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Chemical composition and energy potential of woody species in dry forest: subsidies for sustainable forest management

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ABSTRACT: Energy demand, especially in developing countries, is partly supplied by firewood and charcoal from natural forests. However, there are not always previous studies of energy quality, with implications for forest management. This study aimed to characterize the energy potential of the wood of six shrub-tree species from the Caatinga and the influence of the circumference class on their chemical properties and energy potential to subsidize forest management. Thus, *Anadenanthera colubrina* var. *cebil* (Angico), *Cenostigma bracteosum* (Catingueira), *Cnidoscolus quercifolius* (Faveleira), *Mimosa ophthalmocentra* (Jurema branca), *Mimosa tenuiflora* (Jurema preta) and *Aspidosperma pyrifolium* (Pereiro) from an area of Dry Forest (Caatinga) in Floresta, Pernambuco state, Brazil, were analyzed. Each species had three individuals sampled in five circumference classes (I a V) at 1.30 m from the ground. Carbon, hydrogen, nitrogen, insoluble lignin, and ash contents, as well as higher and lower calorific values, apparent and energetic densities and energy production were evaluated. Then, a completely randomized design in a factorial arrangement (species x circumference classes) with three replications, and comparison of means (Tukey's test, $p < 0.05$) were considered in the statistical analysis. A Cluster analysis was also performed aiming at joint analysis of variables. The results showed that the biomass of *M. ophthalmocentra* and *M. tenuiflora* have the highest energy density and amount of energy per unit of mass. *C. quercifolius* and *A. pyrifolium* were lower when compared to the other species. In addition, *M. ophthalmocentra*, *M. tenuiflora*, *A. colubrina* and *C. bracteosum* stood out for energy generation. Classes IV and V can be indicated as biomass for combustion, while class I has disadvantages due to higher nitrogen content and lower upper and lower calorific values.

Key words: biomass; Caatinga; dimensions; native species; calorific value; Brazilian semi-arid region

Composição química e potencial energético de espécies lenhosas em floresta seca: subsídios para o manejo florestal sustentável

RESUMO: A demanda de energia, especialmente nos países em desenvolvimento, é parcialmente suprida por lenha e carvão vegetal de florestas naturais. No entanto, nem sempre existem estudos prévios de qualidade energética, com implicações para o manejo florestal. O estudo objetivou caracterizar o potencial energético da madeira de seis espécies lenhosas da Caatinga e a influência da classe de circunferência em suas propriedades químicas e potencial energético para subsidiar o manejo florestal. Foram estudadas *Anadenanthera colubrina* var. *cebil* (Angico), *Cenostigma bracteosum* (Catingueira), *Cnidoscolus quercifolius* (Faveleira), *Mimosa ophthalmocentra* (Jurema branca), *Mimosa tenuiflora* (Jurema preta) e *Aspidosperma pyrifolium* (Pereiro) procedentes de uma área de Floresta Seca (Caatinga) em Floresta, estado de Pernambuco, Brasil. Cada espécie teve três indivíduos amostrados em cinco classes de circunferência (I a V) a 1,30 m do solo. Avaliaram-se os teores de carbono, hidrogênio, nitrogênio, lignina insolúvel e cinzas, bem como maiores e menores valores caloríficos, densidades aparente e energética e produção de energia. Na análise estatística se considerou um delineamento inteiramente casualizado em arranjo fatorial (espécies x classes de circunferência), com três repetições, e comparação de médias (Tukey, $p < 0{,}05$). Também foi realizada uma análise de agrupamento visando análise conjunta das variáveis. Os resultados mostraram que as biomassas de *M. ophthalmocentra* e *M. tenuiflora* apresentam as maiores densidades energéticas e quantidades de energia por unidade de massa. *C. quercifolius* e *A. pyrifolium* foram inferiores quando comparados às demais espécies. Além disso, *M. ophthalmocentra*, *M. tenuiflora*, *A. colubrina* e *C. bracteosum* se destacaram pela geração de energia. As classes IV e V podem ser indicadas como biomassa para combustão, enquanto a classe I apresenta desvantagens, causado pelo maior teor de nitrogênio e menores valores caloríficos superior e inferior.

Palavras-chave: biomassa; Caatinga; dimensões; espécies nativas; poder calorífico; semiárido brasileiro

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Introduction

The evolution in the dynamics of energy use in its relationship with climate change has profound consequences on forests (FAO, 2008) due to the growing need to use clean energy from renewable resources, and of course because they are suppliers of woody biomass, which is among the most important energy sources. It is estimated that about 10-40% of the world's primary energy consumption could be supplied by woody biomass by 2050 (Lauri et al., 2014). Therefore, forest biomass plays an important role in the production of renewable energy (Tarvainen et al., 2015), with growing interest in renewable and domestically produced energy motivating evaluation of woody bioenergy feedstock production (Griffiths et al., 2017) and because of increasing concerns about predicted climate changes (De Long & Dahlberg, 2017).

The total global biomass supply from agriculture and forestry is estimated at around 11.9 billion tons of dry matter per year, of which 61% is produced by agriculture and 39% by forestry (firewood, including power generation, is responsible for 23%, followed by industrial round wood with 8% and residues with 8%) (Popp et al., 2021). Firewood and charcoal production reached about 1.41 billion tons in 2019 (FAO, 2021). Therefore, traditional woody biomass, mainly in the form of firewood and charcoal, remains an important energy source, especially in rural regions of developing countries (Rodríguez-Jímenez et al., 2019).

In addition, about 7.5% of the energy matrix in Brazil was supplied from 8.3 million tons of firewood in 2020, corresponding to 8.9% of the internal energy produced in the country (EPE, 2021). Much of this demand is met by wood from planted forests, especially Eucalyptus, with extensive knowledge of its technological properties for energy. On the other hand, native wood species are also used, mainly in the Northeast Region of Brazil, despite little knowledge of their real energy potential.

There is notably greater dependence on the use of both residential and industrial firewood as an energy source in the North, Northeast, and Midwest in Brazil, creating pressure on their native forests, and constituting a demand which should be met in a sustainable way. An alternative in the Brazilian Northeast is to produce energy biomass from its dry forest (Caatinga) through sustainable forest management plans (Brand, 2017; Carvalho et al., 2020). This aspect becomes even more relevant due to the fact that the Caatinga is characterized by several types of vegetation, with few tree species, endemic and at risk of extinction (Milliken et al., 2018).

On the other hand, the regulations which enable conducting a forest management plan for production are based on control by area, clear cutting, recovery through natural regeneration, generally with dendroenergetic purposes (firewood and/or charcoal), generalized minimum cutting cycle for all vegetation types of Caatinga, and without solid scientific bases regarding the resistance and resilience properties of the vegetation, meaning in the way the community reacts to disturbance (harvest) and in the processes that occur for their recovery (Meunier et al., 2018). There are also deficiencies in information regarding the technological aspects of its shrub-tree species, such as the sizes and quality of its wood, as well as the potential for energy production and usage efficiency of each one of them for this purpose.

The use of wood for energy production is a simple process, but the energy yield depends on its chemical constitution, varying from species to species (Jesus et al., 2017). Therefore, the wood of a species for energy use must have certain characteristics such as high density, high carbon (C), hydrogen (H) and lignin levels, high calorific value, and low oxygen (O), nitrogen (N), moisture and ash levels, in addition to ratios between chemical elements such as C/N, C/H and C/O (Brand, 2010; Protásio et al., 2011; Komilis et al., 2012; Velázquez-Martí et al., 2014; Leite et al., 2015). Therefore, one can only expect quality and performance of the wood of a species in direct use or in its transformation with joint knowledge of these characteristics, which can guarantee better energy efficiency.

