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Original Research Article

Bioenergy potential of shrub from native species of northeastern Mexico

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The potential contribution of bioenergy in the global energy system is 17% - 36% of primary energy consumption. To avoid a warming higher than 2 Â °C by 2050, it is estimated that biomass should provide 60% of total renewable energy consumption. This requires amplification in efficient alternatives of energy production from renewable sources. In Mexico there is a great potential of biomass resources to produce biofuels, in which the wood is 54% with low contribution of forest plantations. The need to give greater value to forest plantations with native species is urgent in elaborating prospects for bioenergy development. In this sense, was determined the production and quality of charcoal of five native species of Tamaulipan thorn scrub, *Acacia berlandieri*, *Havardia pallens*, *Helietta parvifolia*, *Ebenopsis ebano* and *Acacia wrightii*. Analyzes conducted to define the quality of charcoal sampled referred to their yield, percentages of moisture content, ash, volatile material and fixed carbon of each species, based on international standards. It was found that the yield of charcoal was from 20 to 30%, corresponding to branches of *A. berlandieri* and trunk of *A. wrightii,* respectively. The percentages of moisture content, volatile material, ash and fixed carbon presented ranges of 4.25 to 4.9%, 12.29 to 22.28%, 1.68 to 6.49% and 68.26 to 81.34%. The average calorific value was 30 000 kJ kg^{-1}, consistent with the requirement for use for energy purposes.

Key words. Bioenergetics, charcoal, timber species, thorn scrub

INTRODUCTION

From biomass, it is obtained bioenergy derived from solid biofuels such as wood, charcoal, agricultural residues, forest residues, pellets and briquettes; liquid biofuels such as bioethanol and biodiesel; and gaseous biofuels such as biogas (González, 2009). These biofuels replace part of the consumption of traditional fossil fuels and also have the advantage of being renewable and having a low impact on environmental degradation (Inter-American Development Bank, 2008).

Firewood and other wood products are widely used worldwide, as they are considered a modern and clean way to generate energy (Patiño and Smith, 2008). 50% of the planet's population uses biofuel for heat (Wu et al., 2011).

The forest harvesting in Mexico produces about eight million cubic meters of wood (Carrillo, 2013), from which various products are obtained, including: the sawn wood with 71.75% pulp, veneer and plywood, poles, sleepers, firewood and charcoal provide the remaining 28.25% (INEGI, 2013). These last two represent the third place in volume of extraction, with 9.9% (SEMARNAT, 2007). During forest production and mechanical wood processing as the exploitation in plantations, large volumes of waste are generated, that are not used often. These residues can be generated in the short end or during silvicultural practices and are an important part of the structure of production costs, which absorbs high extraction costs and transportation.

The charcoal production is an opportunity for the recovery of waste, not only of the processing industry of wood but also for the waste generated by silvicultural

Figure 1: Carbonization a) in furnace, b) final product

practices. Charcoal is traditionally done with species that lead to a dense product and of slow-combustion. These species are of slow growing and are therefore highly vulnerable to intensive exploitation. The integral processing of timberland to feed biorefineries, produces electricity and biodiesel in the case of fast-growing coniferous trees such as eucalyptus (Enecon, 2013). It is therefore necessary to stimulate the diversification and use of plantation species, but this stimulation should consider establishing plantations with native species to facilitate obtaining biofuels from species adapted to habitats without breaking the balance in nature.

In this paper, it is evaluated the potential of plantations of five native species in the area of Tamaulipan thorn scrub, vegetation type that characterizes northeastern Mexico and occupies more than half of the total area of the country. This evaluation, based on the quality of charcoal according to international standards, is posed as an alternative for the generation of biofuels within the lines of action established by the Kyoto Protocol for the development of sustainable energy projects.

MATERIAL AND METHODS

Description of experimental site and sampling design

Five species characteristics of Tamaulipan thorny scrub, *Acacia berlandieri* (Benth.), *Havardia pallens* (Benth.) Britton & Rose, *Helietta parvifolia* (Gray) Benth., *Ebenopsis ebano* (Berl.) Barneby y *Acacia wrightii* (Benth.), were selected. The species selection criterion were the adaptability and the growth rate from 30 years old plantations of scrub at the school of the Faculty of Forestry at Linares, located in a plain region at 430-450 m altitude in the foothills of the Sierra Madre Oriental in Mexico (24° 47' north latitude and 99° 32' west longitude). The regional climate in the scheme of Köppen modified by García (2004) is defined as semiarid and subhumid [(A) C (Wo)] with two rainy seasons (summer and autumn) and a dry spell between November and April (Cavazos and Molina, 1992). According to Foroughbakhch et al. (2012), September is the month with the highest precipitation (180-200 mm), and December and January with the lowest rainfall (15-20 mm).

