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Complete Valorization Of Canna Indica: Biochar And Charcoal Briquette Production From Crop Residues And Distillation Waste

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Abstract— This study explores novel valorization pathways for Canna indica biomass, extending beyond traditional ethanol production. Through pyrolysis, we transformed non-conventional plant parts such as stems and leaves into charcoal and biochar, aligning with a circular economy approach. Despite having lower calorific value compared to traditional coal, our biochar offers significant environmental benefits, including carbon sequestration. Furthermore, Canna indica briquettes are easier to handle and store compared to conventional charcoal. Moreover, we innovated by utilizing distillation residues as a binder for briquette production, enhancing their physical properties. This multidisciplinary approach paves the way for sustainable energy production and environmentally friendly agriculture.

Keywords— Canna indica; Biomass valorization;Charcoal; Biochar; Carbon sequestration; Renewable energy.

I. Introduction

Agricultural waste management is a major challenge in the context of sustainable agriculture and a circular economy ([11], [22], [25]). Crop residues, often considered waste, hold untapped potential for valorization ([6], [13], [15], [17]). Among these residues, Canna indica, a plant with multiple uses, is gaining increasing interest. Traditionally cultivated for its edible rhizomes, Canna indica is now being valorized for alcohol production, generating new by-products [15].

To optimize ethanol yield, incorporating other plant parts such as flowers and leaves into the extraction process is a promising avenue [18, 19].

The by-products of bioethanol production can be effectively utilized [14].The liquid waste can be used as a nutrient-rich fertilizer, while the solid residue can be repurposed as animal feed or a feedstock for cellulosic ethanol production ([2], [7], [10], 12], [16], [21]).

This study proposes a novel application for distillation sludge: as a binding agent in charcoal briquettes, in combination with the leaves and stems of Canna indica.

Traditionally, biochar and briquette production has relied on conventional binders like starch, molasses, or synthetic resins [5]. These binders can have limitations in terms of cost, availability, or environmental impact. By leveraging distillation sludge as a binder, we offer a sustainable and cost-effective alternative.

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The initial objective was to develop an integrated approach transforming these residues into biochar and briquettes, thereby producing a soil amendment, a renewable fuel, and a material for the treatment of textile effluent ([3], [7], [8], [16], [23], [21], (27]).

While the production of these products was successful, a detailed physicochemical characterization, necessary to fully understand their properties and potential applications, was not conducted in this study but remains a priority for future research.

More specifically, this research enabled us to:

- Assess the technical feasibility of producing briquettes from Canna indica distillation residues [28].
- Develop a briquette manufacturing process using distillation residues as a natural binder [26].
- Compare the performance of Canna indica briquettes to those of eucalyptus charcoal in water boiling tests [9].

The results obtained open up interesting prospects for the valorization of Canna indica by-products and contribute to reducing the environmental footprint of alcohol production [20]. This research could have significant implications for local communities by providing an alternative energy source and a potential soil amendment, while creating new economic opportunities in the agricultural sector [29].

To further explore these promising results and fully exploit the potential of this approach, the next steps in this research will involve:

- Characterizing the physicochemical properties of the produced biochar and briquettes.
- Evaluating the effectiveness of biochar as a soil amendment.
- Optimizing the briquette production process to improve their calorific value.

These future studies will consolidate the acquired knowledge and optimize the use of Canna indica by-products, thus contributing to a more sustainable management of agricultural resources ([24], [26]).

II. MATERIALS AND METHODS

A. Waste Collection and Preparation

Once the Canna indica rhizomes have been extracted, the remaining leaves and stems are collected.

Spread the leaves and stems evenly on a flat surface or drying rack in direct sunlight. Allow them to dry naturally until they turn beige in color. This indicates that the moisture content has been sufficiently reduced.

Once dried, carefully gather the leaves and stems and store them in a breathable bag or container. Place the storage container in a warm, dry location to prevent reabsorption of moisture. Moreover, the waste from distillation in the form of paste was sieved and dried in the sun. The drying process is considered complete when the paste turns into powder and releases dust when shaken abruptly. Once this operation is completed, the entire batch will be stored in the same location as the dry stems and leaves.


A

B

Fig. 1: Fresh (A) and Dried (B) Canna indica Leaves and Stems

B. Charcoal Production

The valorization of Canna indica residues (stems, leaves, and distillation waste) was extended to charcoal production. A two-stage process was adopted: equipment fabrication and carbonization.

a. Carbonization Equipment Fabrication

The developed oven is a rustic design, intended to be cost-effective and meet the specific needs of this production. It consists of three components: a 50-liter barrel serving as the combustion chamber, and two 9-liter metal buckets nested together to form a 15-liter airtight container for carbonizing materials. A 20 cm diameter, 90 cm high cylinder, attached to the removable barrel lid, acts as a chimney. Three 25 cm diameter openings are made in the upper part of the barrel to ensure combustion, while three 40 cm² openings are located in the lower part for feeding the raw material. This symmetrical arrangement of openings guarantees homogeneous combustion.

