THERMAL DECOMPOSITION AND CHARACTERIZATION OF CHARCOAL FROM THREE SPECIES OF THE CERRADO BIOME FOR PRODUCTION FOR ENERGY PURPOSES AND FOR ACTIVATED CHARCOAL

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Luiz Berber Costa[1]

ABSTRACT

Charcoal is used mostly in the production of pig iron and steel, and also in the production of activated charcoal. The exploitation of wood for energy purposes has fostered the reduction of native vegetation and also had consequences for fauna, flora and soil. Charcoal is produced from planted forests, highlighting Brazil as the only country to use a renewable source in the steel sector. Thus, the objective was to analyze the quality of charcoal produced from the species of the Cerrado biome (Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis) for energy purposes and for the production of activated charcoal, aiming to contribute to sustainable practices in the use of renewable sources. For the analysis of the physical properties of the coal, the density, porosity and moisture content were determined, for the chemical properties the chemical composition (percentage of carbon, hydrogen, oxygen, nitrogen and sulfur), calorific value, volatile and ash content, hydrogen potential (pH) and fixed carbon content and, as for the biological aspects, decomposition, microorganisms and ecological impact. Among the charcoals of the species analyzed, the species Myracrodruon urundeuva stands out, which showed the highest values of plant yield and energy density, followed by the species Amburana cearensis and, finally, the species Tachigali vulgaris. The stimulus to the use of charcoal reflects economic, environmental and social benefits for the country, and the environmental aspect is relevant, reducing the consumption of non-renewable sources and greenhouse gas emissions.

Keywords: Carbonization. Physical Properties. Density.

[1] Advisor: Hamilton Barbosa Napolitano
Name of the institution: Evangelical University of Goiás – UniEVANGÉLICA

INTRODUCTION

The growing demand for renewable energy sources has led to the exploration of sustainable alternatives, among which the use of charcoal stands out. This biofuel, produced from the carbonization of biomass, such as that from trees and native vegetation, emerges as a viable solution to meet energy needs in a more environmentally friendly way.

The Cerrado biome, with its rich biodiversity, is home to a variety of plant species that can be used in the production of charcoal, among them Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis. This study aims to investigate the thermal decomposition and characterization of charcoal of these species, in order to understand their potential for energy generation.

Carbonization is a procedure of thermal deterioration that wood faces, at high temperatures (300 to 500 ºC), with the lack or presence of regulated amounts of oxygen, producing a solid residue, called charcoal. (Wenzl, 1970).

Thermal decomposition consists of a chemical reaction that occurs when biomass is subjected to high temperatures, resulting in the decomposition of its elements, the result of which is the production of charcoal and gases, that is:

Carbonization is an incomplete or indirect combustion reaction of wood. The liquids are volatilized and produced into gaseous compounds, leaving only a solid composed almost exclusively of pure carbon.

The carbonization of the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis allows the determination of several physical, chemical and biological aspects essential for the evaluation of its viability as an energy source, as well as the obtaining of vegetable activated charcoal. It is crucial to carry out integrated studies that consider not only the characteristics of charcoal, but also the environmental and social impact of the exploitation of these species in the Cerrado biome.

Activated Charcoal (CVA) is a biomaterial that can be produced from various plant species, including Amburana cearensis, Tachigali vulgaris, and Myracrodruon urundeuva. It is a porous material produced from the carbonization of wood, followed by an activation process, which can be done through physical methods (such as steam or gases at high temperatures) or chemical (using acids or bases).

The activation process involves two main steps:

a) Carbonization: The wood is heated in a monitored environment (300 to 500 ºC), with the lack or presence of regulated amounts of oxygen, producing a solid residue, called charcoal.

b) Activation: Charcoal is treated with chemical agents or exposed to high temperatures to increase its porosity and surface area.

The production of activated carbon from Amburana cearensis, Tachigali vulgaris and Myracrodruon urundeuva involves these carbonization and activation processes, allowing these natural materials to be transformed into products with applications in various sectors, such as: Water Treatment; Effluent Treatment; Detoxification; Food Industry; Air Filters; Cosmetics; Pharmaceutical industry; Food Preservation.

In this way, activated charcoal is an excellent example of a material that can be used in sustainable and beneficial ways, highlighting its value as both a functional biomaterial and a bioproduct.

As for carbonization, a thermal process involving the heating of organic materials in the absence of oxygen, resulting in the production of charcoal, the evaluation of the various physical, chemical and biological aspects of wood, including the species under study: Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis, which are typical of the Cerrado biome, are of great importance, namely:

Physical Aspects:

1. Density: The density of the coal obtained can influence its energy capacity.
2. Porosity: The structure of coal, including its porosity, affects the burning rate and energy efficiency.
3. Humidity: The amount of moisture in the charcoal before and after carbonization is critical, as it interferes with the calorific value and effectiveness of combustion.

Chemical aspects:

1. Chemical Composition: The analysis of chemical constituents, i.e., the amount of carbon, hydrogen, oxygen, nitrogen, and sulfur, is essential to determine the calorific value of coal. Carbon is primarily responsible for the energy released in burning.
2. Calorific Value: This is one of the main parameters to be measured. Both the upper calorific value (PCS) and the lower calorific value (PCI) are fundamental for the examination of the efficiency of coal.
3. Ash Analysis: The percentage of ash produced in the combustion of coal is an important factor in the purity of the material. Ash content impairs the quality of combustion and the dispersion of pollutants.

Biological Aspects:

1. Decomposition: The carbonization process can impact the ability of plant material to decompose in the soil, influencing soil quality and the production of organic carbon in the soil.
2. Microorganisms: The presence of certain microorganisms can influence the carbonization efficiency and quality of the coal. The biological aspect of charcoal can also impair its interrelationship with the soil and fertility.
3. Ecological Impact: Assessing the effects of the removal of species from the Cerrado biome for charcoal production purposes on local biodiversity and ecosystem services is important.

Thus, the general objective of the research is to analyze the quality of charcoal produced from three species of the Cerrado biome (Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis) for energy purposes and for the production of activated charcoal, aiming to contribute to sustainable practices in the use of renewable sources in the steel sector.

To achieve the proposed general objective, the following specific objectives were established in order to direct the research:

(1) Physically/Chemically and Biologically Characterize Charcoal; (2) analyze the Energy Properties; (3) study thermal decomposition; (4) Characterize Activated Charcoal; (5) Analyze Sustainability; (6) Compare the species; (7) Study Compatibility with Industrial Processes; (8) Propose Sustainable Forest Management.

Throughout the research, the yields and energy properties of the charcoal generated from the three species will be compared, in order to identify which one has the most favorable characteristics for use as an energy source, as well as for obtaining activated charcoal.

In addition, an analysis of the environmental impact and sustainability of charcoal production will be carried out, considering aspects such as forest management and the preservation of local biodiversity.

The Cerrado biome, one of the richest vegetation zones in biodiversity in Brazil, is characterized by its xerophilous vegetation and a great diversity of tree and shrub species. Among these, Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis are native trees that have the potential to be used in the production of charcoal.

However, the energy efficiency of this charcoal depends on several factors, including its physicochemical properties, which can be influenced by variables such as the species of origin, the carbonization method, and environmental conditions.

Through the evaluation of thermal decomposition and characterization of the charcoal produced, this research aims to provide essential information that helps in the selection of best practices for charcoal production in the biome in question, providing a more efficient and sustainable use of this renewable energy source.

In summary, understanding the properties of charcoal from species of the Cerrado biome is fundamental, not only for the advancement of academic knowledge in the area, but mainly aiming at the application of public policies that encourage the sustainable use of resources available in forests and the conservation of biodiversity.

Charcoal is acquired from the carbonization of wood, being used as fuel in various sectors, such as: fireplaces, barbecues, wood stoves and heaters. In addition, it is also used in some industrial sectors, such as steel mills. It is a renewable and low-polluting source of energy, but its rudimentary production in brick kilns can emit polluting gases.

With a vast production chain in the areas related to the production of pig iron, metallurgy, machining and production of parts, the metallurgy and steel sectors are of great importance in the Brazilian economic panorama, being the support of other activities, such as the automobile industry, civil construction, for example.