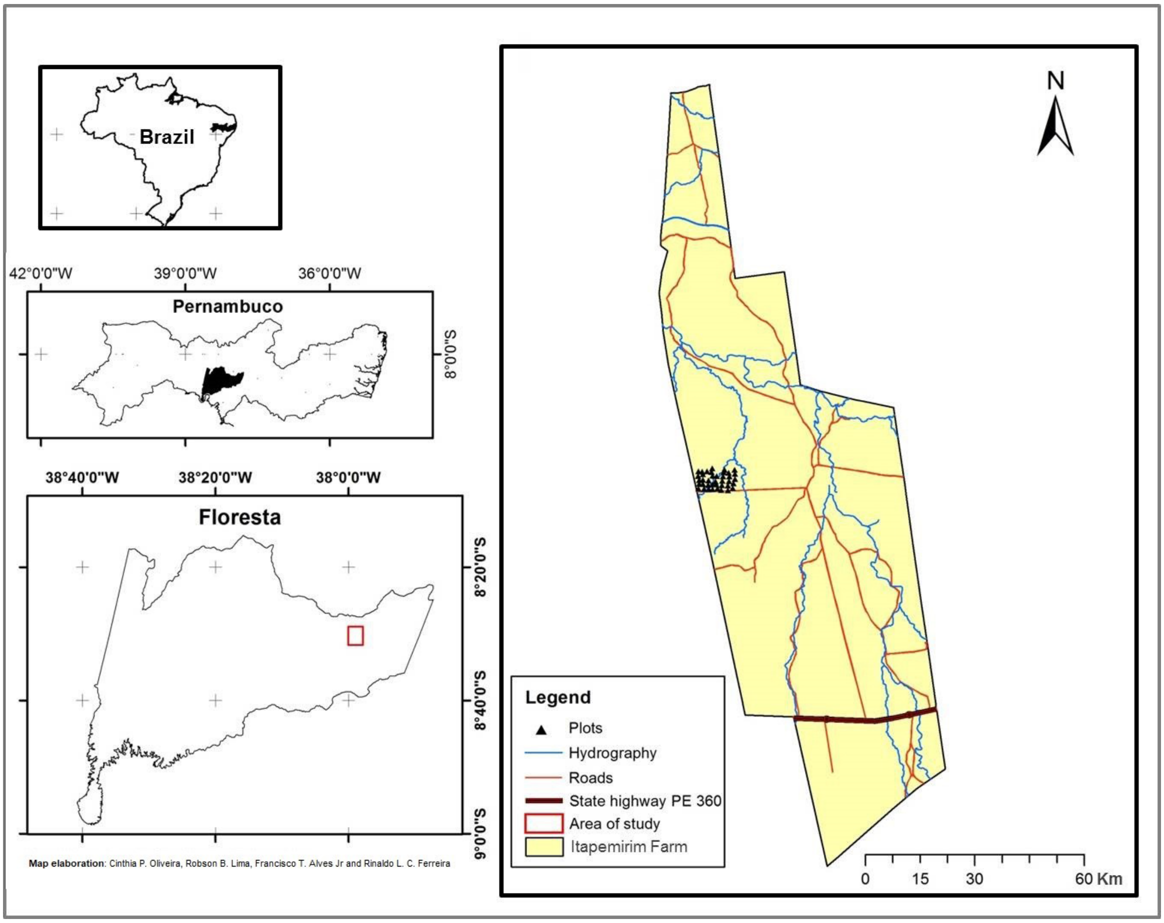
In this sense, investigating the energetic characterization of forest species in the Caatinga can support energy production systems based on their biomass from implementing sustainable forest management plans, in which species which are really suitable for this purpose are harvested. Therefore, the removal of species that can minimize the impacts on the remaining resources would be avoided, generating other ecosystem services such as protection of the soil and direct radiation, the landscape, and a refuge and food for wildlife. Within this context, this study aimed to characterize the energy potential of the wood of six shrub-tree species from the Caatinga and the influence of the circumference class on their chemical properties and energy potential to subsidize forest management.

Materials and Methods

Study area, selection of species and collection of wood samples

This study was performed with material from woody species from a Caatinga area located in the municipality of Floresta, Pernambuco state, Brazil, located at the geographic coordinates 8°33'20.9"S Latitude and 37°56'27.4"W Longitude (Figure 1).

The region's climate is BS'h (hot semi-arid climate) according to the Köppen classification. The average annual accumulated precipitation is 650 mm and the average annual temperature is 26 °C (INMET, 2022). The vegetation can be classified as wooded steppe-savanna, presenting an endemic floristic characteristic of semi-arid climates, with intermittent torrential rains followed by a long dry period, which can last for a few years (IBGE, 2012). The region's soil is classified as Chronic Luvissol, characterized by being shallow and usually presenting an abrupt change in its texture (Santos et al., 2018).



Source: Lima et al. (2017).

Figure 1. Location of the study area in the municipality of Floresta, state of Pernambuco, Brazil.

The following species were selected from the study by Dalla Lana et al. (2018): *Aspidosperma pyrifolium* Mart. (Pereiro), *Anadenanthera colubrina* var. *cebil* (Griseb.) Altschul. (Angico), *Cenostigma bracteosum* E. Gagnon & G. P. Lewis (Catingueira), *Cnidoscolus quercifolius* Pohl. (Faveleira), *Mimosa ophthalmocentra* Mart. ex Benth (Jurema branca) and *Mimosa tenuiflora* (Willd.) Poir (Jurema preta). The collection of wood samples was performed using a circumference of 1.30 m from the ground and distributed in the following classes: I – 6.0 ├ 12 cm; II – 12.0 ├ 18 cm; III – 18.0 ├ 24 cm; IV – 24.0 ├ 30 cm and V - ≥ 30 cm. Each species had three individuals sampled in each circumference class, collecting a wooden disk from the central trunk at a height of 1.3 m from the ground.

Elemental chemical analysis

Wood samples from each individual were ground in a Wiley mill and classified in 200/270 mesh sieves to perform an elemental chemical analysis. The samples were dried in an oven at 103 ± 2 °C for 24 hours, and ≈1.0 gram of the samples were weighed and put into a CHN Perkin Elmer II 2400 series CHNS/O elemental analyzer (Perkin Elmer, EUA) determining the Carbon (C, %), Hydrogen (H, %) and Nitrogen (N, %) contents and the Carbon/Nitrogen (CN) and Carbon/Hydrogen (CH) ratios. The oxygen content (O %) was obtained through Equation 1 (Bech et al., 2009), and the Carbon/Oxygen ratio was consequently obtained (CO).

$$O = 100 - C - H - N - S - Ash \quad (1)$$

In which: O = oxygen content (%); C = carbon content (%); H = hydrogen content (%); N = nitrogen content (%); S = sulfur content (%) obtained from the work of Alves (2011); Ash = ash content (%).

Duplicates were used by the Klason method according to TAPPI -T 222 om-02 (Tappi, 2002a) to determine the acid-insoluble lignin content - Lig (%). The ash content - Ash (%) was determined by the mass of the mineral residue of lignocellulosic materials resulting from the complete combustion of the sample. Incineration was carried out at a temperature of 600 ± 5 °C in an electric muffle furnace for three hours according to TAPPI - T 211 om-02 (Tappi, 2002b).

Higher and lower calorific value

The higher calorific value (HCV) was determined in a digital calorimeter C-2000 (IKA-WERKE GMBH & CO. KG, Germany) according to ISO 9831:1998 (ISO, 1998). The samples were classified in 40/60 mesh sieves. The fractions of the samples retained in the 60 mesh sieve were dried in an oven at 103 ± 2 °C until constant weight to determine the higher calorific value. The lower calorific value (LCV) was estimated using Equation 2.

$$HCV = \frac{(LCV - 600) \times 9.H}{100} \quad (2)$$

In which: HCV = higher calorific value (kcal kg^{-1}); LCV = lower calorific value (kcal kg^{-1}); %H = Hydrogen content in the material (%).

Apparent and energetic density of wood

The apparent density of wood - AD (g cm^{-3}) was determined using the hydrostatic balance method, obtaining the volume by the displacement of the liquid and the mass with a precision scale of 0.01g, reaching a 12% moisture content. The energy density of wood - EDW was calculated using the Equation 3.

$$EDW = AD \times HCV \quad (3)$$

In which: EDW = energy density of wood (kcal m^{-3}); HCV = higher calorific value (kcal kg^{-1}); AD: apparent density of wood (kg m^{-3}).

Potential and energetic estimate of the species

The biomass and percentages of the species were considered according to the circumference class (Table 1) obtained in the area of the present study by Dalla Lana et al. (2018) in order to estimate the energy potential of the species.

Thus, the energy supply per hectare (kcal ha^{-1}) was estimated with the higher calorific value (kcal kg^{-1}) of the woods, the biomass (kg ha^{-1}) for each species and circumference class, which divided by 860 provides an estimate of energy production in kW h ha^{-1}.

Statistical analyses

A completely randomized design in a factorial arrangement (species x circumference classes), with three replications (individuals) at a 5% probability level was considered for the analysis of variance (ANOVA). The Tukey's test was used ($p < 0.05$) to compare the means in case of significant ANOVA. The Shapiro-Wilk and Levene tests were applied to verify the assumptions of normality and homogeneity of the residuals, respectively ($p < 0.05$).

