries like Thailand, Malaysia, and Indonesia, the output of the Philippines concerning the topic is still comparably higher (Harun *et al.*, 2021; Kilowasid *et al.*, 2023; Mulyadi & Jiang, 2023; Jatuwong *et al.*, 2024).

Economic return on biochar applications in the Philippines

The increase in biochar research in the country has led to numerous benefits across various fields and industries. From an agricultural perspective, the benefits of increased crop production can be examined, leading to potentially high returns. For example, Carnaje *et al.* (2015) determined that adding biochar to the soil increased the growth of mungbean at 60 days, with a 27% improvement in height and a 102% increase in pods. Similarly, Sabijon & Gulla (2018) investigated the effects of guano char on sweet corn, which resulted in improved growth and yield at increasing application rates. Selected soil properties also improved, indicating potential applications in soil remediation. However, the problem with understanding the economic return on biochar applications is that limited studies have aimed to quantify the benefits from the production cost to the return on the investment. Currently, only 24 published articles are related to the economic aspects of biochar. However, only six relevant studies in the Philippines focus on the economic return. Most studies published have been overly focused on the effects of biochar on soil, water, plants, and air, but the impacts on the socioeconomic aspect remain lacking. This problem hinders the adoption of technology by end users who could benefit from biochar utilization. According to Latawiec *et al.* (2017), at the farmers' level, the drivers of adopting biochar mainly include the enhancement of soil quality and higher income, while the high cost of production and inputs were identified as constraints. Further, the importance of information flow and farmers' engagement in participatory research was also emphasized. Thus, studies on the economic benefits and constraints could provide information on the feasibility of biochar utilization in the country.

Chronological advancement of biochar research in the Philippines

The advancement of biochar research in the Philippines demonstrates the material's utilization over the years. Notably, in **Figure 5**, the associated colors indicate that recent articles are distributed across various topics and fields, suggesting broad biochar applications. On the other hand, colors that are associated with older publications are more closely related to searching for potential biomass sources for biochar production. However, in a similar review, biochar production consistently dominated the clustering of studies from various periods, indicating a continual search for potential biomass sources for biochar (Wu *et al.*, 2019). The difference lies in the fact that biochar research in the Philippines originated from studying the properties of biomass sources for biochar, followed by its application or utilization. Examples of the earliest related studies in the Philippines, which first focused on understanding the properties of biochar and then applying them, include the studies by Vicente *et al.* (2014), Genuino *et al.* (2017), Papa (2017), and Villota *et al.* (2019). As publications have gradually increased over the years, the utilization of biochar has also become more distributed across various topics, which generally cover studies from soil (Bobon-Carnice, 2014; Sarong *et al.*, 2017), water (Pueyo, 2022; Nebrida & Rodolfo, 2024), air (Bulfa *et al.*, 2021), crops (Aggangan *et al.*, 2019a; b; Solis *et al.*, 2022), microorganisms (Rollon *et al.*, 2018; Doctolero *et al.*, 2020), and bioenergy (Ubando *et al.*, 2014; Bongabong *et al.*, 2023). For the year 2024, some studies included biomethane (Valentin & Bialowiec, 2024), chemical adsorption

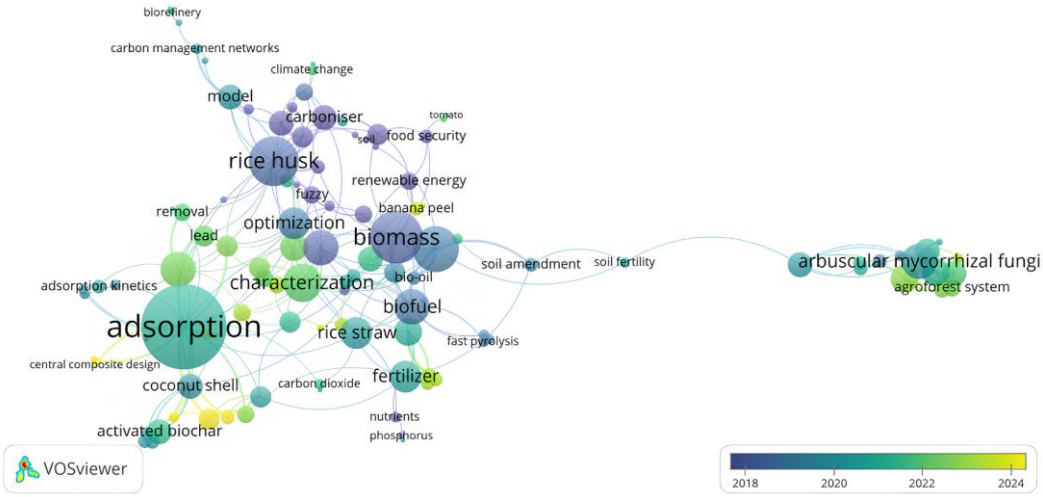

Figure 5. Overlay visualization of biochar research trends in the Philippines from average publications

(Gonzales *et al.*, 2024), electrocatalysts (Rañoa et al., 2024), biochar briquettes (Gumban *et al.*, 2024), and ethanol electro-oxidation (Villanueva *et al.*, 2024) as the newest topics on biochar research in the Philippines.

Conclusions

The present review provides valuable insights into biochar research in the Philippines, resulting in an understanding of its potential for wider fields of study. In general, the application of biochar research remains limited. The number of publications is significantly lower than in other nations, primarily due to challenges such as limited research funding, market constraints, procurement regulations, human resource shortages, and a lack of a clear innovation vision. The number of Filipino researchers and collaborations among local and international researchers were also lacking, limiting their potential growth in advancing biochar research. Three main thematic clusters were identified: (1) pyrolysis feedstocks, emphasizing agricultural waste like rice hulls and coconut husks; (2) sorptive applications of biochar for pollutants, including heavy metals in the environment; and (3) biochar as a carrier for arbuscular mycorrhizal fungi, mainly applied in crop enhancement. However, given the number of related published articles, these clustered topics are still good research hotspots for future studies. Additionally, soil fertility improvement, biorefinery, and carbon management networks, among others, were all found to have low research densities, indicating potential growth in these areas for biochar research. Additionally, the economic return of biochar remains lacking, which impacts how the end users benefit from its utilization. Early biochar studies in the Philippines focused on biomass characterization and later expanded to bioenergy, environmental remediation, and advanced material applications. These findings suggest the potential for the Philippines to expand its biochar research by strengthening collaborative networks and securing government funding, resulting in more intensive and extensive studies.

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