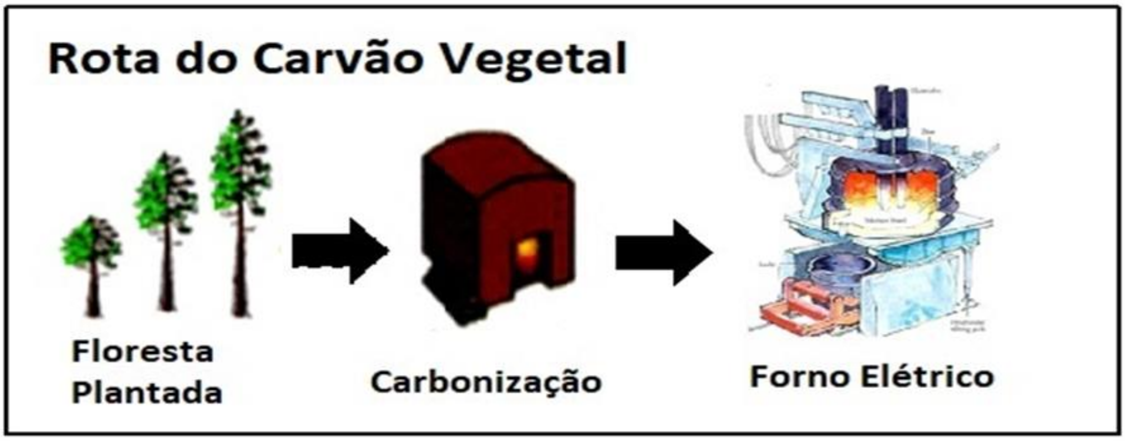
The main inputs used as reducing terms can come from non-renewable or renewable sources, such as mineral coal and charcoal, respectively.

In Brazil, the mineral coal consumed is 100% imported, due to the characteristics of the coal deposits in the country not having the good quality necessary for this purpose.

Charcoal, on the other hand, is produced from planted forests, where Brazil stands out as the only country to use a renewable source in the steel sector (Figure 1).

The charcoal used by companies in the steel and metallurgy sector comes from planted forests, corresponding to 91% of production (IBÁ, 2019). Charcoal has a carbon, ash and calorific value content ranging on average between 75 and 80%, 1% and from 7,500 to 8,000 kcal.kg-1, respectively (PROTASIO et al., 2014).

Figure 1 - Schematic representation of the charcoal route in the ferroalloys sector



Source: Brazilian Tree Industry (IBA, 2019).

The incentive to use charcoal represents dividends in the economic, environmental and social spheres for the nation. In this way, environmental profit is significantly converted, curbing the consumption of non-renewable sources and greenhouse gas (GHG) emissions.

In spite of the productive aspects and the use of coal, the use of charcoal emerges as a way to contribute significantly to the Brazilian trade balance. Furthermore, the production and use of activated carbon from these wood species represent a sustainable and efficient application of forest resources, contributing to environmental quality and public health.

MATERIALS AND METHODS

EVALUATION OF THE PHYSICAL PROPERTIES OF THE CHARCOAL PRODUCED FROM THE SELECTED SPECIES, THAT IS: DENSITY, POROSITY AND MOISTURE CONTENT

To analyze the physical properties of the coal, the carbonization procedure was developed in the laboratory. For each species, ten test elements with approximate dimensions of 2.5cm x 2.5cm x 2.5cm were used.

The samples were weighed and measured before carbonization to determine the apparent specific mass. Subsequently, the evidence was covered with aluminum foil, sorted and inserted into muffle furnace for carbonization.

For the carbonizations, the chips were previously dried in an oven at 105±3°C, up to constant weight. The carbonizations were conducted in reproduction for each material, using a muffle furnace with electric heating.

The final carbonization temperature was 550 °C, considering 50°C every 30 minutes, recovering the pyroligneous liquor by condensation with water. The defined carbonization temperature of 550°C was indicated because it is close to that which has been used in industrial retort systems, which are the most suitable for carbonization of products in the form of chips.

After carbonization and cooling, the weight of the evidence was verified by measuring them again, to calculate the gravimetric and volumetric yield of the coal. The gravimetric yield is the ratio between the final weight of the charcoal and the dry weight of the wood (before carbonization), expressed as a percentage.

The volumetric yield is the ratio between the final weight of the coal and its volume before carbonization, also presented as a percentage.

In addition, immediate thermogravimetric (TGA) analyses were performed. The TGA test, or Thermogravimetry, measures the variation in the mass of the sample (loss and/or gain) as a function of the temperature variation imposed on the analyzed material.

A gravimetric scale was used, following the ASTM D 1762 standard (American Society for Testing and Materials, 2007), with temperatures of 900 °C for the percentage of volatiles and fixed carbon and 525 °C for ash.

The charcoal samples obtained to characterize the physical properties were treated and analyzed in this study, determining the density, porosity and moisture content.

To determine the **basic density,** two methods were used, namely: the so-called immersion and displacement method and the so-called Maximum Moisture Content method (SMITH, 1954).

To obtain the values referring to the porosity of the charcoal of the species in question, laboratory analyses were first carried out to determine the apparent density of the charcoal. And the true density was determined according to the ABNT NBR 9165 (1985) Standard. By relating the true density to the apparent density, the measurement of the porosity of the coal was obtained (PENEDO, 1980).

Thus, the porosity of the charcoal was obtained from the data of apparent and true densities, through the formula:

$PO (\%) = 100 - (DRA*100) / DRV$, onde:

PO (%) = Porosity in (%);

DRA = Apparent Relative Density (g/cm^3);

DRV = True Relative Density (g/cm^3).

The moisture content was determined by the so-called traditional, gravimetric method, in accordance with NBR 14929 (ABNT, 2003).

DETERMINATION OF THE CHEMICAL PROPERTIES OF THE CHARCOAL OF THE SPECIES UNDER STUDY, I.E.: THE CHEMICAL COMPOSITION (PERCENTAGE OF CARBON, HYDROGEN, OXYGEN, NITROGEN AND SULFUR), CALORIFIC VALUE, VOLATILE AND ASH CONTENT, PH AND FIXED CARBON CONTENT

Thermal decomposition and characterization of charcoal are fundamental processes in the production of charcoal from organic matter, such as plant waste.

This process involves pyrolysis, which is the thermal decomposition of biomass in the absence of oxygen, resulting in the conversion of wood or other plant parts into charcoal.

- **Thermal decomposition.**

Thermal decomposition is a transformation process that involves breaking chemical bonds in organic materials when subjected to high temperatures.

- **Characterization of Charcoal.**

After the thermal decomposition process, the charcoal produced must be characterized to understand its properties and potential applications.

- **Chemical composition:**

Analysis of chemical constituents, including the amount of carbon, hydrogen, oxygen, nitrogen, and sulfur, is critical to determining the calorific value of coal. Carbon is primarily responsible for the energy released in burning.

The values of chemical composition (carbon, hydrogen, oxygen, nitrogen and sulfur) of the plant species Tachigali vulgaris, Amburana cearensis and Myracrodruon urundeuva may vary according to different factors, such as growing conditions, extraction methods and analysis of charcoal. However, previous studies often report compositions typical for such species.

The immediate chemical analysis was performed according to ABNT NBR 8112 (1986), with determinations of ash content, volatile materials and fixed carbon content on a dry basis. The coal densities were calculated according to ASTM-D-167-93, adapted by Oliveira, Gomes and Almeida (1982).

- **Calorific value**

This is one of the main parameters to be measured. The higher calorific value (PCS) and the lower calorific value (PCI) are important for assessing the efficiency of coal for energy purposes.

The calorific value is divided into upper (PCS) and lower (PCI). The calorific value is said to be higher when there is condensation of water (or liquefaction that occurs when the vapor or gas reaches a temperature lower than its boiling point).

In the case of water vapor, for example, condensation begins when the temperature is below 100 degrees Celsius, after the complete process of combustion at a constant pressure and in a standard state (FIGUEREDO, 2009).

The calorific value is said to be lower when there is no condensation of the water. PCI comes from combustion at constant pressure, in the open, without the condensation of H2O formed (DOAT, 1977).

The calorific value is not directly linked to the density of the wood, but is influenced by the chemical composition and directly affected by the moisture content. Even the PCI is reduced with the increase in humidity (DOAT, 1977).