Three plots of 100 m^2 each were used per species, and one tree representative of the plot, without mechanical damage, insect attack or visible defects was felled down. From both types of materials (trunk and branches), were elaborated test samples of length 20 mm that were subject to the carbonization process.

Conditioning and measurement of specimens

The test pieces were conditioned at 26°C and 90% relative humidity in a bioclimatic chamber for 30 days, in order to homogenize the moisture content. After this period of time the weight and dimensions in the longitudinal, radial and tangential planes were recorded.

Carbonization process

The carbonization was performed in an electric muffle at a temperature of 650 °C for three hours (Figure 1a). Previously, five samples of each type of material per tree were introduced in metal cylinders with cap, to prevent complete combustion of the material. Ended the carbonization cycle, a period of cooling was taken and then we proceeded to the extraction of the specimens (Figure 1b).

Determination of charcoal yield

The charcoal obtained from each species and type of material was conditioned to the environment, and the weight was recorded as initially took with the wood specimens. The data were used to calculate the yield by the following equation.

$$\text{Yield} = \left(\frac{\text{Charcoal weight}}{\text{Conditioned wood weight}}\right) * 100 \qquad (1)$$

Immediate analyses

The sampled charcoal was milled and sieved to a particle size of 425µm. The analyzes referred to their moisture content, volatile material, ash and fixed carbon, according to the international standard ASTM D 1762-84 (ASTM, 2001).

Moisture content

Crucibles were placed in muffle at 750 °C for 10 minutes and after cooling, the initial weight was recorded. One gram of the sieved sample was put in crucibles and after passing to the drying oven at 105 °C for two hours, the weight was recorded after cooling. The recorded data permitted to calculate the moisture content, using the following equation.

$$MC = \left(\frac{Pi-Ps}{Pi}\right) * 100 \qquad (2)$$

Where:
MC is the moisture content,

Figure 2: Process of determination of the volatile with different positions of crucibles in the muffle: a) at the door, b) in the entry, c) at the background

Pi, the initial weight,
Ps, the weight of charcoal after subjecting to 105 °C.

Volatile material

The determination of the volatile material was done by placing the crucibles with caps in the muffle at a temperature of 950 °C. The process started with the crucibles in the muffle door for two minutes (Figure 2a), then in the entry for three minutes (Figure 2b) and finally, at the background of the muffle with the door closed for six minutes (Figure 2c), in order to reach the 950 °C temperature.

The percentage of volatiles was calculated using the following equation.

$$VM = \left(\frac{Ps - Pv}{Ps}\right) * 100 \quad (3)$$

Where:
VM is the volatile material,
Ps, the weight of charcoal after subjecting to 105 °C
Pv, the charcoal weight after subjection to 950 °C.

Ash content

Crucibles without caps were placed in a muffle furnace at 750 °C for six hours to reach the total incineration of charcoal. The incineration was checked by observing the whitish color of ashes. After leaving to cool to obtain its weight discounting the weight of the crucible, the ash content was determined by the equation:

$$A = \left(\frac{Pa}{Pv}\right) * 100 \quad (4)$$

Where:
A is the ash content,
P_a, the weight of the ashes
Pv, the weight of coal after subjection to 950 °C.

Fixed carbon

To calculate the percentage of fixed carbon (FC), the moisture contents, volatile material and ash were subtracted to the mass of milled and sieved charcoal, using equation 5 (Márquez-Montesino et al., 2001).

$$FC = 100 - (MC + VM + A) \quad (5)$$

Calorific value

The determination of calorific value (PC) was performed knowing the percentage of moisture content, volatile material, ash and fixed carbon. To this effect, it was calculated according to equation 6 below.

$$PC = 354.3\,FC + 170.8\,VM \quad (6)$$

Statistical analysis

The percentage data were transformed using the arc cosine square root function of p, where p is the proportion of the dependent variable (Schefler, 1981). Subsequently, tests for normality of the data for each variable were performed by the Kolmogorov-Smirnov test. Then, they were analyzed with the Statgraphics program, Centurion 16.1.11, to determine the significance of results. Mean comparison of Tukey tests were made according to Zar (2010), at a confidence level of 95% (p = 0.05).