Fig. 2: Top view of the barrel without the lid (A) and side view with the lid (B)

A custom-built, low-cost kiln was designed for this study. The kiln's design prioritized simplicity and effective carbonization.

Kiln components: The kiln comprised a nested configuration of metal containers:

- Primary chamber: A 50-liter barrel functioned as the combustion chamber.
- Internal reactors: Two 9-liter metal buckets, nested, served as carbonization reactors, offering a working volume of approximately 15 liters.
- Draft inducer: A 20 cm diameter, 90 cm high metal cylinder attached to the barrel lid promoted draft and expelled fumes.

Apertures:

- Feed port: Three 40 cm² openings in the barrel's base facilitated material loading and airflow control.
- Combustion ports: Three 25 cm diameter perforations in the upper section supplied the required combustion air.

Design rationale: The symmetrical distribution of apertures was implemented to ensure uniform combustion within the reactors.

b. Mold Fabrication

The mold used for charcoal compression consisted of two main components: a piston and a hollow cylinder.

- Piston: A solid cylinder with a diameter of 27 mm and a height of 33 mm. The piston slides within the hollow cylinder.

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- Hollow cylinder: A 30 mm diameter round tube was cut to a length of 60 mm to form the hollow cylinder of the mold. The annular space between the piston and the cylinder served as a channel to evacuate any water present in the charcoal before pressing.

The mold was designed to accommodate the piston, as the latter was more difficult to fabricate**.**

Fig. 3: Photo of the mold and piston

C. Charcoal Production Process

The production of charcoal from Canna indica residues follows a multi-step process, illustrated in Figure 15. This process transforms plant waste into a renewable energy source through a series of unit operations, from the collection of raw materials to the quality control of the final product.

a. Collection and Preparation of Raw Materials

The leaves and stems of Canna indica, residues from rhizome extraction, are initially collected. These raw materials are then subjected to natural or artificial drying to significantly reduce their moisture content. This step is essential to facilitate subsequent operations and improve the quality of the resulting charcoal. The color change of the residues, from green to beige, indicates that drying is complete. The dried materials are stored in a dry and ventilated area to prevent rehydration.

b. Carbonization (Pyrolysis)

Carbonization, also known as pyrolysis, is the key step in charcoal production. The dried and ground plant material is introduced into a specially designed kiln and heated to a high temperature in the absence of oxygen. Under the influence of heat, the organic matter decomposes, releasing combustible gases and leaving a solid residue: charcoal.

With our type of rustic oven, torrefaction pyrolysis was chosen. Indeed, this method is the most feasible since the temperature of the rustic oven we have selected cannot exceed 350°C. Moreover, according to Table 1, the biochar yield is high when the temperature is relatively high.

c. Screening

The charcoal obtained after carbonization is generally heterogeneous in terms of particle size. To obtain a more homogeneous product and facilitate subsequent operations, the charcoal is screened. This operation separates the charcoal particles into different size fractions.

d. Binder Addition

To enhance the cohesion of charcoal particles and facilitate molding, binders are often added. These can be of mineral origin (clay) or organic origin (tar, starch, cow dung, cassava pulp, shea butter cake). The choice of binder depends on the desired properties of the charcoal briquettes (mechanical strength, calorific value). In this study, distillation waste was explored as a potential binder. By combining charcoal powder, distillation waste, and water, a gel-like mixture was formed, allowing for the creation of molded charcoal briquettes.

e. Pressing

A mixture of charcoal powder and binder is subjected to high pressure in molds to form charcoal briquettes. The pressing process shapes the mixture, removing excess water and compacting the particles. The shape and density of the briquettes can be adjusted according to their intended use. To facilitate the molding process, the interior of the molds was lubricated with used engine oil.

f. Final Drying

The freshly pressed charcoal briquettes still contain a certain amount of moisture. A final drying step is therefore necessary to remove this residual moisture and improve the calorific value of the charcoal.

g. Charcoal Testing and Comparison with Eucalyptus Charcoal

Following the drying process, the produced charcoal will undergo testing to assess its performance. For comparative purposes, eucalyptus charcoal of equivalent weight will be subjected to the same evaluation. Three key parameters will be measured:

- autonomy: the charcoal's ability to sustain combustion without additional fuel will be determined;
- combustion intensity: the time taken to boil one liter of water will serve as a measure of the charcoal's heat output;
- combustion duration: the overall burning time of the charcoal will be recorded.