Wood expresses a PCS of around 4,500 kcal/kg (KOLLMAN & CÔTÉ, 1984). (NUMAZAWA, 2000), on the other hand, says that tropical wood expresses a SWP between 4,171.68 and 5,106.53 kcal/kg.

The information was obtained through bibliographic research of the values of the amount of internal energy available in technical compendia and some calculated by the Institute of Forest Studies Research - EPEF - Forest Products Laboratory - LPF - IBAMA.

The tests carried out at LPF/IBAMA, to determine the PCS (Higher Calorific Value), were carried out according to the guidelines of NBR 8633-ABNT (1984), Charcoal – Determination of Calorific Value and the manual of the calorimeter PARAR 1201. The upper calorific value (SSP), dry mass basis, was determined using a digital calorimeter, brand IKA - C 200, according to ABNT NBR 8633 (1984) (Figure 2).

While the lower calorific value (PCI), dry mass basis, was estimated according to the equation below (BRAND, 2010).

$PCI = PCS – (600x9H/100)$, where: PCI is the lowest calorific value (Kcal/Kg); PCS is the highest calorific value (Kcal/Kg; H is the Hydrogen content (%) on the dry basis of the wood.

Figure 2 - Digital calorimeter, brand IKA-C 200

Source: Unip/Uniplan Laboratory.

The samples used to determine the PCS were prepared as follows:

- **Crushing**: for chip extraction;

- **Grinding**: for conversion to sawdust;
- **Screening**: for particle selection;
- **Drying**: ground wood with an index of less than 60 mesch was dried in an oven at 105 ± 2ºC until a constant amount.

➢ **Teor de cinzas**

The ash content was determined by ASTM D1102-84 (2007), and was carried out in the wood chemistry laboratory of INPA, using porcelain crucibles for calcination of the samples in a muffle furnace at a temperature of 580~600°C. The ash content was obtained by the ratio between the weight of the ash obtained in calcination (a procedure performed in the laboratory.

An electric muffle furnace, Bunsen burner, analytical balance, porcelain crucibles, desiccant, crucible tweezers and inkil) and the mass of the sample dried in an inkil, expressed as a percentage, and calculated by Equation 2 were used.

The determination of the ash content was made using equation 2, below:

$C = mc/ms \times 100$ (%) – Equation 2

Where: C = Ash content (%); mc = Ash mass (g); ms = Dry wood mass (g).

➢ **Volatile content**

Knowing that the volatile content expresses the ease of burning a material, it is defined as the mass fraction of the fuel that volatilizes during the heating of a standard sample, in an immobile atmosphere, up to a temperature of around 850 ºC, for seven minutes.

After the measurements, the amounts of volatile and non-volatile substances were calculated as follows:

Total Volatile Solids Content = (Weight of Container and Substance Before Being Dried in the Oven - Weight of Container and Substance After Incineration) x Volume of Sample in Milliliters.

➢ **Hydrogen Potential (PH)**

The pH of the soil where species such as Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis develop varies significantly with respect to geographic location, environmental conditions and how much soil they have. These species in question are associated with soils that have a pH that varies from acid to neutral.

The species Tachigali vulgaris is found in soils with a pH that usually varies between 5.0 and 6.5. While the species Myracrodruon urundeuva grows in soils with a pH ranging from 5.0 to 7.0, although it can adapt to a wide range of soil conditions. The species Amburana cearensis, on the other hand, prefers soils with a pH between 5.0 and 6.5.

- **Fixed carbon content**

Fixed carbon content (TCF) is an indicator of the quality of coal, as it indicates its energy potential:

TCF is calculated by the formula yCf=100- (yC + yV).

Where:

yCf is the fixed carbon content;

yC is the ash content and

yV is the volatile content.

EVALUATION OF THE BIOLOGICAL CHARACTERISTICS OF CHARCOAL PRODUCED FROM THE SELECTED SPECIES, I.E.: DECOMPOSITION, MICROORGANISMS AND ECOLOGICAL IMPACT

- **Decomposition**

The carbonization process can impact the ability of plant material to decompose in the soil, influencing soil quality and the production of organic carbon in the soil.

The biological decomposition of species such as Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis is a natural and complex process that varies in rate and efficiency, depending on the specific characteristics of each species and the environmental conditions in which they are found.

It involves the degradation of organic matter, which facilitates the recycling of nutrients in the ecosystem and the maintenance of ecosystem health. Thus, each of these species has characteristics that influence the way this process takes place.

To determine the decomposition rate (k), the following equation was used: C = Co. and ^(-Kt),

Where:

C is the final mass of the samples;

C0 is the initial mass (30 g);

T is the time elapsed in the experiment (360 days) and

K is defined as the decomposition constant (PARDO et al., 1997).

To measure the half-life period or essential period for 50% of the biomass to be transformed, the following equation was used: t0.5 = ln.2/K (COSTA; ATAPATTU, 2001).

- **Microorganisms**

The presence of microorganisms in wood, including species such as Tachigali vulgaris, Myracrodruon urundeova, and Amburana cearensis, can have a significant impact on the efficiency of carbonization and the quality of the charcoal produced.

The quality of the charcoal produced is influenced by the chemical composition of the wood, which in turn can be altered by the activity of microorganisms.

The presence of microorganisms that promote degradation can result in a charcoal with lower calorific value and higher ash content.

Charcoal produced from healthy wood free of microbial infestation is more likely to have desirable characteristics such as: higher energy density, lower contaminant content and better energy performance.

To optimize charcoal carbonization and quality, forest management practices that minimize colonization by decomposer organisms are recommended. This can include the use of wood with rapid processing after harvest, and storage in dry conditions to prevent the proliferation of microorganisms.

The application of preservation methods, such as drying and chemical treatment, can help protect the wood from the action of microorganisms, increasing the efficiency of carbonization and improving the final quality of the charcoal.

In summary, the presence of microorganisms can significantly affect both the carbonization efficiency and the quality of charcoal produced from the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis. The practice of sustainable management and control of microbial infestation are fundamental to optimize these processes.

➢ **Ecological Impact**

Assessing the effects of the removal of species from the Cerrado biome for charcoal production purposes on local biodiversity and ecosystem services is important.

The removal of native species of the Cerrado biome, such as Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis, for charcoal production purposes, can have significant ecological impacts that affect local biodiversity and ecosystem services.

1. Impact on Biodiversity

- Habitat Loss; - Reduction of Native Species; - Change in Microbial Communities.

2. Impact on Ecosystem Services

- Nutrient Cycle; - Carbon Storage; - Microclimate regulation; - Water Conservation.

To mitigate these impacts, it is essential to consider sustainable management methods and alternatives to charcoal production that minimize the removal of native species, such as the use of agricultural residues or the implementation of silvicultural systems that seek conservation.

The dismissal of the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis from the Cerrado biome for charcoal production purposes can have severe consequences for local biodiversity and essential ecosystem services, leading to environmental degradation and the loss of natural resources.

The preservation of these species is essential to maintain the health of the ecosystem and the functionality of the Cerrado.

ANALYSIS OF ENERGY PROPERTIES

Evaluation of the calorific value and energy efficiency of charcoals of the three species, in order to determine their viability as an energy source for the steel industry.

STUDY OF THERMAL DECOMPOSITION

Conducting thermal decomposition analyses (Thermal Difference Thermogravimetry) in order to understand the thermal conduct of materials with pyrolysis.

PRODUCTION AND CHARACTERIZATION OF ACTIVATED CHARCOAL:

Development and optimization of processes for the production of activated charcoal from the coals obtained, and characterize their properties (porosity, surface area, adsorption capacity).

SUSTAINABILITY ANALYSIS

Evaluation of the sustainability of charcoal and activated charcoal production, considering economic, social and environmental aspects associated with the use of native species of the Cerrado biome.

COMPARISON BETWEEN SPECIES

Comparison of the properties of charcoal produced from the three species in terms of quality, yield and applicability, both for energy purposes and for the production of activated carbon.

STUDY OF COMPATIBILITY WITH INDUSTRIAL PROCESSES

Investigation of the compatibility and effectiveness of charcoals obtained in existing industrial processes in the steel sector, identifying possible necessary adaptations.

