ADSORPTION OF PHENOLIC COMPOUNDS IN SUGARCANE BAGASSE HYDROLYSATES USING SPENT COFFEE GROUND BIOCHAR

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INTRODUCTION

Global coffee production is expected to grow by 8% in the 2024–2025 harvest, with Brazil remaining the top producer (33% of global volume)

It is estimated that for every ton of coffee processed, about 480 to 650 kg of spent coffee ground (SCG) are generated

SCG are rich in lignocellulosic materials, containing approximately 30–40% hemicellulose, 8.6–13.3% cellulose, 25–33% lignin, as well as proteins (6.7–13.6%) and lipids (10–20%)

Development of higher value-added products: Biochar is a carbon-rich material obtained through pyrolysis. It has a high surface area, porosity, and adsorption capacity

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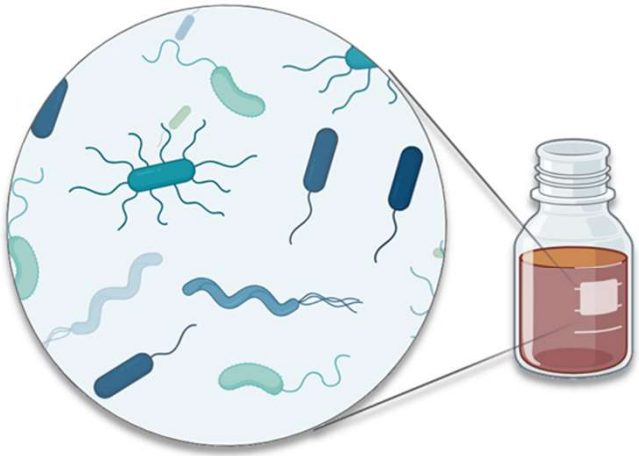
PHENOLIC COMPOUNDS IN HYDROLYSATES

Phenolic compounds released during acid or enzymatic hydrolysis of residues such as sugarcane bagasse are known for their toxicity and inhibitory effects on microorganisms used in fermentation processes for the production of bioproducts, such as xylitol.



- **Inhibition of microbial growth;**
- **Reduction in enzyme activity;**
- **Decrease in bioproduct yield.**

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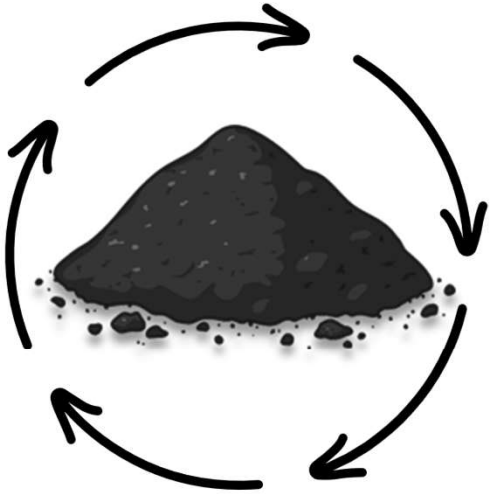
BIOCHAR AS SOLUTION

- High porosity and surface area increase retention capacity.
- Functional groups such as –OH, –COOH and C=C interact by:
  - Hydrogen bonds
  - π–π interactions (aromatic molecules)



12 RESPONSIBLE CONSUMPTION AND PRODUCTION

13 CLIMATE ACTION

- **Detoxification of hydrolysates;**
- **Recovery of waste (SCG);**
- **Adoption of practices aligned with the circular economy and the UN SDGs.**

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OBJECTIVES

1. Production of biochar from the pyrolysis process of coffee grounds biomass;
2. Characterize the biochar produced using TGA and FTIR;
3. Evaluate the adsorptive capacity of biochar in the adsorption process of phenolic compounds;
4. Compare the different biochars;
5. Perform experiments to adjust kinetics and isotherm.