RESULTS AND DISCUSSIONS

Yield

The charcoal yield showed significant variation (P<0.05) with respect to species; however, the different types of material (trunk and branches) showed similar results (P>0.05) (Table 1).

The highest value corresponded to *A. wrightii* with 30.15% of charcoal produced by the trunk and the lowest value to *H. parvifolia* with 19.94% of charcoal produced by its branches (Table 2).

These values corroborate with those reported by Hernandez and Tello (2014) who obtained yields of 22.2 to 40.3% (mean = 30.3%) for the same species from native areas. According to Corradi et al. (2013), the yield of commercial carbon does not exceed 30%, not only because of the fact that raw material influences the yield of charcoal,

Table 1. Analysis of Variance for the different parameters

	Df	Yield		Moisture		Volatile		Ash		Fixed carbon	
		F	P	F	P	F	P	F	P	F	P
Type of material	1	1.05	0.3079	0.05	0.8252	8.25	0.0052	1.92	0.1698	7.95	0.0060
Species	4	3.34	0.0138	18.07	0.0000	26.59	0.0000	19.03	0.0000	24.57	0.0000
Residual	84										
Total (corrected)	89										

Table 2. Mean and standard deviation of charcoal yield for each species

Species	Trunk		Branches	
	Mean	Standard deviation	Mean	Standard deviation
H. parvifolia	20.96	0.23	**19.94**	0.23
E. ebano	25.31	2.72	26.22	4.25
H. pallens	22.66	1.53	22.61	0.56
A. wrghtii	**30.15**	5.23	24.53	1.26
A. berlandieri	21.98	1.68	20.28	3.65

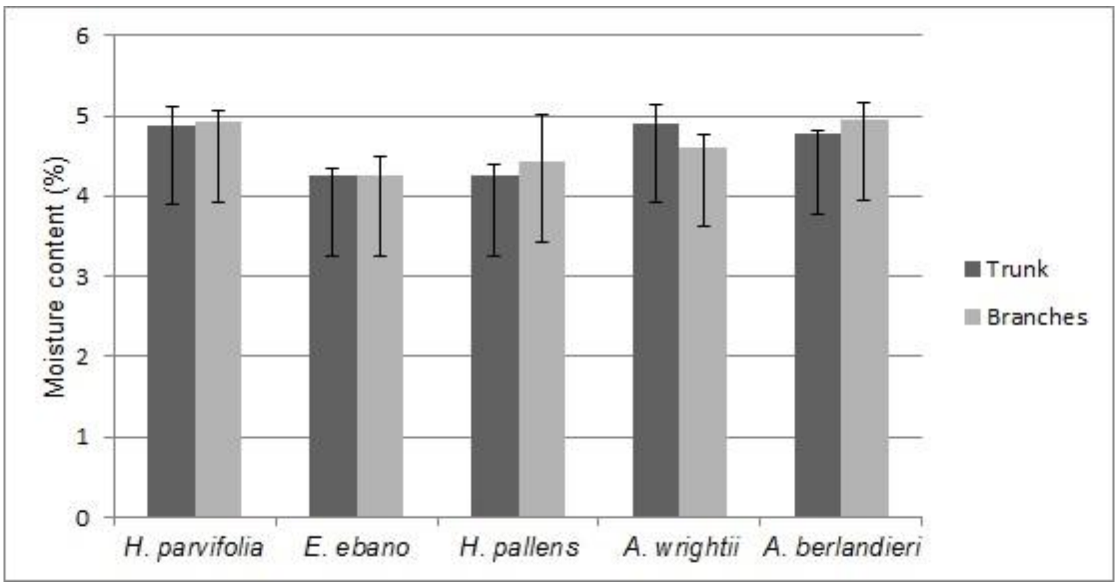

Figure 3: Moisture content of charcoal per species

but also due to the conversion process used. In this study, the conditions for obtaining charcoal were controlled.