III. Results and Discussion

A. *Results*

a. Waste Combustion Results

The waste carbonization process required several iterations to optimize. Table 7 presents the results obtained after two successive combustions.

TABLE 1: CARBONIZATION TEST RESULTS

Combustion	Initial waste quantity (g)	Firewood quantity (kg)	Combustion duration (min)	Charcoal quality	Charcoal quantity obtained (g)
First	1750	6	75	Poor	-
Second	-	7.5	90	Good	460

During the first combustion, the high compression of the waste in the buckets, combined with an insufficient quantity and poor quality of firewood (pine), resulted in incomplete and short-duration combustion. To address these issues, several modifications were made for the second combustion:

- Improved fuel quality: Larger eucalyptus firewood was used to achieve a more intense and longer-lasting fire.
- Improved ventilation: Holes were drilled in the bottom of the buckets to facilitate the oxygen supply necessary for combustion.

Figure 3 illustrates the different stages of the carbonization process, highlighting the modifications made between the two tests.

Fig.3: Different stages of carbonization: (A) First carbonization (failure), (B) Bucket drilled to improve ventilation, (C) Second carbonization (successful).

b. Powdering Results

Following carbonization, the charcoal was pulverized into a powdered form. The resulting powder maintained the initial weight of 460 grams.

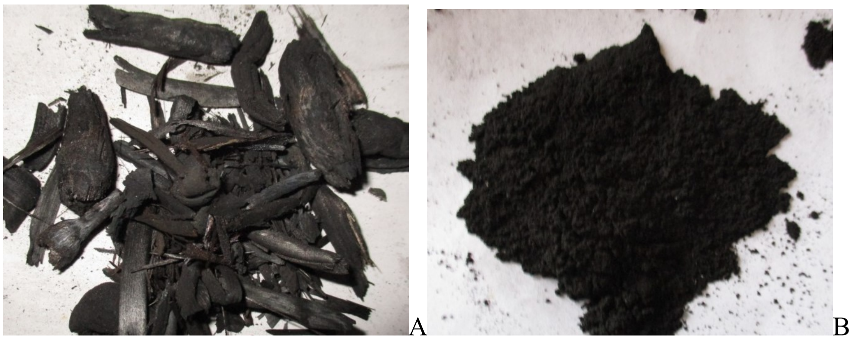

Fig. 4: Photographs of the charcoal (A) and powder (B) from the canna waste after carbonization

This powdered material, derived from Canna indica waste, is commonly referred to as biochar. It possesses potential benefits as a soil amendment due to its nutrient-rich composition. Of the total 460 grams, 100 grams were allocated for biochar application, while the remaining 360 grams were designated for charcoal combustion.

c. Charcoal Briquetting and Drying

A mixture of 360 grams of charcoal powder and 270 grams of binder was combined with 250 ml of water. The resulting mixture was subsequently pressed into 39 briquettes of uniform shape, as depicted in Figure 5.

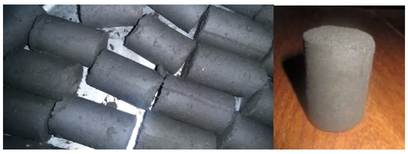

Fig. 5: Charcoal Briquettes after Pressing

Each briquette measured approximately 28 mm in diameter and 41-44 mm in length, with an average weight of 12-16 grams. The briquettes underwent a five-day drying process until a constant weight of 550 grams was achieved.

d. Comparative energy efficiency study of the two charcoals

For the comparative energy efficiency test, 250 grams of each charcoal type was used. The results of this test are presented in Table 2.

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TABLE 2: CHARCOAL EFFICIENCY TEST RESULTS

Test type	Canna indica briquette	Eucalyptus charcoal
Power source	Autonomous	Autonomous
Water boiling time	20 minutes	15 minutes
Fire duration	62 minutes	95 minutes

Results indicate that Canna indica briquettes sustained autonomous combustion for approximately one hour. While boiling water took five minutes longer compared to eucalyptus charcoal, suggesting a lower heat intensity, the Canna indica briquette exhibited a significantly shorter burn time. This rapid ash formation might be attributed to insufficient compaction during the pressing process.

B. Discussion

a. Waste Valorization

Our study on the combustion of canna waste revealed interesting results, particularly regarding pyrolysis duration and the quality of the resulting charcoal.

b. Pyrolysis Duration and Efficiency

We observed that the pyrolysis duration in our process was significantly longer than for torrefaction pyrolysis. Specifically:

- First combustion: 75 minutes (4600 seconds), resulting in lower quality charcoal (combustion < 5%).
- Second combustion: 90 minutes (5400 seconds), producing high-quality charcoal (100% combustion).