The average patterns for the studied characteristics of the species and diameter classes were obtained using the generalized Mahalanobis distance and Unweighted Pair Group Method using Arithmetic Averages (UPGMA) (Cruz & Carneiro, 2003). The consistency of the clustering pattern was evaluated using the cophenetic correlation coefficient (Rao, 1952).

Standardized mean values of the studied variables were calculated ranging from -1 to 1, aiming at the decision regarding the energetic potential based on its set. Standardization was performed by species, species group, circumference class and circumference class group (Equation 4). The analyzes were performed using the R 4.01 program (R Core Team, 2022).

$$M_i = \left(\frac{\bar{X}_i - \bar{X}}{S_{\bar{X}}} \right) \quad (4)$$

In which: M_i = standardized mean value of the i-th species or species group or circumference class or circumference class group; X_i = mean of the i^{th} species or group of species or class of circumference or group of class of circumference; X = overall mean of the i-th species or species group or circumference class or circumference class group; S_x = standard deviation of the i-th species or species group or circumference class or circumference class group.

Results

Elemental chemical analysis

The Shapiro-Wilk test for the C, H, N, O, CO, Lig, HHV and LHV variables showed that the normality assumption was only not met for CN, CH and Ash ($p < 0.05$). On the other hand, all variables showed homogeneity of residual variances by the Levene test ($p \geq 0.05$).

No significant effects ($p \geq 0.05$) of species, circumference, and interaction for carbon content (C) were observed in ANOVA. On the other hand, effects ($p < 0.01$) of the interaction were observed for the hydrogen (H), oxygen (O) and insoluble lignin (Lig) contents, indicating a need to jointly study the species and circumference class for these variables. On the other hand, N, CN, CH, and Ash were only influenced by the species factor ($p < 0.05$).

Table 1. Estimated dry biomass (Mg ha^{-1}) and proportion of total dry biomass (%) above ground by circumference class of woody species in Caatinga area, Floresta, Pernambuco state, Brazil.

Species	Dry biomass (Mg ha^{-1})	Circumference class (cm)				
		I 6.0 ├ 12	II 12.0 ├ 18	III 18.0 ├ 24	IV 24.0 ├ 30	V ≥ 30
*C. bracteosum**	18.3811	67.2	65.6	57.1	49.9	57.2
A. pyrifolium	1.4744	66.1	47.2	60.0	50.3	37.1
M. ophthalmocentra	1.2746	64.8	43.1	43.8	70.3	52.4
A. colubrina	0.9403	44.5	57.1	60.9	57.5	47.8
C. quercifolius	0.8374	39.6	35.4	44.7	37.2	37.6
M. tenuiflora	0.8186	43.4	47.4	59.3	49.9	57.2

* For this species, Dalla Lana et al. (2018) observed higher density, frequency, and dominance in the forest community. Which explains higher dry biomass among studied species.

Next, C levels of 45.0% for *C. bracteosum*, 46.8 for *C. quercifolius*, 47.1 for *M. ophthalmocentra*, 47.2 for *A. colubrina* var. *cebil*, 47.2 for *M. tenuiflora* and 47.8 for *Aspidosperma pyrifolium* were observed. Moroever, 45.9% were observed for class I, 46.1 for class II, 46.3 for class III, 47.5 for class V, and 48.1 for class IV regarding the classes.

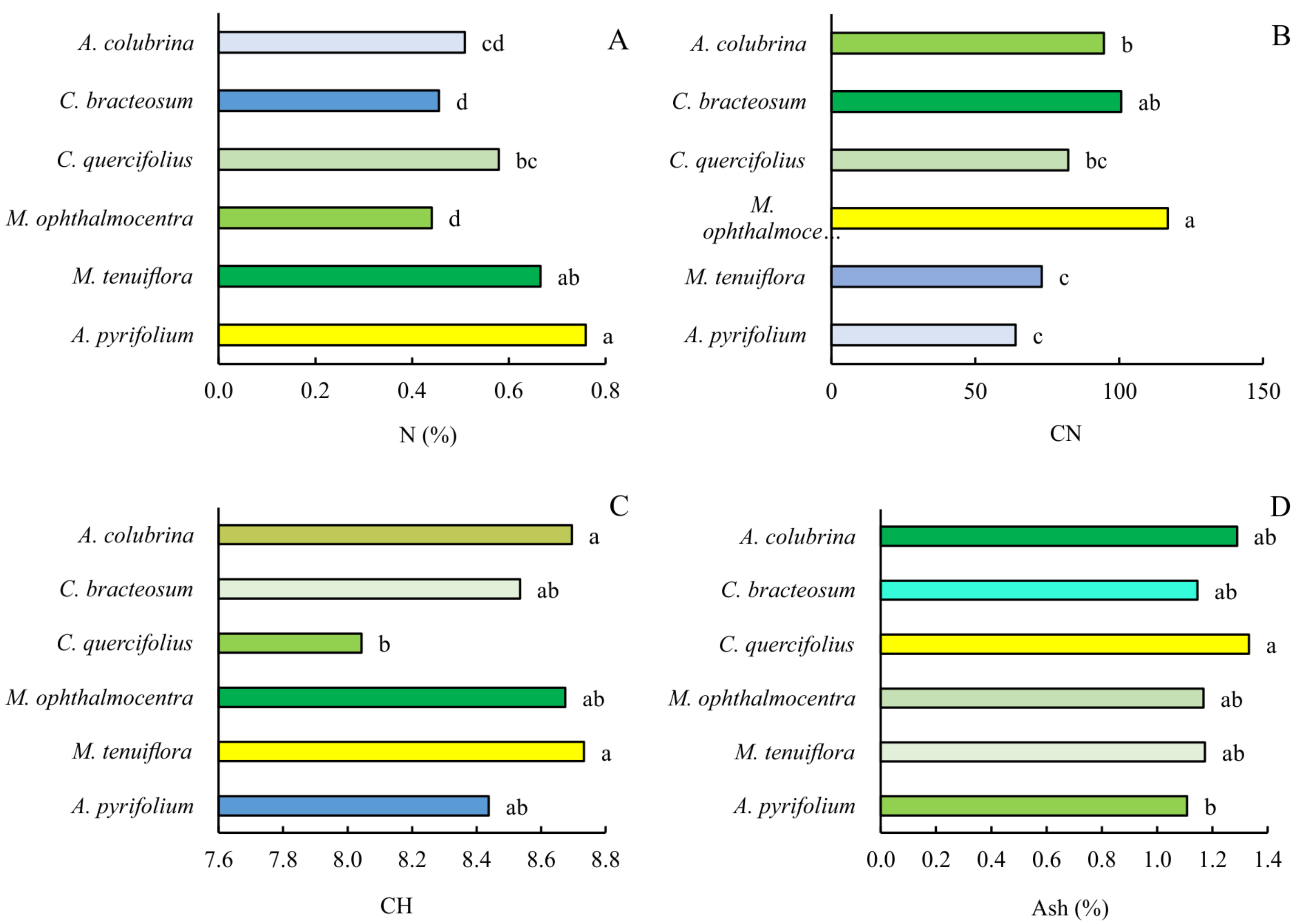
A. pyrifolium presented the highest value for the N content with 0.77%, showing no significant difference when compared to *M. tenuiflora* (0.68), but differing from the other species (Figure 2A). Differences from *A. pyrifolium* and *M. tenuiflora* to *M. ophthalmocentra*, *A. colubrina* and *C. bracteosum* were observed for the CN relationship (Figure 2B). *C. quercifolius* differed from *M. tenuiflora* and *A. colubrina* for CH (Figure 2C). It is observed that *C. quercifolius* (Figure 2D) had the highest ash content (1.18%), showing a significant difference from *M. ophthalmocentra* (1.04), but with no other differences.

It is observed that *C. quercifolius* differs ($p < 0.05$) from *C. bracteosum*, *M. ophthalmocentra* and *M. tenuiflora* in class III for the H content (Table 2). *C. bracteosum* differs from *M. tenuiflora* and in class IV, while *C. quercifolius* differs from *C. bracteosum* in class V. Only *M. tenuiflora* presents differences from class IV in relation to classes II and III in the analysis of species within the classes.

M. tenuiflora was similar ($p \geq 0.05$) to *A. colubrina* and *A. pyrifolium* for O only in class IV, but different from the other species (Table 2). Only *M. tenuiflora* presents class IV differences in relation to II and III for the circumference classes.