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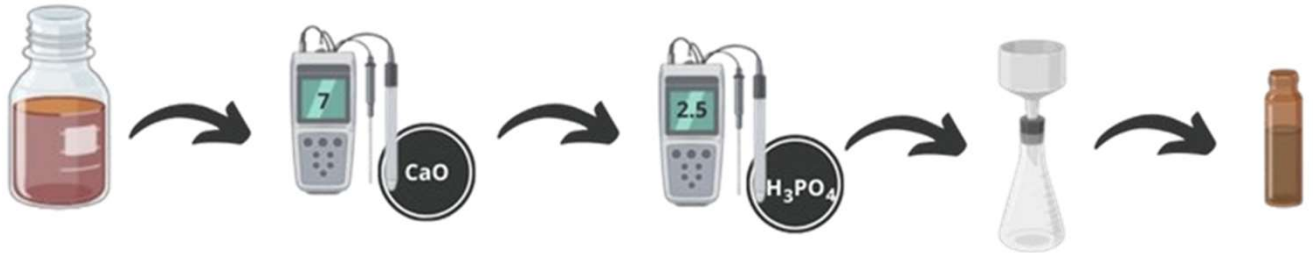
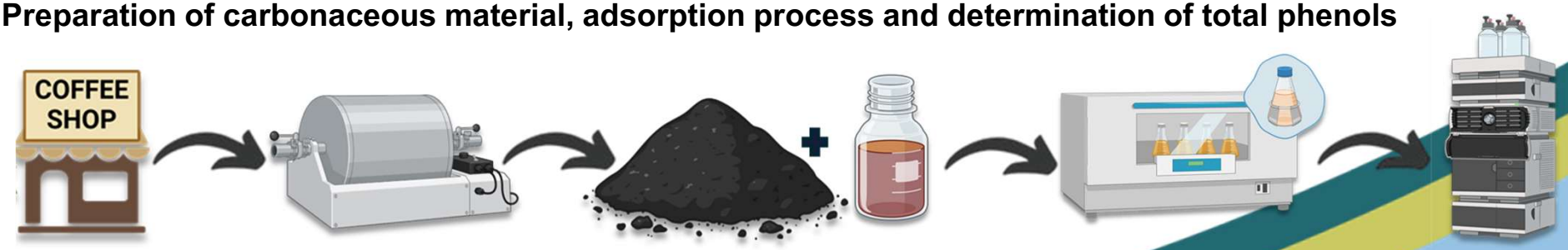
METHODS

- **Preparation of the sugarcane hydrolysate that was concentrated 1.5 times, 2 times, 2.5 times and 3 times using a rotary evaporator**



- **Preparation of carbonaceous material, adsorption process and determination of total phenols**



E1 (400 °C, 6.7°), E2 and E6 (600 °C, 6.7°), E3 (400 °C, 2.1°), E4 (600 °C, 2.1°), and E5 (500 °C, 4.4°)

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METHODS

- **Isotherm fitting (Freundlich, Temkin, Redlich-Peterson and Langmuir);**
  - Each concentrated hydrolysate (1-3 times) was tested with each biochar (E1 – E5).
- **Kinetic fitting (pseudo first-order, pseudo-second-order, and Elovich);**
  - Different time intervals: 15, 30, 45, 60, 75, 90, 105 and 120 minutes.
- **Thermogravimetric analysis (TGA) was used to assess their thermal stability and decomposition profile;**
- **Fourier-transform infrared spectroscopy (FTIR) was employed to identify surface functional groups, together, these techniques help elucidate the structural features that may influence adsorption behavior.**

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ADSORPTION REMOVAL EFFICIENCIES

E1 (400 °C, 6.7°), E2 and E6 (600 °C, 6.7°), E3 (400 °C, 2.1°), E4 (600 °C, 2.1°), and E5 (500 °C, 4.4°)

Table 1. Adsorption removal efficiencies.

BC	Hydrolysate 1x		Hydrolysate 1.5x		Hydrolysate 2x		Hydrolysate 2.5x		Hydrolysate 3x	
	Time (min)	Removal efficiency (%)	Time (min)	Removal efficiency (%)	Time (min)	Removal efficiency (%)	Time (min)	Removal efficiency (%)	Time (min)	Removal efficiency (%)
E1	45	19.0 ± 0.2	75	10.7 ± 1	105	8.0 ± 0.3	60	12.4 ± 0.3	45	47.9 ± 2.2
E2	75	3.1 ± 0.4	60	17.9 ± 2.7	45	**19.2 ± 1.3**	60	**14.1 ± 0.1**	75	36.8 ± 0.5
E3	90	16.1 ± 1.8	90	8.5 ± 1.3	60	12.4 ± 1.1	60	4.3 ± 0.2	90	40.4 ± 0.7
E4	90	9.1 ± 0.7	75	**21.2 ± 2.7**	45	15.9 ± 0.9	60	13.3 ± 0.4	75	36.1 ± 1.0
E5	105	**19.6 ± 1.9**	75	11.5 ± 1.2	90	18.3 ± 1.4	45	6.7 ± 0.5	60	**49.5 ± 2.6**