SUSTAINABLE FOREST MANAGEMENT PROPOSALS

Suggestion of sustainable management practices for the harvest and use of the species studied, promoting the conservation of the Cerrado biome while taking advantage of its resources.

RESULTS AND DISCUSSION

EVALUATION OF THE PHYSICAL PROPERTIES OF CHARCOAL PRODUCED FROM THE SELECTED SPECIES, I.E.: DENSITY, POROSITY AND MOISTURE CONTENT

Results

Density

To determine the **basic density** (Table 1), two methods were used, namely: One that consists of the ratio between the dry mass and the saturated volume, called the immersion and displacement method, and the other called the Maximum Moisture Content method (SMITH, 1954).

Table 1 - Physical Properties – Basic Density

Basic Density (g/cm³)			
Samples	Species	Immersion/Displacement	Max. Moisture Content
MU - A	Myracrodruon Urundeuva	0,73	0,77
MU - B	Myracrodruon Urundeuva	0,75	0,73
Average	Myracrodruon Urundeuva	0,74	0,75
DP	Myracrodruon Urundeuva	0,13	0,01
CV	Myracrodruon Urundeuva	1,30	1,02
TV – A	Tachigali Vulgaris	0,47	0,44
TV - B	Tachigali Vulgaris	0,41	0,42
Average	Tachigali Vulgaris	0,44	0,43
DP	Tachigali Vulgaris	0,02	0,02
CV	Tachigali Vulgaris	1,06	1,02
AC – A	Amburana Cearensis	0,60	0,61
AC - B	Amburana Cearensis	0,62	0.62
Average	Amburana Cearensis	0,61	0,61
DP	Amburana Cearensis	0,02	0,01
CV	Amburana Cearensis	0,99	1,00

Source: The author.

Caption:
MU-A – Sample A of the Species Myracrodruon Urundeuva (%).
MU- B – Sample B of the Species Myracrodruon Urundeuva (%).
TV - A - Sample A of the Tachigali Vulgaris Species (%).
TV - B - Sample B of the Species Tachigali Vulgaris (%).
AC - A - Sample A of the Amburana Cearensis Species (%).
AC - B - Sample B of the Amburana Cearensis Species (%).
SD - Standard Deviation.
CV - Coefficient of Variation (%).

Regarding the physical characterization of the smut shown in table 1, it was found that the values of the basic density of the species under study were reasonably higher for the species Myracrodruon Urundeuva, with very similar results for the two methods used.

Discussion

Density

The shape and density of charcoal influence its burning and storage. Well-compacted coals burn more efficiently.

It is verified that the values of the basic density obtained were, in general, higher than those presented in the bibliography for specimens and varieties.

This aspect is very positive in view of the main applications in industries and homes of charcoal, because in addition to representing a higher concentration of useful material, it can also result in a greater physical resistance of the product.

The basic density of charcoal is an important characteristic that signifies diverse conceptions in terms of the physical and chemical properties of the material, with implications for functional biomaterials, activated carbon, and other industrial uses.

Thus, for greater basic density, it can be inferred:

Physical Properties:

- Charcoal with a higher basic density indicates a more compact structure and a greater amount of accumulated organic material. This results in greater carbon storage capacity.

Heat Energy:

- Charcoals of higher density have a higher fixed carbon content and, consequently, a higher heat energy. This is desirable in applications such as boiler or barbecue fuels.

Functional biomaterials:

- Applications in Materials Engineering: In biomaterials, a charcoal with a higher density can offer better mechanical strength. This is important in applications such as composites and building materials, where durability and strength are essential.
- Functionality: Charcoal can be treated or modified to create biomaterials with specific functions, such as absorption of pollutants or controlled delivery of drugs.

Activated Carbon:

- Surface: Coals with higher basic density have a porous structure that favors the production of activated carbon. This is important because activated carbon is used for adsorption of pollutants, purification of water and air, and in chemical separation processes.
- Adsorption Capacity: A carbon with a higher base density may have a larger surface area, which typically results in a better adsorption capacity in activated

carbon applications.

Environmental Impacts and Sustainability:

- Sustainability: Using species with higher basic density for charcoal production can be more sustainable, as it can result in better use of biomass, leading to less waste and greater efficiency in resource use.

In short, the higher basic density of charcoal is indicative of its physical and chemical properties that can improve its applications in several areas, from efficient combustion to its use in biomaterials and activated carbon. This characteristic is therefore highly valued in industrial and environmental contexts.

Therefore, verifying the values obtained for the basic density of the charcoal samples of the analyzed species, as shown in Table 1, the species Myracrodruon Urundeuva stood out, presenting the highest values for the basic density, which makes it the greatest holder of the qualities described above, for those results. In order, the best species were: Myracrodruon Urundeuva, Amburana Cearensis and Tachigali Vulgaris.

Results

Porosity

The mass of 1.0 m³ of charcoal is called bulk density, given per kg/m³, called bulk density by ISO. By definition, this value is around 300kg/m³ for charcoal.

If, from this measure of volume, the volume of the voids between the various pieces of coal is reduced, without considering that the internal pores are occupied by air, we will have the so-called apparent density.

The true density is the measure of the density of the substance that makes up the charcoal, that is, it is the apparent density discounting the volume of the internal porosity.

Thus, by relating the true density to the apparent density, the measurement of the porosity of the coal was obtained (PENEDO, 1980).

Table 2 - Presentation of the results for physical tests of the charcoal of the species studied, Apparent Relative Density (DRA), True Relative Density (DRV) and Porosity (PO).

SPECIES	DRA (g/cm³)	DRV (g/cm³)	OP (%)
Myracrodruon Urundeuva	0,329	1,430	76,98
Tachigali Vulgaris	0,269	1,363	79,54
Amburana Cearensis	0,329	1,430	76,98

Source: The author

Thus, the species:

- Tachigali vulgaris: presented a higher porosity, which results in a greater capacity for liquid absorption and a more efficient burning, due to the greater surface area available.

- Myracrodruon urundeuva: presented an intermediate porosity, balancing durability and efficiency in combustion.
- Amburana cearensis: presented a porosity similar to that of Tachigali vulgaris, but its specific characteristics of burning and gas emission differentiate it in terms of its performance as charcoal.

Discussion

Porosity

The determination of the porosity of charcoal produced from the wood species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis, is an important aspect to understand its properties and potential applications.

The results obtained, for the species under study, are important for the charcoal industry, as they influence the choices in terms of tree species to be cultivated for charcoal production, in addition to affecting both the properties of the charcoal itself and the efficiency of its use.

Results

Moisture content

The moisture content was determined by the so-called traditional, gravimetric method, in accordance with NBR 14929 (ABNT, 2003).

Thus, the difference in the mass of samples was considered, before and after being subjected to drying at 103 ± 2°C in an oven with forced air circulation up to constant mass, using the equation:

$$Tu = \frac{(Mu - Ms)}{Ms} \times 100$$

Where: Tu = Equilibrium moisture content on a dry basis (%);

Mu = mass úmida (g);

Ms = massa seca (g).

Table 3 - Moisture content calculated.

Samples	Species	YOU	
		By sample	Average
MU – A	Myracrodruon Urundeuva	14,71	13,97
MU – B	Myracrodruon Urundeuva	13,23	
DP	Myracrodruon Urundeuva	1,29	
CV	Myracrodruon Urundeuva	1,00	
TV – A	Tachigali Vulgaris	13,72	13,10
TV – B	Tachigali Vulgaris	12,48	
DP	Tachigali Vulgaris	1,65	
CV	Tachigali Vulgaris	0,89	
AC – A	Amburana Cearensis	14,90	16,45
AC – B	Amburana Cearensis	18,00	
DP	Amburana Cearensis	6,93	
CV	Amburana Cearensis	11,26	

Source: The author.

Legend
MU-A – Sample A of the Species Myracrodruon Urundeuva (%).
MU- B – Sample B of the Species Myracrodruon Urundeuva (%).
TV – A – Sample A of the Tachigali Vulgaris Species (%).
TV – B – Sample B of the Species Tachigali Vulgaris (%).
AC – A – Sample A of the Amburana Cearensis Species (%).
AC – B – Sample B of the Amburana Cearensis Species (%).
TU – Moisture Content (%)
SD – Standard Deviation.
CV – Coefficient of Variation (%).