M. tenuiflora presents differences for CO in class IV in relation to II and III. *M. tenuiflora* differs from *C. bracteosum*, *C. quercifolius* and *M. ophthalmocentra* in class IV. *M. tenuiflora* presents differences between II and III for Lig, while V is similar to I for *A. pyrifolium*. *C. quercifolius*, *A. colubrina* and *M. tenuiflora* are similar in class I ($p \geq 0.05$); *C. quercifolius* is similar to *C. bracteosum* and *M. tenuiflora* differs ($p < 0.05$) from *C. bracteosum*, *C. quercifolius* and *A. pyrifolium* in class II; there is a difference between *M. tenuiflora* and *C. quercifolius* and *M. ophthalmocentra* in III; *C. quercifolius* was different from the other species in IV; and finally, *A. colubrina* differed from *A. pyrifolium* and *C. quercifolius* in V.

M. tenuiflora and *A. pyrifolium* show differences between circumference classes for Lig. Class II differs from V for *M. tenuiflora*, and there are differences among II, II and IV for *A. pyrifolium*. Among the species, differences from *C. quercifolius* to *A. colubrina* and *M. tenuiflora* are observed



Means followed by the same letter do not differ (Tukey's test, $p \geq 0.05$).

Figure 2. Mean values of woody species in Caatinga area, Floresta, Pernambuco state, Brazil. (A) Nitrogen (N) content; (B) Carbon/nitrogen ratio (CN); (C) Carbon/hydrogen ratio (CH); (D) Ash content (Ash).

Table 2. Means of hydrogen content (H), oxygen content (O), CO ratio and lignin content (Lig), considering the interaction between species and circumference class of woody species in a Caatinga area, Floresta, Pernambuco state, Brazil.

Species	I	II	III	IV	V
			Circumference class/Hydrogen content - H (%)		
A. colubrina	5.35 aA	5.36 aA	5.48 abA	5.36 abA	5.63 abA
C. bracteosum	5.43 aA	5.69 aA	5.17 bA	4.98 bA	5.15 bA
C. quercifolius	5.84 aA	5.74 aA	6.01 aA	5.56 abA	5.94 aA
M. ophthalmocentra	5.61 aA	5.35 aA	5.22 bA	5.49 abA	5.50 abA
M. tenuiflora	5.73 aAB	5.03 aB	5.13 bB	5.87 aA	5.26 abAB
A. pyrifolium	5.52 aA	5.45 aA	5.58 abA	5.85 aA	5.77 abA
			Circumference class/Oxygen content - O (%)		
A. colubrina	49.46 aA	47.70 aA	46.23 aA	44.56 abA	45.57 aA
C. bracteosum	49.00 aA	46.55 aA	50.48 aA	48.82 aA	50.39 aA
C. quercifolius	47.12 aA	47.16 aA	44.84 aA	48.77 aA	45.70 aA
M. ophthalmocentra	45.73 aA	47.92 aA	48.17 aA	48.32 aA	44.17 aA
M. tenuiflora	44.05 aAB	51.53 aA	50.60 aA	39.61 bB	46.79 aAB
A. pyrifolium	49.98 aA	47.07 aA	45.20 aA	43.81 abA	44.48 aA
			Circumference class/CO ratio		
A. colubrina	0.90 aA	0.98 aA	1.03 aA	1.13 abA	1.06 aA
C. bracteosum	0.92 aA	1.02 aA	0.87 aA	0.93 bA	0.87 aA
C. quercifolius	0.99 aA	0.99 aA	1.08 aA	0.92 bA	1.07 aA
M. ophthalmocentra	1.06 aA	0.97 aA	0.95 aA	0.95 bA	1.15 aA
M. tenuiflora	1.14 aAB	0.83 aB	0.89 aB	1.36 aA	1.02 aB
A. pyrifolium	0.87 aA	0.99 aA	1.07 aA	1.15 abA	1.10 aA
			Circumference class/Lignin content – Lig (%)		
A. colubrina	19.06 bA	17.73 bcA	19.14 abA	18.29 bA	16.37 cA
C. bracteosum	24.21 abA	21.47 abA	21.77 abA	19.09 bA	20.18 bcA
C. quercifolius	25.53 aA	26.62 aA	24.11 aA	26.94 aA	24.35 abA
M. ophthalmocentra	21.76 abA	19.85 bcA	23.85 aA	20.57 bA	20.54 bcA
M. tenuiflora	19.99 bAB	15.37 cB	17.87 bAB	19.91 bAB	20.37 bcA
A. pyrifolium	22.47 abAB	20.83 bB	21.64 abB	20.42 bB	26.66 aA

Means followed by the same lowercase letter in column and uppercase in row do not differ (Tukey's test, $p > 0.05$). I - 6.0 ├ 12 cm; II - 12.0 ├ 18 cm; III - 18.0 ├ 24 cm; IV - 24.0 ├ 30 cm and V - ≥ 30 cm.

in I. *C. quercifolius* and *C. bracteosum* are similar in II, and *M. tenuiflora* does not differ only from *M. ophthalmocentra*. Furthermore, *C. quercifolius* only differs from *M. tenuiflora* in III, while *C. quercifolius* was superior to the other species in class IV. Finally, *A. pyrifolium* and *C. quercifolius* were similar and differed from *A. colubrina* in class V.

Higher and lower calorific value, apparent density and energy density

Significant effects of species ($p < 0.01$) and circumference class ($p < 0.05$) were observed for HCV in the ANOVA; an interaction effect ($p < 0.05$) for LCV, indicating the need to study the influence of species and circumference class together; and finally, only a species effect ($p < 0.01$) for AD and EDW.

The highest average value for HCV was presented by the *M. tenuiflora* species (Figure 3A), which presented significant differences for the other species evaluated. It is observed in Figure 3B that class V (4653.56) differs from I (4587.11) regarding the circumference classes.

It can be seen in Table 3 that the best values for the LCV for all species were in circumference class IV, and it can also be observed that the best values were for the *M. tenuiflora* species, confirming the potential of this species for energy production.

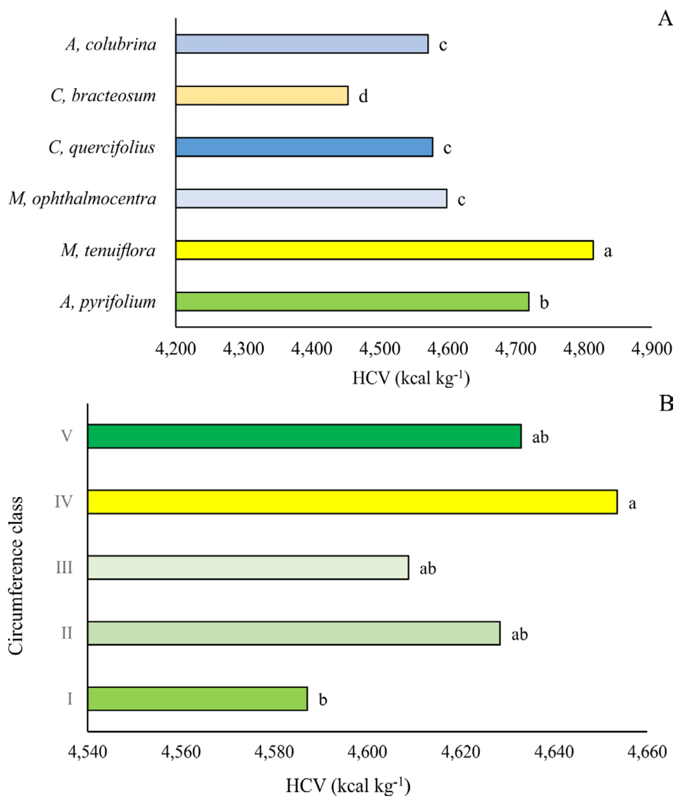
In general terms, AD showed more marked differences between the *C. quercifolius* (0.56 g cm^{-3}) and *A. pyrifolium* (0.76) species in relation to the other species (Figure 4A). *M. ophthalmocentra* (1.02) and *M. tenuiflora* (0.97) are similar, but there are no differences from *M. tenuiflora* to *A. colubrina* (0.91) and *C. bracteosum* (0.91).

Potential and estimation of energy production

C. quercifolius (2,430 KWh ha^{-1}) and *M. tenuiflora* (1,797) presented the lowest amount of energy per hectare (Table 4), considering that the results are directly related to biomass productivity, basic density and calorific value; these factors provide a good tool for making forest management decisions for energy purposes from the biomass produced.