Moisture content

Analysis of variance of moisture content indicated highly significant differences (P<0.01) between species, while the types of material did not vary significantly (P>0.05) (Table 1). The greater values were presented by the species *A. berlandieri*, *H. parvifolia*, and *A. wrightii*, with 4.94%, 4.93% and 4.91%, respectively, in the trunk and branches. *E. ebano* and *H. pallens* showed the lowest moisture content with 4.26% on the trunk of the two species, 4.25 and 4.41% in branches, respectively (Figure 3).

The moisture content of charcoal was found to be less than 8% in all species studied, in conformity with the provisions of international markets, and according to Carrillo et al. (2013) who defined the charcoal as a material with low moisture and low hygroscopicity. Moisture values greater than 8% induce greater material consumption during combustion in order to induce the evaporation of excess water. Moreover, under conditions of low moisture content, is obtained a product more resistant to biodegradation, being hardly alterable to normal atmospheric conditions and less susceptible to attack by biological agents.

Volatile material

The volatile material content showed highly significant differences between species studied (P <0.01) and significant differences between parts of the tree (P<0.05)

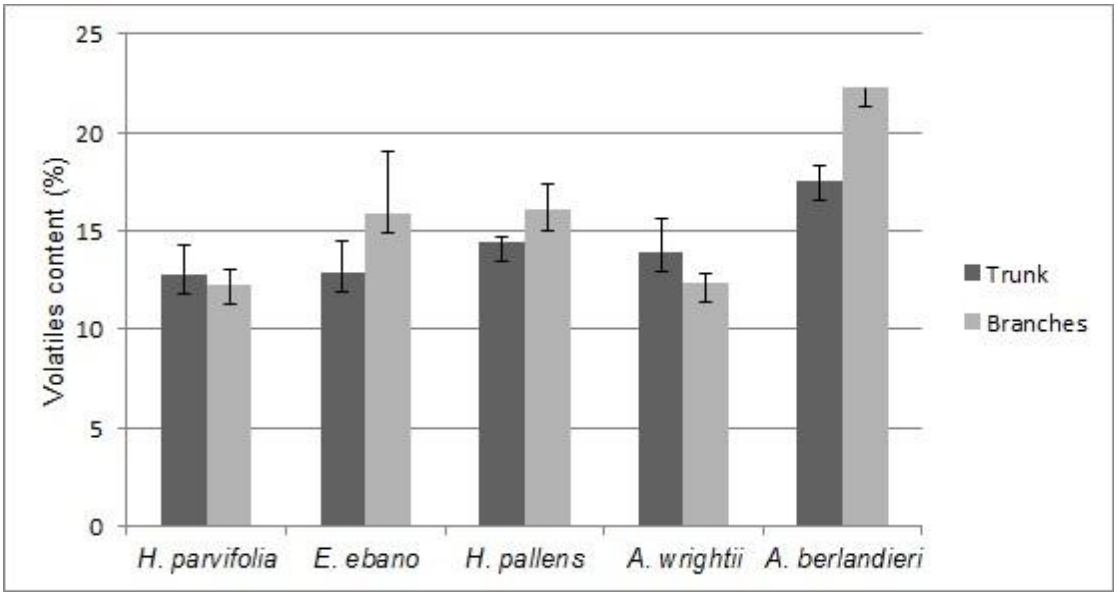

Figure 4: Content of volatile material in charcoal of each species

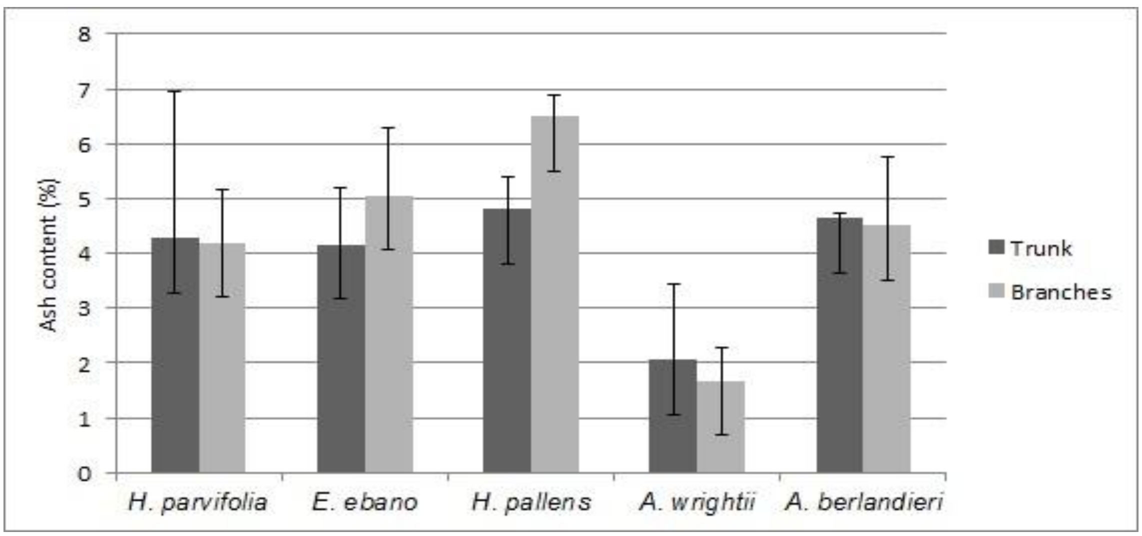

Figure 5: Ash content from charcoal produced per species