These durations fall within the range of modern slow pyrolysis (1800-5600 seconds). Despite these extended durations, our results surpass those of modern slow pyrolysis in terms of the quality of charcoal obtained.

c. Process Optimization

Several factors contributed to the efficiency of our method:

- Wood selection: the use of Eucalyptus logs or wood with similar properties proved crucial for successful combustion. However, the need for a second combustion doubles the amount of wood required, which could be a drawback in terms of resources.
- Device design: the presence of small holes in the upper part of the buckets allowed for controlled oxygen intake, thus improving the quality of pyrolysis and the resulting charcoal.
- Optimizing biochar production requires a holistic approach encompassing both process innovation and feedstock diversification. By exploring more efficient heating methods like solar furnaces and prioritizing non-woody plant-based alternatives such as agricultural residues (straw, nut shells) or fast-growing herbaceous plants (miscanthus), we can significantly reduce the environmental impact of carbonization while enhancing overall efficiency. Additionally, developing and implementing innovative production technologies, including low-temperature pyrolysis and gasification, can substantially improve biochar quality, characterized by increased density, porosity, and fixed carbon content, while minimizing the generation of unwanted by-products.

d. Quality and Applications of the Obtained Charcoal

Comparative tests with eucalyptus charcoal showed that canna charcoal is less resistant. Nevertheless, it remains suitable for short-duration cooking applications. To further improve its quality and compactness, the use of professional compressors could be considered, as manual compression proved insufficient.

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Comparative tests between canna indica and eucalyptus charcoal that canna charcoal is less resistant. Canna indica charcoal demonstrated shorter burn times and lower calorific value, primarily attributed to lower energy density resulting from insufficient compaction during the pressing process. Nevertheless, it remains suitable for short-duration cooking applications.

To enhance its suitability for various applications, improvements in quality and compactness are necessary. Further optimization of the manufacturing process is essential. Increasing pressing pressure, adjusting carbonization temperature, or exploring the addition of natural binders are potential avenues for improving burn time, calorific value, and overall performance.

e. Biochar Potential

Although we did not conduct specific tests on biochar efficiency, the work of Allaire et al. (2013) emphasizes that its action strongly depends on the characteristics of the soil to be amended. It is therefore crucial to conduct thorough pedological studies before using this type of amendment to avoid potential negative post-application effects [1].

C. Improvement Perspectives

To fully realize the potential of canna indica biochar, further research is imperative. Optimizing pyrolysis for reduced combustion time and increased charcoal quality, enhancing energy efficiency, and conducting comprehensive soil trials are key areas for future investigation.

IV. Conclusion

This study has demonstrated the potential of valorizing Canna indica into biochar and briquettes, opening up new opportunities in bioenergy and agroecology. The innovative use of distillation residues as a binder for briquettes represents a significant advancement.

Biochar produced from Canna indica exhibits promising combustion and carbon sequestration properties. However, further research is needed to comprehensively characterize these properties and assess their potential.

Optimizing production processes, including exploring alternative binders and developing of efficient, affordable, and durable pressing tools, is crucial for enhancing briquette quality and expanding their market potential. By evaluating the performance of distillation waste as a benchmark, researchers can identify other suitable binders that could improve briquette properties and broaden their applications.

Canna indica fibers, renowned for their exceptional mechanical and thermal properties [22], offer significant potential for innovation in the fuel industry. Their incorporation into fuel briquettes could not only substantially enhance their mechanical strength but also optimize their combustion, increasing their lower heating value (LHV). This innovative approach paves the way for more efficient and sustainable alternative fuels.

To maximize the value of both products, future research should focus on the long-term stability of biochar in soil, its role in carbon sequestration and soil improvement, and the energy performance of briquettes. Comprehensive product characterization and real-world testing are essential to establish correlations between material properties and performance. A multidisciplinary approach, integrating agronomic, energy, economic, and environmental aspects, is necessary to develop innovative and sustainable solutions.

This research has highlighted the innovative and sustainable potential of valorizing the Canna indica plant by producing biochar and charcoal briquettes from its vegetative parts, notably by utilizing distillation residues as a binder. This novel approach has not only optimized the use of an abundant resource but has also opened up new avenues for valorization.

With the goal of optimizing and ensuring the sustainable use of this resource, we aim to expand our research to valorize the flowers. Inspired by studies conducted on other floral species, such as Marigold flower and Allamanda Schottii, [4], we propose to assess the feasibility of converting Canna indica flowers into bioethanol. This comprehensive approach will not only allow us to valorize the entire biomass of this plant but also contribute to diversifying biofuel sources and reducing our reliance on fossil fuels.

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