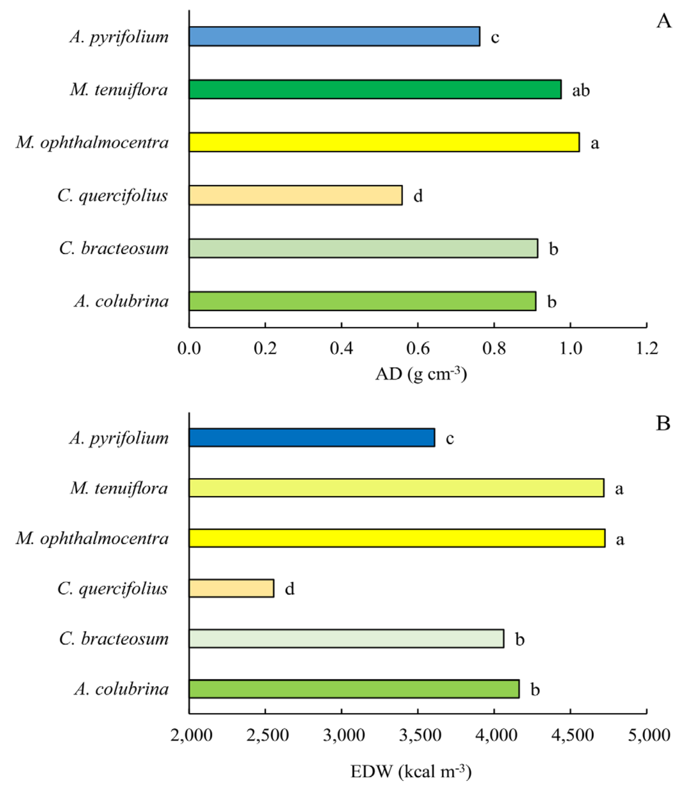
Joint analysis of variables

In Figure 5A, it is observed that *A. pyrifolium* stands out with potential characteristics for energy with high C, H, N, CO, HCV, LCV and low Ash, but with other undesirable characteristics such as high O and low AD and EDW. *A. colubrina* has high C, CN, CH, average AD and EDW, but low Lig and high Ash. *C. quercifolius* presented high H, Lig, medium C, HCV and LCV, low CH, high Ash, low AD and EDW. *M. ophthalmocentra* had medium C, CH, AD and EDW and low Ash, low H, O, CN, and medium Lig. *M. tenuiflora*



Means followed by the same letter do not differ (Tukey's test, $p \geq 0.05$). I – 6.0 ├ 12 cm; II – 12.0 ├ 18 cm; III – 18.0 ├ 24 cm; IV – 24.0 ├ 30 cm and V - ≥ 30 cm.

Figure 3. Mean values of higher calorific value (HCV) according to species (A) and circumference class (B) in an area of Caatinga, Floresta, Pernambuco state, Brazil.



Means followed by the same letter do not differ (Tukey's test, $p \geq 0.05$).

Figure 4. Mean values according to the species in the Caatinga area, Floresta, Pernambuco state, Brazil. (A) Apparent density of wood (AD). (B) Energy density of wood (EDW).

Table 3. Comparisons between means considering the interaction between species and circumference for lower calorific value (LCV) in wood in a Caatinga area, Floresta, Pernambuco state, Brazil.

Species	Circumference class/ Lower calorific value (kcal kg^{-1})				
	I	II	III	IV	V
A. colubrina	4252.1 bcA	4275.05 cA	4307.9 bA	4313.56 bA	4238.31 cA
C. bracteosum	4192.27 cA	4200.07 cA	4131.97 cA	4140.26 cA	4175.23 cA
C. quercifolius	4265.13 bcA	4241.86 cA	4213.64 bcA	4338.58 bA	4257.24 cA
M. ophthalmocentra	4216.88 cA	4326.43 bcA	4341.97 bA	4324.54 bA	4314.33 bcA
M. tenuiflora	4409.07 aB	4546.56 aA	4566.98 aA	4523.69 aAB	4563.63 aA
A. pyrifolium	4378.59 abAB	4418.85 abAB	4330.86 bB	4492.77 aA	4453.42 abAB

Means followed by the same lowercase letter in column and uppercase in row do not differ (Tukey's test, $p \geq 0.05$). I - 6.0 ├ 12 cm; II - 12.0 ├ 18 cm; III - 18.0 ├ 24 cm; IV - 24.0 ├ 30 cm and V - ≥ 30 cm.

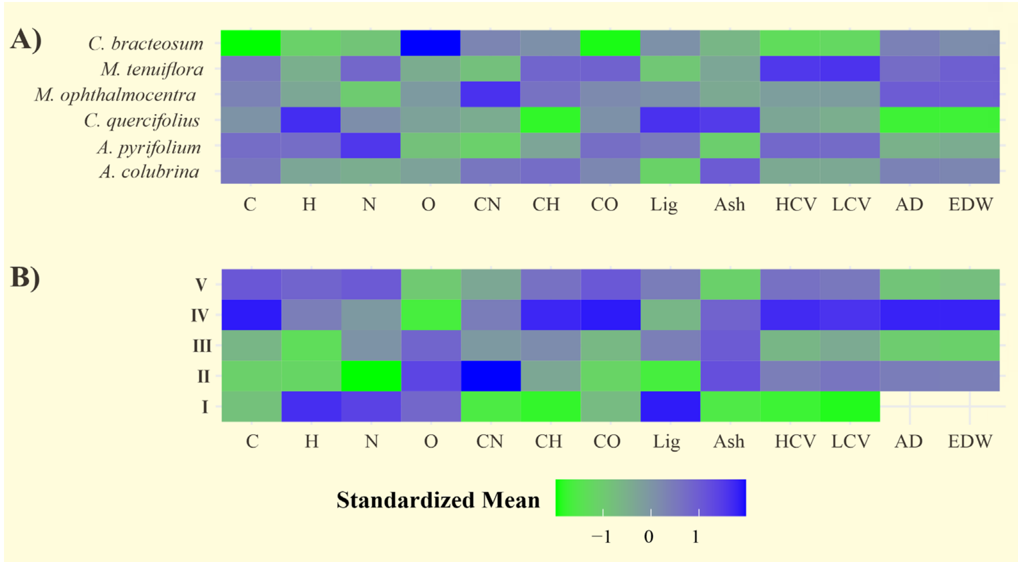
Table 4. Wood energy production by species and circumference classes in Caatinga area, Floresta, Permanbuco, Brazil.

Species	Circumference class/Wood energy production (KW h ha^{-1})				
	I	II	III	IV	V
	6.0 ├ 12 cm	12.0 ├ 18 cm	18.0 ├ 24 cm	24.0 ├ 30	≥ 30 cm
A. colubrina	1156	722	588	277	336
*C. bracteosum**	36534	12571	5047	1742	743
C. quercifolius	997	435	280	219	499
M. ophthalmocentra	2252	795	144	13	11
M. tenuiflora	465	410	520	278	125
A. pyrifolium	1852	1277	419	134	29

* For this species, Dalla Lana et al. (2018) observed higher density, frequency, and dominance in the forest community. Which explains higher dry biomass among studied species.

showed high CO, HCV, LCV, medium C, N, CH, low O, CN, Lig, and medium Ash. *C. bracteosum* had low C, H, N, CO, high O, medium CN, CH, low HCV, LCV, medium Lig, low Ash, and medium AD and EDW.

For circumference classes (Figure 5B), I showed low C, CO, CN, CH, HCV, LCV and Ash, high H, N and medium O. Class II had low C, H, N, CO CH, and Lig, high O, CN and Ash, and medium HCV, LCV, AD and EDW. Class III presented low



Note: Standardized averages (close to 1) with stronger shades of blue represent the highest values, standardized averages (close to 0) with shades between blue/green have average values, and standardized averages (close to -1) with shades of green stronger correspond to the smallest values. I - 6.0 ├ 12 cm; II - 12.0 ├ 18 cm; III - 18.0 ├ 24 cm; IV - 24.0 ├ 30 cm and V - ≥ 30 cm.