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ADSORPTION REMOVAL EFFICIENCIES

- **Higher temperatures (600 °C) consistently showed higher adsorption efficiencies for phenolic compounds, especially in the 1.5- and 2.0-fold range**
- **Higher inclinations (6.7°) showed higher adsorption efficiencies in most cases, suggesting that reactor inclination may influence heat distribution and gas flow during pyrolysis, leading to variations in biochar structure**
- **Hydrolysate at 3.0 times showed the best results, with removal rates from 36.1% to 49.5%**

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ADSORPTION ISOTHERM

Temkin Isotherm

R^2 values consistently close to or above 0.9. This indicates the effects of adsorbate interactions and a uniform distribution of binding energies.

Freundlich Isotherm

R^2 values above 0.8. indicates the presence of heterogeneous adsorption sites and varying adsorption intensities on the biochar surfaces (more complex interactions).

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ADSORPTION ISOTHERM

Langmuir isotherm

Moderate fits, particularly for biochars E3 and E5. Monolayer adsorption may not fully describe the adsorption dynamics.

Redlich-Peterson Isotherm

R^2 values often negative or significantly lower than the other models - The adsorption behavior does not clearly follow either a monolayer or a heterogeneous multilayer pattern.

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ADSORPTION KINETICS

For the hydrolysate 3x, all models performed well, with R^2 values above 0.900 for E2 to E5. This may point to the simultaneous presence of physisorption and chemisorption or simply reflect the complexity of the system. The pseudo-second-order and Elovich models, which are often associated with chemisorption and heterogeneous surfaces, followed a consistent pattern that supports this interpretation.

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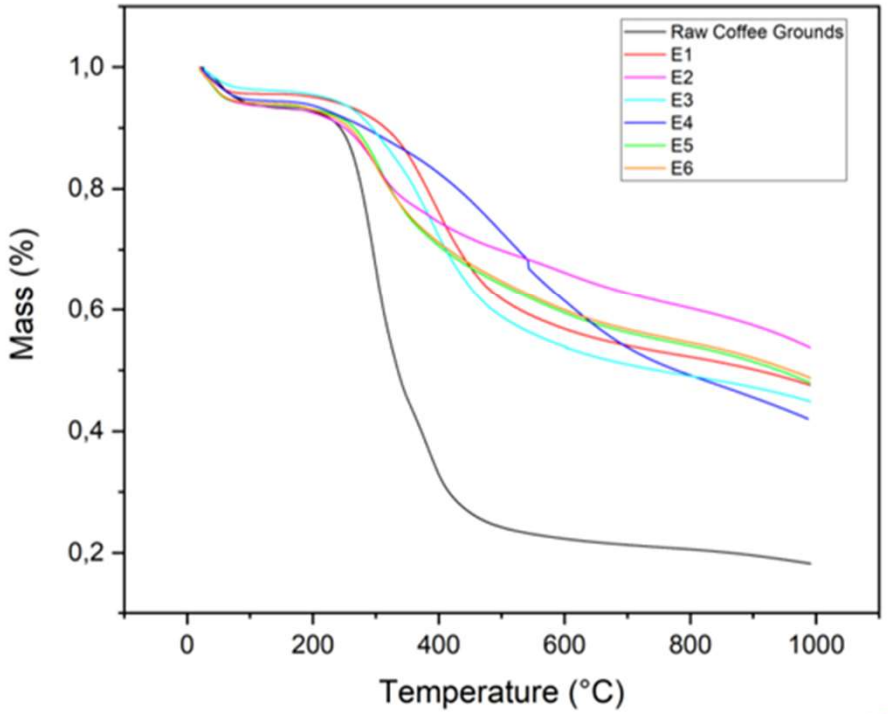
THERMAL STABILITY ASSESSMENT OF BIOCHARS: TGA ANALYSIS

Figure 1. TGA comparison between raw coffee grounds and biochar.