and highly significant between the species studied (P<0.01) (Table 1). The values of charcoal volatile material of the studied species ranged from 12.29 to 22.28%. The highest content corresponded to *A. berlandieri* both in branches (22.28%) than in trunk (17.51%) (Figure 4).

These values are lower than the 20-30% range established by Williamson (2006) for the volatile fraction of charcoal, except the branches of *A. berlandieri*. The trunks of *E. ebano*, *H. pallens* and *A. berlandieri* showed lower volatile material content than its branches, thus presenting an advantage from the energy point of view, because they burn slower than the branches, which have greater amount of volatile, as Cuvilas et al. (2014) indicated that species with less volatile material burn slower than those with more volatile material. Moreover, a low percentage of volatile promotes a clean charcoal combustion, key to efficient resource use and environment careful, that is then important according to Luxán Jimenez (2003) to be used in thermoelectric centrals.

Ash content

The ash content showed highly significant differences between species (P<0.01), whereas among types of material there were no significant differences (P>0.05) (Table 1). The major and minor ash values were 6.49 and 1.68% respectively presented by branches of *H. pallens* and *A. wrightii* (Figure 5).

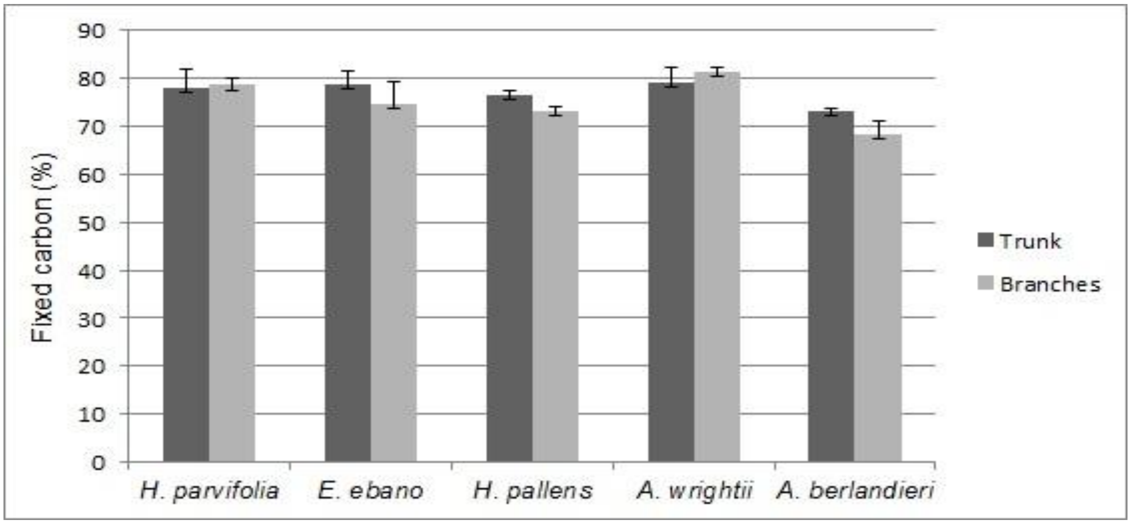

Figure 6: Content of fixed carbon in the charcoal of each species

Table 3. Mean and standard deviation of calorific values from charcoal of the species studied

species	Trunk		Branches	
	Mean	Standard deviation	Mean	Standard deviation
H. parvifolia	29839	1130	29940	453
E. ebano	30085	676	29221	980
H. pallens	29561	292	28620	225
A. wrghtii	30404	834	**30933**	290
A. berlandieri	28879	112	**27992**	650