Figure 5. Standardized mean values of the characteristics Carbon (C - %), Hydrogen (H - %), Nitrogen (N - %), Oxygen (O - %), Carbon/Nitrogen Ratio (CN), Carbon/Hydrogen Ratio (CH), Carbon/Oxygen Ratio (CO), Insoluble Lignin (Lig - %), Ash (Ash - %), Higher and Lower Calorific Value (HCV and LCV - kcal kg^{-1}), Apparent Density (AD - g cm^{-3}) and Energy Density of Wood (EDW - kcal m^{-3}) as a function of species (A) and circumference class (B) in an area of Caatinga, Floresta, Pernambuco state, Brazil.

C, H, CO, HCV, LCV, AD and EDW, medium N, CH, CN and Lig, high O and Ash. Class IV had high C, CH, CO, HCV, LCV, AD and EDW, medium H, N, CN and Ash, and low O and Lig. Finally, V showed medium C, H, N, CO, CH, HCV, LCV, Lig, low O, CN, Ash, AD and EDW.

In the cluster analysis, it was possible to reveal the formation of two groups of species (Figure 6A), with Group 1 being formed by *C. quercifolius*, *A. pyrifolium* and *A. colubrine*, and Group 2 by *M. ophthalmocentra*, *M. tenuiflora* and *C. bracteosum*. Groups are also observed in terms of

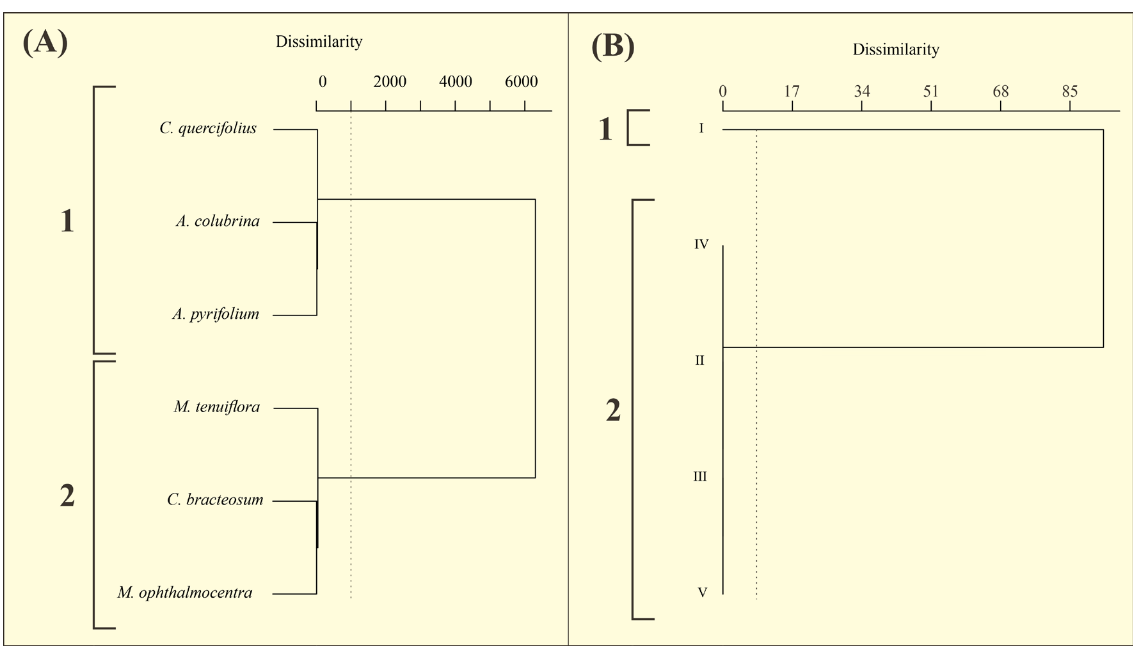
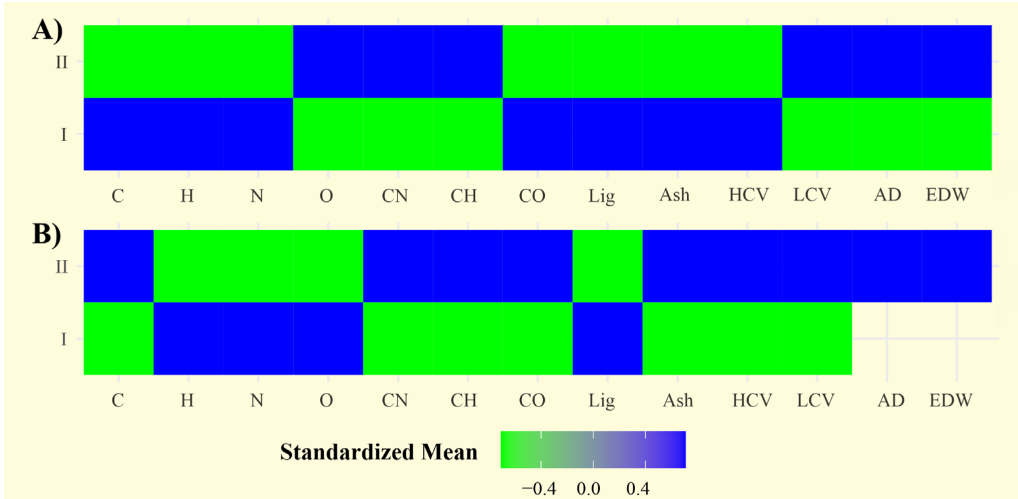


Figure 6. Cluster analysis of woody species (A) and circumference classes (B) in a Caatinga area, Floresta, Pernambuco state, Brazil, established by the Unweighted Pair Group Method using Arithmetic Averages (UPGMA) method based on the generalized Mahalanobis distances of the following characteristic: Carbon content (C - %), Hydrogen (H - %), Nitrogen (N - %), Oxygen (O - %), Carbon/Nitrogen Ratio (CN), Carbon/Hydrogen Ratio (CH), Carbon/Oxygen Ratio (CO), Insoluble Lignin (Lig - %), Ashes (Ash - %), Higher Calorific and Lower Calorific Values (HCV and LCV - kcal kg^{-1}), Apparent Density (AD - g cm^{-3}) and Energy Density of Wood (EDW - kcal m^{-3}). The dashed line represents the division of groups. Cophenetic correlation = 0.99 (A) and 0.99 (B). I - 6.0 ├ 12 cm; II - 12.0 ├ 18 cm; III - 18.0 ├ 24 cm; IV - 24.0 ├ 30 cm and V - ≥ 30 cm.



Note: Standardized averages (close to 0.5) with stronger blue tones represent the highest values, standardized averages (close to 0) with shades between blue/green have average values, and standardized averages (close to -0.5) with stronger shades of green correspond to the lowest values. Class I - 6.0 ├ 12 cm; Class II - 12.0 ├ 18 cm; Class III - 18.0 ├ 24 cm; Class IV - 24.0 ├ 30 cm and Class V - ≥ 30 cm.

Figure 7. Standardized mean values of woody species grouping (A) (Group 1: *C. quercifolius*, *A. colubrina* and *A. pyrifolium*; and Group 2: *C. bracteosum*, *M. ophthalmocentra* and *M. tenuiflora*); and (B) circumference classes (Group 1: Class I; Group 2: Class II, III, IV, and V) in Caatinga area, Floresta, Pernambugo state, Brazil, established by the UPGMA method based on the generalized Mahalanobis distances of the characteristics: Carbon content (C - %), Hydrogen (H - %), Nitrogen (N - %), Oxygen (O - %), Carbon/Nitrogen Ratio (CN), Carbon/Hydrogen Ratio (CH), Carbon/Oxygen Ratio (CO), Insoluble Lignin (Lig - %), Ash (Ash - %), Higher and Lower Calorific Value (HCV and LCV - kcal kg^{-1}), Apparent Density (AD - g cm^{-3}) and Energy Density of Wood (EDW - kcal m^{-3}).

circumference class (Figure 5B) as: 1 (circumference class I) and 2 (classes II, III, IV, and V).

In Figure 7A, it is observed that Group 2 formed by *M. ophthalmocentra*, *M. tenuiflora* and *C. bracteosum* stands out in terms of O, CN, CH, LCV, AD and EDW; while Group 1 stands out for C, H, N, CO, Lig, Ash and HCV. For the circumference class groups (Figure 7B), 2 (II, III, IV and V) stands out in terms of C, CN, CH, CO, Ash, HCV, LCV, AD and EDW, while 1 (I) stands out in terms of H, N, O and Lig.

Discussion

Elemental chemical analysis

Despite the non-normality for CN, CH and Ash, the indications by Blanca et al. (2017) were considered that classical ANOVA is robust to deviations from normality in balanced experiments, opting to present and interpret the results of analysis of variances of all variables studied and, when applicable, of mean comparisons.