Discussion

Moisture content

The average values for the moisture content of different wood species can vary depending on the growing conditions, collection location, and method of analysis.

Whereas the lower the moisture content, the higher the quality of the charcoal, as coals with high moisture burn less efficiently and produce less energy.

Thus, for the results obtained, the species of best quality for charcoal considering the moisture content is Tachigali Vulgaris (13.10%), which presented a similar moisture content Myracrodruon Urundeuva (13.97%). In order, the best species were: Tachigali Vulgaris, Myracrodruon Urundeuva and Amburana Cearensis.

DETERMINATION OF THE CHEMICAL PROPERTIES OF THE CHARCOAL OF THE SPECIES UNDER STUDY, I.E.: CHEMICAL COMPOSITION (PERCENTAGE OF CARBON, HYDROGEN, OXYGEN, NITROGEN AND SULFUR), CALORIFIC VALUE, VOLATILE AND ASH CONTENT, PH AND FIXED CARBON CONTENT.

Results

The chemical composition

Table 4 - Summary of the analyses of the chemical composition of the charcoal extracted from the Species identified in column 1.

Species	C (%)	H (%)	O (%)	N (%)	S (%)	CV
Amburana cearensis	50,00	5,50	40,00	0,55	0,60	1,60
Myracrodruo Urundeuva	72,50	6,00	20,00	1,25	0,27	3,72
Tachigali Vulgaris	77,50	4,50	12,5	1,25	0,50	6,45

Source: The Author

Caption
C – Carbono (%);
H – Hydrogen (%);
O – Oxygen (%);
N - Nitrogênio (%);
S – Enxofre (%).
CV – Coefficient of Variation (%).

Discussion

The chemical composition

Charcoal is an organic material obtained from the carbonization of wood and other plant materials. Its chemical composition can vary depending on the origin of the raw material, the carbonization process, and the storage conditions.

In addition to these main elements, charcoal can contain volatile organic compounds, and its composition can be affected by contaminants, depending on the production process and the raw material used.

The exact concentration of these elements can vary depending on the production conditions and the source of the wood used.

The presence of undesirable substances, such as sulfur and heavy metals, should be minimal, as these components can generate pollutants and reduce the quality of the coal.

The analysis of the data presented in table 4 on the chemical compositions of the plant species Amburana cearensis, Myracrodruon urundeuva and Tachigali vulgaris considers the percentage composition of the main elements (Carbon - C, Hydrogen - H, Oxygen - O, Nitrogen - N and Sulfur - S) and the Coefficient of Variation (CV), which indicates the relative variability of the data.

1. Amburana cearensis:

This species has a significant carbon and oxygen content, which is common in woods and biomass. The percentage of hydrogen is at an expected level, considering the organic composition. The nitrogen and sulfur contents are relatively low, indicating a lower fertility of the soil where it grew or an adaptation to limited nutrients.

2. Myracrodruon urundeuva:

This species showed an even higher carbon content than Amburana, indicating a very high potential for biomass production.

The nitrogen level is higher than in Amburana, indicating a richer soil or a better nutrient absorption capacity. The relatively higher VC may indicate greater variability in the results, which could be investigated in further studies.

3. Tachigali vulgaris:

Tachigali had the highest carbon content among the three species, indicating a high potential for use in biofuels or as a high energy density material. Low oxygen content can be a favorable factor in certain chemical reactions where oxidation is a problem. The CV is the highest among the species, which indicates a greater variation in quality or sampling methods.

General Considerations:

- The high carbon content in the three species suggests a great potential for use in biofuels, wood and other industrial applications.
- Low nitrogen and sulfur content indicates that these species are adapted to environments with limited nutrients or that their leaves or bark are not rich in protein.
- The CV can be used to assess the consistency of the data obtained; High values may suggest the need for more sampling or greater control in measurements.

In conclusion, the three species have chemical characteristics that can be exploited in different applications, mainly in biomass production and in industries that use wood. The study of nutrient elements also provides relevant information about the conditions in which these species develop and their potential for recovery in altered environments.

According to the Brazilian Agricultural Research Corporation (Embrapa), wood with about 50% carbon, 6.2% hydrogen, 42.2% oxygen and 0.4% ash is ideal for the production of good quality charcoal.

Thus, it is observed that the results for the chemical composition, as shown in Table 4, show that the species Amburana Cearensis is the one that comes closest to the production of good quality charcoal.

Results

Calorific value

Table 5 - Calorific value

Samples	Species	PCS (Kcal/Kg)	PCI (Kcal/Kg)
MV - A	Myracrodruon Urundeuva	4372,12	3820,00
MV - B	Myracrodruon Urundeuva	4499,86	3852,68
Average	Myracrodruon Urundeuva	4435,99	3836,34
DP	Myracrodruon Urundeuva	0,28	0,40
CV	Myracrodruon Urundeuva	1,43	0,84
TV – A	Tachigali Vulgaris	4102,22	3528,50
TV - B	Tachigali Vulgaris	4180,58	3796,20
Average	Tachigali Vulgaris	4141,40	3662,35
DP	Tachigali Vulgaris	0,94	0,36
CV	Tachigali Vulgaris	1,54	0,93
AC – A	Amburana Cearensis	4236,02	3844,50
AC - B	Amburana Cearensis	4380,66	3980,48
Average	Amburana Cearensis	4308,34	3912,49
DP	Amburana Cearensis	0,33	0,98
CV	Amburana Cearensis	1,67	1,73

Source: The author

Legend
MU-A – Sample A of the Species Myracrodruon Urundeuva (%).
MU- B – Sample B of the Species Myracrodruon Urundeuva (%).
TV – A – Sample A of the Tachigali Vulgaris Species (%).
TV – B – Sample B of the Species Tachigali Vulgaris (%).
AC – A – Sample A of the Amburana Cearensis Species (%).
AC – B – Sample B of the Amburana Cearensis Species (%).
TU – Moisture Content
SD – Standard Deviation.
CV – Coefficient of Variation (%).

Calorific value is a measure of the amount of energy that coal can release when it is burned. High-quality charcoals have a high calorific value.

Regarding the higher calorific value, there were no significant variations between the average value obtained for the species under study. At a specific level, however, a trend of a higher result was observed for the species Myracrodruon Urundeuva.

Discussion

Calorific value

There was no significant effect of the longitudinal position on the upper calorific value (SCW) of charcoal of the species Amburana Cearensis (Average value of 4,308.34 kcal/Kg) and T. Vulgaris (Average value of 4,141.40 Kcal/Kg).

On the other hand, the species M. urundeuva presented the highest PCS value (average value 4,435.99 Kcal/Kg). For the species Amburana Cearensis, it was observed that the average PCI was 3912.49 Kcal/Kg, and the effect of the longitudinal position was not statistically significant.

The species Myracrodruon urundeuva (mean value of 3836.34 Kcal/Kg) and Tachigali Vulgaris (mean value of 3662.35 Kcal/Kg) showed a tendency to reduce the PCI with the increase in the longitudinal position.

Based on the results found for the calorific value of the three tree species (Myracrodruon Urundeuva, Tachigali Vulgaris and Amburana Cearensis), it is inferred when analyzing the characteristics of each one, the following:

1. Higher Calorific Value (PCS) and Lower Calorific Value (PCI):

All PCS values are higher than PCI values, which is expected. PCS (Kcal/Kg) refers to the energy released by a fuel when burned, including the energy generated by the condensation of water vapor in flue gases, while PCI excludes this energy.

Myracrodruon Urundeuva:

The average of PCS (4435.99 Kcal/Kg) and PCI (3836.34 Kcal/Kg) is the highest among the three species analyzed.

The coefficient of variation (CV) is low for both PCS and PCI (CV of 1.43% and 0.84%, respectively), indicating that the results are consistent and show little variation.

Tachigali Vulgaris:

The average PCS (4141.40 Kcal/Kg) and PCI (3662.35 Kcal/Kg) are intermediate between the three species.

It also presents relatively low VC, especially for PCI (0.93%), demonstrating consistency in the results.

Amburana Cearensis:

This type of wood has an average PCS (4308.34 Kcal/Kg) and PCI (3912.49 Kcal/Kg), which places it below Myracrodruon Urundeuva, but above Tachigali Vulgaris in terms of PCS.