- TGA analysis showed that raw coffee grounds lose mass in stages due to degradation of hemicellulose, cellulose, and lignin, while biochars exhibited lower mass loss due to prior thermal decomposition during pyrolysis.

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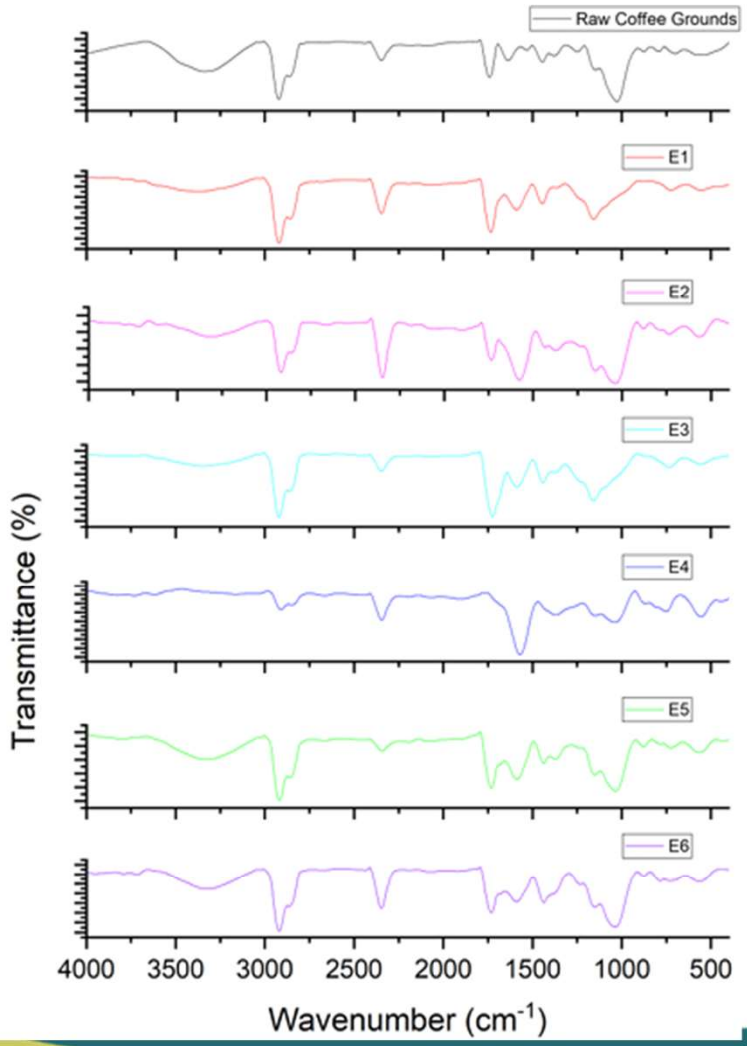
Figure 2. FTIR comparison between raw coffee grounds and biochar.



SURFACE FUNCTIONAL GROUPS CHARACTERIZATION OF BIOCHARS: FTIR ANALYSIS

- FTIR analysis showed that raw coffee grounds have stronger peaks in regions like O-H and C=O, associated with water and carboxylic groups. Biochar samples, especially E4, showed reduced peak intensity due to thermal degradation during pyrolysis. Changes in fingerprint and aromatic regions indicate structural transformations and increased complexity in biochar.

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CONCLUSIONS

Coffee grounds biochar is efficient in removing phenolic compounds, with the 3x hydrolysate and E5 biochar (500°C, 4.4°) achieving 49.5% removal.

FTIR and TGA analyses confirm functional groups and thermal stability, contributing to adsorption and environmental applications.

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FUTURE PERSPECTIVES

Modifications using magnetic particles, acidic or basic treatments, or other functional agents have been shown to increase surface area, porosity, and the number of active sites, factors that could enhance adsorption capacity even further.

The approach promotes the valorization of waste and cleaner and more sustainable biotechnological processes, aligned with the UN SDGs.

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REFERENCES:

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