The values obtained are higher than those presented by Hernández and Tello (2014) who found in the same temperature conditions (750 °C), the values 1.1, 2.2, 3.4, 3.6% for *A. wrightii*, *H. parvifolia*, *E . ebano* and *H. pallens*, respectively. This could be due to the harvest period.

According to Cuvilas et al. (2014), biofuel with low ash content is desirable; because its accumulation dirties heat exchangers and obstructs the flow of flue gases, with the risk of causing problems in the reactors (Werkelin et al., 2011). Thus, *A. wrightii* it is the species that would cause less problems, for presenting the values 2.05 and 1.68% for the trunk and branch, respectively. *Havardia pallens* generated a high amount of ash, which is a challenge for the chemical industry and energy production, due to the cost and logistics for its collection, transport, handling and storage (Kargbo et al., 2009). Furthermore, the ash has an alkaline reaction that when mixed with water, the pH of the solution increases and induces corrosion of metal (Karltun et al., 2008). Therefore, Obernberger et al. (2006) noted that the determination of the concentration and composition of ash is essential for the choice of combustion technologies and debugging of appropriate gas.

Fixed carbon

The content of fixed carbon showed highly significant differences (P<0.01) between species, and significant (P<0.05) between the types of material (Table 1). The lowest percentage was recorded in the branches of *A. berlandieri*, with the value of 68.26% (Figure 6).

Demirbas (2003) notes that a low fixed carbon content increases friability and fragility, and reduces the resistance to compression and cohesion. The species *H. parvifolia*, *E. ebano*, *A. wrightii* and trunk of *H. pallens* showed a rate greater than 75%, as required by European market for charcoal use with industrial purposes (Carrillo et al., 2013).

Calorific values

Highly significant differences (P<0.01) on calorific values were detected between species, and significant differences (P<0.05) between types of material (Table 1). The results varied between 28000 and 30932 kJ kg^{-1}, values corresponding respectively to the branches of *A. berlandieri* and *A. wrightii* (Table 3).

These data are similar to those reported by Masera et al. (2005), values between 29 000 and 35 000 kJ kg^{-1}, showing charcoal as an important source of energy. But the FAO (1993) found that although they may have different physical properties, there is no difference from the energy perspective, between charcoals of various species. In this sense, the results of this research allow to note that