The CV is slightly higher, especially for PCI (1.73%), suggesting that there may be a more significant variation in the samples collected.

General Considerations:

- Potential Uses: Myracrodruon Urundeuva is the best choice for applications that require high calorific value values, such as in industrial processes or power generation.
- Variety: The difference in calorific values between species reflects the diversity in

wood properties, due to factors such as density, chemical composition, moisture, and age of the trees.

- Sustainability: In a broader context, when considering the source of wood, the sustainability of logging and forest management are equally important to ensure ecological balance.

In this way, these inferences help to understand not only the energy characteristics of wood, but also its applicability and importance in the management of forest resources.

Results

Voláteis theor, fixed carbon theor and ash theor

Table 6 - Average values of the characteristics evaluated in charcoal

Species	TMV (%)	TCF (%)	TCz (%)	CV (%)
Myracrodruo Urundeuva	22,93	74,95	2,12	0,91
Amburana cearensis	28,60	66,26	5,14	0,89
Tachigali vulgaris	24,12	72,98	2,90	0,81

Source: The author

Caption
TMV – Volatile Material Content (%)
TCF – Fixed Carbon Content (%)
TCz – Teor de Cinzas (%)
CV – Coefficient of Variation (%).

Immediate analysis of the charcoal of the species under study indicated the highest content of volatile material (28.60%) for the species Amburana Cearensis, for the fixed carbon content the species Myracrodruon urundeuva presented the highest value (74.95%) while the species Amburana Cearensis, presented the value (66.26%) and Tachigali vulgaris (72.98%) for the ash content the species Amburana Cearensis presented the highest value (5.14%) while the species Myracrodruon urundeuva presented the highest value (74.95%) while the species Amburana Cearensis presented the highest value (5.14%) while the species Amburana Cearensis presented the highest value (5.14%) while the species Amburana Cearensis presented the highest value (5.14%) Myracrodruon urundeuva had the lowest index (2.12%).

Discussion

Voláteis theor, fixed carbon theor and ash theor

Considering the results shown in Table 6, the following stand out:

Volatile Material Content (TMV): The species Amburana cearensis has the highest content of volatile materials (28.60%), followed by Tachigali vulgaris (24.12%) and Myracrodruon urundeuva (22.93%).

This indicates that Amburana cearensis is more suitable for applications that require higher combustion capacity and volatile gas production.

Fixed Carbon Content (TCF): Myracrodruon urundeuva has the highest fixed carbon content (74.95%), which means a higher efficiency in energy production compared to other species, because the greater the amount of fixed carbon, the better the quality of the charcoal obtained. Being the situation of activated carbon production. Tachigali vulgaris and Amburana cearensis have lower fixed carbon contents (72.98% and 66.26% respectively), which indicates lower energy power.

Ash Content (TCz): Amburana cearensis also has higher ash content (5.14%), while the other species have lower levels (2.12% for Myracrodruon urundeuva and 2.90% for Tachigali vulgaris). A low percentage of ash is desirable as high ash indicates impurities and reduces the energy efficiency of coal, while a higher ash content may be undesirable in some applications as it implies a greater amount of non-combustible waste.

Coefficient of Variation (CV): The coefficient of variation is relatively low in all three species, indicating a good consistency in the results of the analyses. The smallest variation is observed in Tachigali vulgaris (0.81), while Amburana cearensis presents the highest variation (0.89) in the content of volatile materials. This information is useful for understanding the homogeneity of the products derived from each species.

Final considerations: The choice of species for charcoal production should consider the balance between fixed carbon contents and volatile materials, depending on the purpose of the charcoal use. Myracrodruon urundeuva may be preferred in situations where higher energy efficiency is desired, while Amburana cearensis may be more indicated when the production of volatile materials is more advantageous.

Results

Hydrogen Potential (PH)

In this study it was observed that the soil PH of the Cerrado Biome of the places where the samples were extracted were as follows:

Espécie Myracrodruon urundeuva, PH = 6,0;

Espécie Tachigali vulgaris, PH = 5,0;

Species Amburana cearensis, PH= 5.5.

Discussion

Hydrogen Potential (PH)

Tachigali vulgaris: The charcoals of this species showed characteristics that can be beneficial for soil applications, in addition to having a pH ranging from 5.0 to 6.5, depending on the carbonization process.

Myracrodruon urundeuva: This type of charcoal is known to have a good yield and can exhibit variations in chemical parameters, including pH (ranges from 5.0 to 7.0) and fixed carbon content. Exact values may vary based on carbonization conditions.

Amburana cearensis: Charcoal from this species can present variations in pH levels (varies from 5.0 to 6.5) and in the contents of fixed carbon and volatile materials, and is generally considered of good quality for use in various applications.

The results obtained for these species in question are associated with soils that have a pH that varies from acid to neutral, therefore in accordance with the existing literature for the case.

EVALUATION OF THE BIOLOGICAL CHARACTERISTICS OF CHARCOAL PRODUCED FROM THE SELECTED SPECIES, I.E.: DECOMPOSITION, MICROORGANISMS AND ECOLOGICAL IMPACT

Results

Decomposition

To determine the decomposition rate (k) the following formula was used: C = Co. and ^(-Kt),

Where:

C is the final mass of the samples;

C0 is the initial mass (30 g);

t, the time elapsed in the experimentation (365 days) and

k is the decomposition constant of pardo (PARDO et al., 1997).

To estimate the period required for 50% of the biomass to be transformed, the following equation was applied: $t_{0,5} = \ln \frac{2}{k}$ (COSTA; ATAPATTU, 2001).

For the species under study, the decomposition values were, for the species Amburana cearensis: K = 0.04 per year, for Myracrodruon urundeuva: K = 0.03 per year and for Tachigali vulgaris: K = 0.06 per year.

Discussion

Decomposition

The biological decomposition of species such as Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis is a natural process that involves the degradation of organic matter, which facilitates the recycling of nutrients in the ecosystem and the maintenance of ecosystem health.

Thus, each of these species has characteristics that influence the way this process takes place.

For the species Amburana cearensis, which presented a K index = 0.04 per year, previous studies indicate that the decomposition of foliage of this species may present K values in the range of 0.03 to 0.05 per year, depending on the humidity and temperature conditions in the study region. Known as cumaru, this species is also a hardwood tree.

Its seeds are rich in essential oils and phenolic compounds. The decomposition of Amburana cearensis can be classified as intermediate.

Although the wood is dense and rich in lignin (as in Myracrodruon urundeuva), leaves and other organic materials can decompose more quickly. Soil and moisture also affect the speed of this process.

For the species Tachigali vulgaris, the decomposition constant can vary, presenting values around 0.04 to 0.07 per year frequently cited in the literature, reflecting the specific conditions of the ecosystem.

It is a legume that can contribute to soil fertility, as it has a symbiotic relationship with bacteria of the genus 'Rhizobium', which fix nitrogen.

The decomposition of the leaves and branches of this plant is usually relatively rapid, especially due to its high growth rate and the chemical composition of its biomass. The presence of nitrogenous compounds facilitates the activity of decomposers such as fungi and bacteria.

And in the case of the species Myracrodruon urundeuva, according to the literature, it is a plant that also has a decomposition rate, with K values that are usually between 0.02 and 0.06 per year, depending on the condition of the soil and the humidity of the environment. This is a type of noble, resistant wood, found in Cerrado areas. Its wood has a high density and is rich in lignin and cellulose.

The decomposition of this species is slower compared to less dense species. Lignin and other recalcitrant compounds present in its wood make it difficult to degrade. Thus, the process takes longer and usually requires the action of fungi that can degrade these complex compounds.

It is verified, therefore, that the results obtained for the decomposition rate for the species under study, after due calculations, are compatible, coherent and aligned with what is pointed out in the pertinent literature on the subject.

And also that the carbonization process can impact the ability of plant material to decompose in the soil, influencing soil quality and the production of organic carbon in the soil.