The non-influence of species and circumference class on C content coincides with the information that there is low variability of this element within the elemental chemical composition of hardwoods (Woodenergy.ie, 2022). It is worth mentioning that the expected variation in carbon content is between 45-50% (Woodenergy.ie, 2022), similar to the results found in the present work. In the area of the present study, Dalla Lana et al. (2019) observed similar carbon contents for the studied species, ranging from 44.8% for *C. bracteosum* to 47.5% for *M. ophthalmocentra*.

It is important to emphasize that the low values of N content (Figure 2A) obtained by *M. ophthalmocentra* (0.40%) and *C. bracteosum* (0.45%) position them as species of high interest in energy production. The expected variation in N content is between 0.3-3.5% (Woodenergy.ie, 2022), with the results being found within that range. It is desirable that the biomass present lower nitrogen contents in its composition for energy use. The presence of nitrogen in the wood composition results in the formation of nitrogen oxides after combustion. Therefore, small amounts of this elemental component are desirable in the combustion and in the carbonization process of wood (Assis et al., 2018); with low emission levels of substances polluting the environment (Cantos-Macias et al., 2018).

The values found differ from those obtained by Santos et al. (2013), who reported higher values in nitrogen content for *M. tenuiflora* (1.2%), *A. pyrifolium* (1.32%) and *Cenostigma piramidale* (1%) for equivalent diameters of 28.4, 32.8 and 31.2 cm, respectively, constituting larger sizes than those studied in the present work. It is worth mentioning that such differences are due to several factors, especially for species in native forest; among them, the site, the plant growth stage and the sociological position of the sampled individual in the community.

The lowest nominal values in N content are generally attributed to leguminous species (*Mimosa ophthalmocentra*, *C. bracteosum*, *A. colubrina*), which may be associated with a lower need for stocking this element considering that species of this family benefit from association with nitrogen fixing bacteria.

High CN ratios, as observed for *M. tenuiflora* (Figure 2B), imply that there will be less nitrogen release in the combustion of its wood, in addition to interfering in the carbon dioxide release speed, together with the moisture of the wood, which is an advantage to reduce air pollution (Cantos-Macias et al., 2018). Moreover, a greater CH ratio (Figure 2C) in the biomass reduces the energy value of the wood of the species (Nordin, 1994), therefore this is a disadvantage for *M. tenuiflora*.

The quality of the fuel decreases with the amount of ash present in the biomass, therefore, less ash is desirable in a fuel. The variability in the wood ash content of the species (Figure 2D) between 1.11 and 1.33% indicates that this element may not be an appropriate criterion to disqualify them as potential for energy production. It is worth mentioning that the ash content observed is within the expected range, which is less than 2% (Woodenergy.ie, 2022). The Ash content was influenced by the species factor, so it was possible to select those with lower levels (Figure 2D). The ash content corresponds to substances that do not burn, remaining in solid form and are undesirable for energy purposes (Silva et al., 2018; Donato et al., 2020). It is also worth mentioning that the values reported in other studies were higher than those found in the present work. Silva et al. (2018) observed values lower than 1.50%, which means a possibility in the use of lignocellulosic materials researched in this work.

The average H content value ranged from 4.85 to 6.01%, within the range of 4.5 to 6% for wood reported by Woodenergy.ie (2022). The results of the present work were lower than those found by Reis et al. (2012) from 5.97 to 6.24% for *Eucalyptus urophylla* in different planting sites in Minas Gerais state, Brazil. The low H levels in the wood composition of the species studied (Table 2) results in a high CH ratio, which is undesirable for energy production, since according to Protásio et al. (2011), there is an increase of approximately 515 kcal kg^{-1} in the higher calorific value of the fuel for a 1% increase in the H content, while a 1% increase in C content only increases the caloric value of biomass by 64.14 kcal kg^{-1}. This reinforces the great importance of H in energy generation, as it releases more energy during burning than carbon (Carneiro et al., 2014). Thus, *C. bracteosum* generally has disadvantages regarding the H content in its caloric biomass when compared to other species.

Regarding O content (Table 2), this element negatively contributes to the calorific value, unlike carbon and hydrogen. Thus, species with higher O contents such as *M. tenuiflora* with some differences between circumference classes imply in lower stored energy (Carneiro et al., 2014) and similar behavior in the CO ratio.

A higher CO ratio, as observed for *M. tenuiflora* between classes, indicates that the surfaces of this material have a low affinity for water, because oxygen binds to hydrogen through H bonds; therefore, a lower O content prevents the occurrence of this link (Chun et al., 2014). In turn, one should look for a fuel with higher CO, as moisture affects its energy potential, since 600 kcal are needed to evaporate 1 kg of water at atmospheric pressure (Brand, 2010).

Table 2 shows that the insoluble lignin (Lig) content for all species, with the exception of *C. quercifolius*, has a tendency of better behavior for smaller circumference classes, which may be related to their potential for energy production (Araujo et al., 2018).

C. quercifolius showed significant insoluble lignin content (26.44%) when compared to *M. tenuiflora* (19.69%). On the other hand, Paes et al. (2013) found a significant difference for total lignin content for *A. colubrina* and *M. tenuiflora*, which did not happen in the present work. The fact that *C. quercifolius* and *A. pyrifolium* present the best insoluble lignin levels can position them as energy suppliers or as interesting species for transforming their products into charcoal due to the slow process of thermal degradation that this molecule undergoes and high yields during carbonization processes (Klock et al., 2005); however, the high ash content of these species can make it difficult to burn their wood and increases equipment maintenance costs. On the other hand, *M. ophthalmocentra* presents average values for the variable insoluble lignin content and the lowest ash content values, presenting good characteristics for obtaining energy.

Calorific power and density of wood

Despite some differences between species ($p < 0.05$) for HCV (Figure 3A), it is important to note that only differences greater than 300 kcal kg^{-1} are considered significant in terms of biomass performance for energy production (Brand, 2010); thus, the differences between *M. tenuiflora*, with an average of 4883.80 kcal kg^{-1}, and *A. pyrifolium* (4719.12 kcal kg^{-1}) and *M. ophthalmocentra* (4598.27 kcal kg^{-1}), are not energetically significant.

However, the differences between M. tenuiflora and the other species considered in the present study are greater than 300 kcal kg^{-1}, which categorizes it as the best among these species for energy production in terms of HCV. The differences between the other species are considered statistically significant, but not in terms of energy. *M. tenuiflora*, *M. ophthalmocentra* and *A. pyrifolium* generally present outstanding values for HCV. The values recorded in the present study are close to those reported in other studies; for example, for a group of species in the Caatinga under a management plan in Piauí state, Brazil, Brand (2017) estimated an average higher calorific value ranging from 4583 to 4701 kcal kg^{-1}; moreover, Carvalho et al. (2020) recorded 4987 kcal kg^{-1} for *M. tenuiflora*.

Regarding the circumference classes (Figure 3B), the difference between classes V and I was only 66.45; therefore, less than the 300 kcal kg^{-1} reported by Brand (2010), which indicates the use of any class for energy production in terms of HCV. However, HCV is influenced by the chemical composition of the biomass (Araujo et al., 2018), and therefore the definition for using biomass of a species as fuel must be linked to joint considerations, also taking into account the elemental chemical analysis.

The importance of LCV during the analysis process is to provide more real values with the combustion processes in the field (Shmulsky & Jones, 2019). It is possible to observe in Table 3, as in the first circumference categories, the LCV disparities between the species are indifferent in terms of energy, since the greatest difference between *M. tenuiflora* (4409.07) and *C. bracteosum* (4192.27) is 217 kcal kg^{-1}, which is not considered different in terms of energy.

It is also worth mentioning that the reduction of lignin and nitrogen, in addition to other elements not studied, such as an accumulation of extractives which play a prominent role in energy production in forest biomass (Araujo et al., 2018), there may be an increase in these differences during the diameter growth process of individuals, and due to changes in variables studied in the present work, such as the increase in hydrogen contents, especially in *M. tenuiflora*, which reaches 4563.62 kcal kg^{-1} in the circumference class V, and presents differences greater than 300 kcal kg^{-1} for *A. colubrina* (325 kcal kg^{-1}), *C. bracteosum* (388) and *C. quercifolius* (306). It is important to observe the tendency of species, with the exception of *C. bracteosum*, to present higher LCV in the largest circumference classes, which is supposed to have better characteristics regarding the quality of lignocellulosic materials classified in these classes.

The species present good conditions for use as fuel material considering the apparent density (Figure 4A), as they presented higher values when compared to lignocellulosic materials used in Brazilian industry as energy sources from plantations, such as the *Eucalyptus* spp. genus which have basic density between 0.37 and 0.54g cm^{-3} (Soares et al., 2015).

Considering that sustainable management plans in the study region have the main objective of producing firewood and/or charcoal, *M. ophthalmocentra*, *M. tenuiflora*, *A. colubrina* and *C. bracteosum* species should be prioritized in energy production due to their higher calorific capacities per mass, which may reduce the amount of biomass required, ensure greater combustion time inside furnaces and provide greater economic viability in the exploitation of these species due to the reduction in material transport costs. In addition, species which have minor potential for energy which should therefore not be managed, could have other purposes, such as identification of non-timber products, soil protection, refuge for fauna, and other environmental services. Therefore, harvests for forest bioenergy, combined with other silvicultural actions, can be used to also favor conservation values, as stated by De Jong & Dahlberg (2017).

The values found in the present study are similar to those reported by Carvalho et al. (2020) for *M. tenuiflora* (0.76 g cm^{-3}) and *C. pyramidale* (0.74). However, it is worth mentioning that the interactions of the anatomical and chemical properties of wood reflect in the density of the material, and many of these variations are caused by variation of the site quality, which leads to a parsimonious look in the comparison of the results between the works.

The energy density of wood (EDW) aims to establish the energy storage capacity per unit of mass in a material; different authors emphasize that wood with higher density provides greater energy per unit of volume (Lima et al., 2011); the relationship between the higher calorific value and the apparent density would enable developing a classification of species which provide more energy per unit of volume.

The highest significant mean EDW value for *M. tenuiflora* and *M. ophthalmocentra* (Figure 4B) were statistically different from the other species, thereby positioning them as the best energy suppliers due to the high values presented by both species for AD and HCV. In addition, they differed energetically when presenting values higher than 4,700 kcal m^{-3}, showing differences greater than 500 kcal m^{-3} in relation to *A. colubrina* and *C. bracteosum*, which presented values close to 4,100 kcal m^{-3}. *C. quercifolius* (2,555 kcal m^{-3}) and *A. pyrifolium* (3,608 kcal m^{-3}) presented the lowest values, showing statistical differences between them.

It is worth mentioning that density should not be used in isolation for quality selection and that it is necessary to study other factors that influence the wood energy quality. It is also important to add that no studies were found in the literature considering circumference or diameter classes in evaluating density for Caatinga species which could be compared with those found herein. However, as in the present work, Lima et al. (2011) found no influence of the diameter on the apparent density, but it was found by Trevisan et al. (2007), which leaves the discussion open.

Potential and estimation of energy production

C. quercifolius (2.430 KWh ha^{-1}) and *M. tenuiflora* (1.797) have the lowest amount of energy per hectare (Table 4), considering that the results are directly related to biomass productivity, basic density and calorific value; these factors provide a good tool for making forest management decisions for energy purposes from the biomass produced.

An analysis of Table 4 allows us to discern that it is not possible to make decisions based on the energy quality of a material without analyzing the biomass productivity considering the management of natural forests as an objective. For example, *M. tenuiflora* showed good results regarding wood quality, but lower amount of biomass (1,797 KWh ha^{-1}). On the other hand, *A. pyrifolium* (3710) presented poor energetic characteristics of the biomass, but it has a high proportion in the biomass available in the study area due to its arboreal size, placing it as the second species with the highest energy per hectare. It is important to emphasize the prominent role of *C. bracteosum* (56,638) which has good wood qualities and the highest amount of biomass in the area.

It is possible to observe an accumulation of 84% of the available energy in the two circumference classes I and II (Table 4) due to the greater accumulation of biomass, which can be explained by the size of the species, meaning by the fact that they do not reach greater circumferences since some are arboreal-shrubs, such as *M. ophthalmocentra*, which presented less than 1% of the energy in circumference classes IV and V. Therefore, as a management action, the possibility of carrying out silvicultural assistance which improves the distribution of individuals in the different circumference classes aiming to reduce the biomass loss, but according to the size of the species.

It is also possible to suggest that *M. tenuiflora*, *M. ophthalmocentra* and *C. bracteosum*, responsible for about 87% of energy production, should be prioritized for energy, since they present better quality for this purpose. On the other hand, the regulations that govern the execution of a forest management plan in the Caatinga, such as that of Pernambuco (CPRH, 2006), are based on regulation by control by area, where clear-cutting is practically allowed, mainly seeking dendroenergetic products (firewood and/or coal). Thus, almost all the woody species in an area are used without concern about the wood quality for energy. However, it was observed that there are differences in energy quality between species and variation according to the circumference class. Therefore, in thinking about the efficiency of the process, forest management should move towards actions via selective cutting, with priority on producing biomass from the species with the best energy quality, so the other species could be left in the area for other purposes, for example, soil protection and/or carbon accumulation, among others.

Joint analysis of variables

The quality of wood of a species, high density, high calorific value, carbon and lignin content, as well as low moisture, volatile materials and ash content are expected for energy production. Therefore, high quality and yield can be expected in the transformation of wood with these characteristics, aiming at better energy efficiency. Therefore, it is possible to observe the species, circumference classes, groups of species and circumference classes which present advantages and disadvantages in terms of desirable and undesirable characteristics for use in energy production together in Figures 5, 6 and 7. Considering the joint analysis of all variables, it is evident that preference should be given to species in group 1 (*M. ophthalmocentra*, *M. tenuiflora* and *C. bracteosum*) and not to use circumference class I.

The information in the present work allowed us to observe the influence of the circumference class according to the species on properties of vital importance in energy generation, such as apparent density, nitrogen content, hydrogen content and higher and lower calorific value, with better behaviors for circumference class IV (24 ├ 30 cm) and V (≥ 30 cm), through which management activities could be defined based on the energy potential of the species in these categories; however, the availability of biomass is more concentrated in the smaller classes, since most are shrubby-tree species and do not reach larger circumferences. In addition, it is not possible to only consider the physical-chemical characteristics of its woods, since studies are needed regarding the growth of the forest and its species-objective of sustainable forest management.

Class I individuals (6.0 – 11.99 cm) showed higher nitrogen content values and lower HCV and LCV, demonstrating a lower amount of energy per unit of mass, which may enhance the production of undesirable gases during the combustion process. On the other hand, most species are shrubby trees, meaning that they do not reach greater circumferences, but are responsible for much of the biomass available for transformation into energy. Thus, there is a need to develop studies which enable optimizing forest management activities through selective cutting techniques or alternatives that present options for maintaining forest cover with individuals from smaller circumference classes and prioritizing the harvest of individuals in the upper classes of species with real energy potential. In addition, it is also necessary to develop technologies to seek efficiency in the processes of transforming forest biomass into energy.

The present study confirms the potential of Caatinga biomass for energy purposes, whose species have the advantage of adapting to the edaphic and climatic conditions of the region, which should enable the sustainable management and use of the species, and consequently income for Brazilian semi-arid communities through forest management activities.

Conclusions

Mimosa ophthalmocentra, *Mimosa tenuiflora*, *Anadenanthera colubrina* and *Cenostigma bracteosum* can be highlighted for their energy production. *Mimosa ophthalmocentra* and *Mimosa tenuiflora* have higher energy density than wood and energy per unit of mass. The performance of *Cnidoscolus quercifolius* and *Aspidosperma pyrifolium* were inferior when compared to other species studied.

Biomass of circumference classes IV and V are the most suitable for energy production. Circumference class I biomass has a disadvantage due to higher nitrogen contents and lower upper and lower calorific values.

Compliance with Ethical Standards

Author contributions: Conceptualization: JAAS, RLB, RLCF; Data curation: JDMM; Formal analysis: JDMM, RG; Funding acquisition: RLCF; Methodology: JDMM, RLB, RLCF; Investigation: JDMM, JAAS, RLB, MDL, GHGC, DAAL, RLCF; Project administration: JDMM, RLCF; Resources: JDMM, RLCF; Supervision: JAAS, RLB, RLCF; Validation: JDMM, RLCF; Visualization: JDMM, RG, RLCF; Writing – original draft: JDMM, RLB, MDL, RG, GHGC, RLCF; Writing – review & editing: JDMM, JAAS, RLB, DAAL, RG, RLCF.

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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