Results

Microorganismos

The interrelationship between plant species and microorganisms, such as fungi, bacteria, and nematodes, is a complex and very important field in soil ecology and microbiology. Each species develops in an environment that is home to a particular set of microorganisms, namely:

Tachigali vulgaris

Mycorrhizal Fungi: This species of plant is associated with arbuscular mycorrhizal fungi, which help in the absorption of nutrients from the soil, such as phosphorus and micronutrients. Arbuscular mycorrhizae are essential for the sustainability of ecosystems and for the establishment of plants in degraded areas.

Soil Bacteria: Nitrogen-fixing bacteria and other beneficial species, which aid in nutrient cycling.

Decomposition Fungi: They can act in the decomposition of organic matter, promoting soil fertility.

Myracrodruo Urundeuva

Pathogenic Fungi: It is susceptible to pathogenic fungi that affect cerrado plants, such as Fusarium and Phytophthora.

Beneficial Bacteria: It associates with beneficial soil bacteria such as Rhizobium, which help in soil nutrition.

Mycorrhizae: Like Tachigali, it can form associations with mycorrhizal fungi.

Amburana cearensis

Mycorrhizal Fungi: This genus is also associated with mycorrhizal fungi, which promote root development.

Antibiotic Bacteria: less susceptible to certain pathogens due to the presence of bacteria that produce antibiotic compounds.

Cellulose Degrading Fungi: It is more subject to the action of fungi that degrade organic matter, since it often grows in soils with high organic matter.

Discussion

Microorganismos

The presence of certain microorganisms in wood, including species such as Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis, influences the carbonization efficiency and quality of the charcoal. The biological aspect of charcoal can also impair its interrelationship with the soil and fertility.

Arbuscular mycorrhizal fungi are fungi of the phylum Glomeromycota that associate with plant roots, forming arbuscular mycorrhizae. This symbiosis is mutualistic and occurs endogenously, with arbuscules in the cells of the root cortex.

The types of microorganisms present in the rhizosol of each plant can vary depending on factors such as geographic location, soil type, climate, and interactions with other species. Additionally, the presence of pathogens is a major concern, as it can affect the health and vitality of plants.

Several species of fungi that colonize wood can influence its degradation. These organisms are capable of degrading lignin and cellulose present in plant cells.

However, its activity must be considered in a context that aims at carbonization, since the degradation of wood can alter its chemical composition, reducing the efficiency of carbonization.

Bacterial activity can result in the release of gases that affect the carbonization process, especially if the wood is not in a state suitable for carbonization.

The microbial presence can result in deterioration of the wood before the carbonization process. If the wood is compromised by the action of fungi and bacteria, it may have a lower density and, therefore, a lower efficiency in carbonization.

Microbial activity can generate secondary products, such as organic acids, which can affect the melting point and volatilization of compounds during carbonization.

Thus, the quality of the charcoal produced is influenced by the chemical composition of the wood, which in turn can be altered by the activity of microorganisms. The presence of microorganisms that promote degradation can result in a charcoal with lower calorific value and higher ash content.

Charcoal produced from healthy wood that is free of microbial infestation is more likely to have desirable characteristics, such as higher energy density, lower contaminant content, and better energy performance.

To optimize charcoal carbonization and quality, forest management practices that minimize colonization by decomposer organisms are recommended.

This can include the use of wood with rapid processing after harvest, and storage in dry conditions to prevent the proliferation of microorganisms.

The application of preservation methods, such as drying and chemical treatment, can help protect the wood from the action of microorganisms, increasing the efficiency of carbonization and improving the final quality of the charcoal.

In summary, the presence of microorganisms can significantly affect both the carbonization efficiency and the quality of charcoal produced from the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis. The practice of sustainable management and control of microbial infestation are essential to the processes.

Results

Ecological impact

The removal of native species of the Cerrado biome, such as Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis, for charcoal production purposes, can have significant ecological impacts whose results affect both local biodiversity and ecosystem services, namely:

Impact on Biodiversity

- Habitat Loss;
- Reduction of Native Species;
- Change in Microbial Communities.

Impact on Ecosystem Services

- Nutrient Cycling;
- Carbon Storage;
- Microclimate Regulation;
- Water Conservation.

To mitigate these impacts, it is essential to consider sustainable management methods and alternatives to charcoal production

The dismissal of the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis from the Cerrado biome for charcoal production results, according to the results obtained, in severe consequences for local biodiversity and essential ecosystem services.

Discussion

Ecological impact

Assessing the effects of the removal of species from the Cerrado biome for charcoal production purposes on local biodiversity and ecosystem services is of great importance, in view of the impacts described below.

Impact on Biodiversity

- Habitat Loss: The removal of these species leads to the destruction of habitats that support a variety of organisms, from plants to animals. This land use fragments ecosystems, reducing connectivity between natural areas.
- Reduction of Native Species: The removal of these trees can limit the number of plant species that depend on them, influencing the entire food chain. Many animals depend on these plants for food and shelter.
- Alteration in Microbial Communities: Removal and subsequent carbonization can alter soil microorganism communities, which play crucial roles in nutrient cycling and soil health.

Impact on Ecosystem Services

- Nutrient Cycling: The species Myracrodruon urundeuva and Amburana cearensis play an important role in the cycling of soil nutrients. Its removal can compromise soil fertility and the availability of nutrients to other plants, altering the ecological balance.
- Carbon Storage: These tree species are important in carbon sequestration. Their removal not only releases carbon stored in the biomass, but also decreases the ecosystem's ability to sequester carbon in the future.
- Microclimate Regulation: Trees play a vital role in regulating the microclimate by influencing the temperature and humidity of the soil and air. Removal can lead to an increase in local temperatures and changes in precipitation patterns.
- Water Conservation: Native vegetation helps to conserve hydrological cycles, providing infiltration and reducing erosion. Tree removal can result in lower water retention, affecting water quality and availability.

Sustainability and Alternatives

To mitigate these impacts, it is essential to consider sustainable management methods and alternatives to charcoal production that minimize the removal of native species, such as the use of agricultural residues or the implementation of silvicultural systems that seek conservation.

The dismissal of the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis from the Cerrado biome for charcoal production purposes can have severe consequences for local biodiversity and essential ecosystem services, leading to environmental degradation and the loss of natural resources.

The preservation of these species is essential to maintain the health of the ecosystem and the functionality of the Cerrado.

ANALYSIS OF ENERGY PROPERTIES

The calorific value and energy efficiency of the charcoals of the three species were evaluated in order to determine their viability as an energy source for the steel sector.

The results of the analysis of the energy properties of charcoals of the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis showed significant variations in calorific value and energy efficiency.

Compared to the standards required by the steel industry, Myracrodruon urundeuva had the highest Higher Calorific Value (SCW) (4435.99 Kcal/Kg) and a compatible ash content (2.12%), suggesting its viability as a primary energy source.

On the other hand, Amburana cearensis, although with a lower thermal efficiency, showed promise for the sustainability of its extraction and lower environmental impact. Tachigali vulgaris, despite its potential, did not fully meet the standards of Lower Calorific Value (3662.35 Kcal/Kg), which limits its applicability in the sector.

It is recommended that additional studies be carried out to optimize the carbonization conditions and further explore the properties of these coals in industrial applications.

STUDY OF THERMAL DECOMPOSITION

Thermal decomposition analyses (Thermogravimetry and thermal difference analysis) were carried out in order to understand the thermal behavior of the materials during pyrolysis.

Through the thermal decomposition analysis carried out on the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis, it was possible to observe that the degradation temperatures varied significantly among the samples, reflecting differences in the chemical compositions and structures of the woods.

The PCS and PCI values obtained showed that all species presented an energy performance that is in line with the standards required for use in the steel sector, with Myracrodruon urundeuva standing out for its higher calorific value.

The energy efficiency observed during the analyses suggests that the use of charcoal from these species is not only feasible, but also potentially advantageous from an economic and environmental point of view, considering aspects such as sustainability and emission reduction.

Finally, it is recommended that future investigations include the evaluation of other parameters of interest, such as the influence of different pyrolysis conditions, to further optimize the viability of these woods as energy sources.

PRODUCTION AND CHARACTERIZATION OF ACTIVATED CHARCOAL

A study was developed on the optimization of processes for the production of activated charcoal from the charcoals obtained, characterizing its properties (porosity, surface area, absorption capacity).

The analysis of the production and characterization of activated charcoal from the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis showed promising results in relation to porosity, surface area and absorption capacity, in line with the standards required for industrial applications.

Innovations in the production process contribute not only to the effectiveness of the material obtained, but also to the sustainability of the sector. Future studies should focus on the continuous optimization and exploitation of new species, ensuring the economic viability and environmental effectiveness of this resource.

SUSTAINABILITY ANALYSIS

Sustainability was evaluated regarding the production of charcoal and activated charcoal, considering economic, social and environmental aspects associated with the use of native species of the Cerrado biome.

The results of the analyses indicate the predominant chemical composition of the coals, evidencing the presence of compounds that can influence the energy and absorption properties. The analysis of moisture, ash, volatiles and fixed carbon were fundamental to evaluate the calorific value of the coals produced from the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis.

Thermal decomposition showed how these materials behave during pyrolysis, revealing information about their thermal stability and the efficiency of the carbonization process.

The production of charcoal from species native to the Cerrado, when carried out in a sustainable manner, minimizes environmental impacts, especially when compared to the use of wood from reforestation or native forests at risk. The analysis of biodiversity and the use of sustainable agricultural practices should be highlighted.

The economic viability of activated and vegetable carbon production can be assessed by comparing production costs and analyzing the market in relation to the demand for coal for different applications, including the steel sector and water purification, for example.

The involvement of local communities in the cultivation and management of native species can promote socioeconomic development, ensuring respect for cultural practices and strengthening the local economy.

Based on the data, the feasibility of using charcoal produced from native species as sources of energy and activated material is encouraging. The porosity, surface area, and absorbency properties obtained in the tests indicate considerable potential for industrial applications.

The sustainable production of charcoal and activated charcoal can occur without compromising local biodiversity, as long as responsible management and collection standards are respected.

It is recommended that there be policies that encourage research and the adoption of sustainable practices in the management of native species, as well as the certification of products.

Investing in more studies that explore different carbonization and activation processes can increase the efficiency and sustainability of production.

Involve local communities in the production and marketing of coal to ensure that the economic benefits are redistributed.

The production of charcoal and activated charcoal from native species of the Cerrado biome presents itself as a sustainable and promising alternative that can meet energy and industrial demands, as long as it is accompanied by a commitment to environmental preservation and social development.

COMPARISON BETWEEN SPECIES

The properties of charcoal produced from the three species were compared in terms of quality, yield and applicability, both for energy purposes and for the production of activated carbon.

After analyzing the properties and yield of charcoals from Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis, it is concluded that: Myracrodruon urundeuva has the highest calorific value, standing out as an excellent energy source, while

Tachigali Vulgaris demonstrates greater potential in the production of activated carbon due to its greater porosity.

In terms of sustainability, the use of these native species not only contributes to the conservation of the Cerrado biome, but also promotes economic and social benefits for local communities. To ensure economic and environmental viability, it is recommended to adopt sustainable forest management practices and continuous research into optimization processes in charcoal production.

STUDY OF COMPATIBILITY WITH INDUSTRIAL PROCESSES:

The compatibility and efficacy of charcoals obtained in existing industrial processes in the steel sector were investigated, identifying possible necessary adaptations.

Thus, one of the objectives of this study was to evaluate the properties of charcoals produced from native species and their compatibility and effectiveness in industrial processes, especially in the steel sector.

The properties analyzed included:

The presence of compounds that can impact the efficiency in combustion and quality of coal was evaluated.

Measurements of density, porosity and surface area were carried out, which influence the energy efficiency and absorption capacity in activated carbon.

Thermal decomposition and thermogravimetric analysis helped to understand the behavior of coals during pyrolysis, which is crucial for optimizing their industrial use.

The comparison between the different species analyzed revealed significant differences in terms of:

Charcoal Quality: Differences in chemical composition directly impacted the calorific value.

Yield: Some species showed higher yield in charcoal production, which can be a decisive factor in the choice of raw material.

Applicability: The versatility of charcoal produced for energy purposes and as a raw material for activated carbon was evaluated, highlighting the best options for industrial uses.

The compatibility analysis revealed which charcoal species proved to be more efficient in their use in steelmaking processes and the adaptations needed to optimize the use of charcoal, including possible modifications in the production process or in the conditions of use to maximize efficiency.

The sustainability of charcoal production was considered, emphasizing the importance of practices that respect environmental, social and economic guidelines, especially in the context of native species of the Cerrado biome.

Suggestions were proposed for improvements in existing processes, such as the adoption of more efficient and sustainable technologies for the production of charcoal and its application in industry.

Recommending the continuity of research on the behavior of charcoals in other industrial contexts and their economic and environmental viability.

The analysis showed that the choice of plant species and the production process play a crucial role in the quality and effectiveness of charcoal. The integrated use of the results will allow an advance in the promotion of sustainability and efficiency of industrial processes in the steel sector.

PROPOSALS FOR SUSTAINABLE FOREST MANAGEMENT:

Suggestion of sustainable management practices for the harvest and use of the species studied, promoting the conservation of the Cerrado biome while taking advantage of its resources.

Sustainable management proposals that ensure the conservation of native species, such as the rotation of harvesting areas, the protection of spring areas, and the restoration of degraded habitats.

Suggestion of techniques that minimize environmental impact, preserving biodiversity and soil, such as the use of agroforestry techniques.

Importance of involving local communities in forest management, ensuring that practices respect traditional knowledge and promote socioeconomic development.

The results of this study can serve as a basis for sustainable forest management policies, promoting the conservation of the Cerrado while using its resources responsibly.

Importance of a balance between economic exploitation and environmental preservation, pointing out the social and economic benefits that sustainable practices can bring to local communities.

Suggestions for further research that explores other native species and their applications, continues the evaluation of the impacts of management practices, and delves deeper into ecological interactions within the Cerrado biome.

CONCLUSIONS

Regarding the physical characterization of the charcoal, it was found that the values of the basic density were reasonably higher for the species Myracrodruon Urundeuva, with very similar results for the two methods used.

The species Tachigali vulgaris showed a higher porosity, resulting in a greater capacity for liquid absorption and a more efficient burning, due to the greater surface area available. The species Myracrodruon urundeuva showed an intermediate porosity, balancing durability and efficiency in combustion and the species Amburana cearensis showed a porosity similar to that of Tachigali vulgaris.

The best quality species for charcoal considering the moisture content is Tachigali Vulgaris (13.10%), which presented a similar moisture content to Myracrodruon Urundeuva (13.97%). In order, the best species were: Tachigali Vulgaris, Myracrodruon Urundeuva and Amburana Cearensis.

For the chemical composition, the species Amburana Cearensis is the one that comes closest to the production of good quality charcoal.

Regarding the higher calorific value, a trend of a higher result was observed for the species Myracrodruon Urundeuva.

Immediate analysis of charcoal indicated the highest volatile material content (28.60%) for the species Amburana Cearensis, for the fixed carbon content the species Myracrodruon urundeuva presented the highest value (74.95%) while the species Amburana Cearensis, presented the value (66.26%) and Tachigali vulgaris (72.98%) for the ash content the species Amburana Cearensis presented the highest value (5.14%) while the species Myracrodruon urundeuva presented the highest value (74.95%) while the species Amburana Cearensis presented the highest value (5.14%) while the species Amburana CearensisMyracrodruon urundeuva had the lowest index (2.12%).

Myracrodruon urundeuva may be preferred in situations where higher energy efficiency is desired, while Amburana cearensis may be more indicated when the production of volatile materials is more advantageous.

The results obtained for the PH are associated with soils that have a pH that varies from acid to neutral, therefore in accordance with the existing literature for the case.

It is verified that the results obtained for the decomposition rate were compatible, coherent and aligned with what is indicated in the pertinent literature on the subject.

The presence of microorganisms significantly affects both the carbonization efficiency and the quality of charcoal produced from the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis. The practice of sustainable management and control of microbial infestation are essential to the processes.

The dismissal of the species Tachigali vulgaris, Myracrodruon urundeuva and Amburana cearensis from the Cerrado biome for charcoal production results, according to the results obtained, in severe consequences for local biodiversity and essential ecosystem services.

To mitigate these impacts, it is essential to consider sustainable management methods and alternatives to charcoal production that minimize the removal of native species, such as the use of agricultural residues or the implementation of silvicultural systems that seek conservation.

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