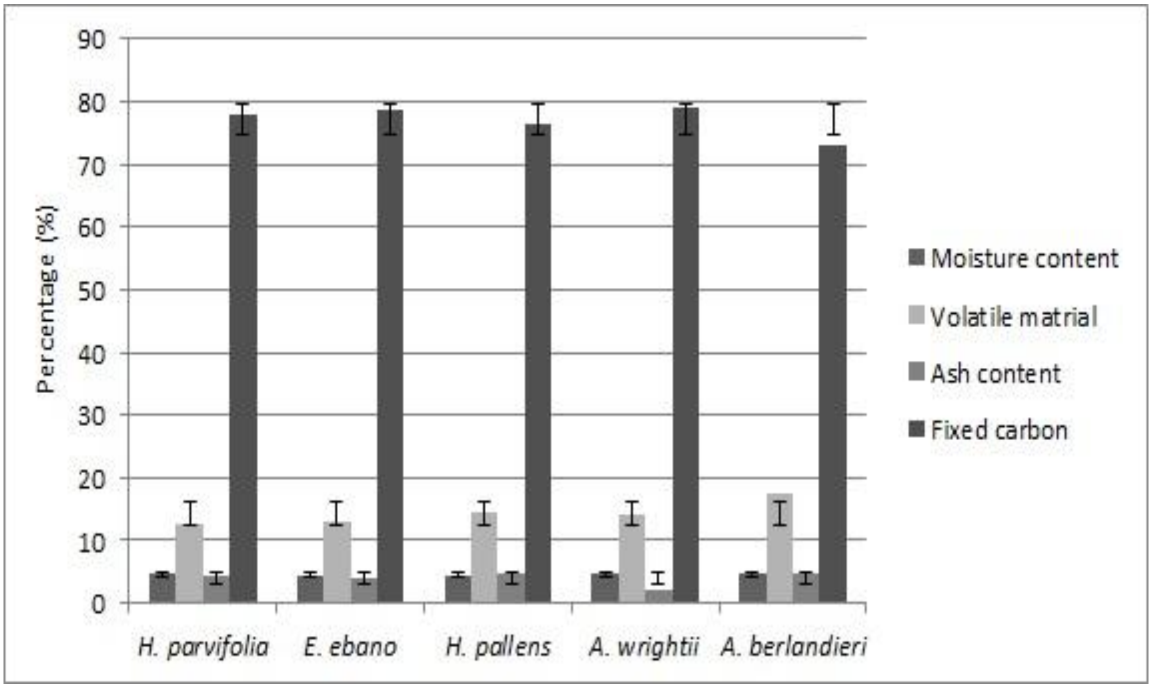

Figure 7: Percent content of the different components of the charcoal

Table 4. Correlations between the variables

	Moisture	Volatiles	Ashes	Fixed Carbon	Calorific value
Moisture		0.2355	0.3021	0.1807	0.1807
Volatiles	0.2355		0.0011	0.0000	0.0000
Ashes	0.3021	0.0011		0.0000	0.0000
Fixed Carbon	0.1807	0.0000	0.0000		0.0000
Calorific value	0.1807	0.0000	0.0000	0.0000	

charcoal production may also include the use of branches with diameter > 5 cm, the above will lead to decrease the intensity of resource exploitation, which is usually done using only the trunk, being the densest part of the tree. This alternative gives greater utility to species that produce many shoots with small diameters, reducing the pressure exerted on the species of large trunk. In a study on the usable timber evaluation of the same species, Maginot et al. (2014) presented *E. ebano* and *A. wrightii* as the species of large trunk and without shoots, and *H. parvifolia*, *H. pallens* and *A. berlandieri* as species of many shoots.

Correlational study of variables

It's highlighted in Figure 7 that the fixed carbon is the main component of the charcoal, with a content exceeding 70% giving to charcoal mayor density energy than firewood. Volatile materials constitute the second major component of charcoal, with more than 15% content. Regarding the moisture content and ash, the percentage values are less than 5%. This reveals that the energy is obtained from the carbon, and that the inorganic fraction constituting moisture and ash, reduces the calorific value, by failing to provide energy. However, as noted by Jenkins et al. (2011), the inorganic fraction is also important for the design and operation of the combustion system, in particular with regard to fouling of ash.

Statistical significance of correlations among the variables studied is presented in Table 4 below.

Moisture content had no significant correlation ($P>0.05$) with other variables, so it does not affect the other properties of charcoal. However, Carrillo et al. (2013) obtained a relation between moisture content and calorific value, where higher moisture decreases the calorific value. But this decreasing was without significance in the present study.

Regarding the content of volatile materials, was found a significant correlation ($P<0.05$) with ash.

Strong correlations ($P<0.01$) were revealed between fixed carbon and volatile material, ash and calorific value of charcoal. This corroborates the results of Jenkins et al. (2011) who related the ash content to calorific value, concluding that species with less than 1% ash usually have a calorific value about 20 MJ kg^{-1}, while each 1% increase in the ash results in a decrease of 0.2 MJ kg^{-1}, because the ash generally does not contribute substantially to the heat released by combustion, despite the fact that some elements in the ash can catalyze the thermal decomposition. Also, these authors found correlations between the carbon content and the calorific value, arriving in that every increase of 1% carbon raises the calorific value of approximately 0.39 MJ kg^{-1}.

CONCLUSION

The charcoal production resulted to be a good option to improve the bioenergy characteristics of firewood from trunk and the underutilized branches of the species studied. The charcoal generated turned out to be an efficient fuel for its considerable carbon content, which induces high calorific value. The quality of charcoal produced from the trunk and branches of all species studied in this work, was adequate for domestic and industrial use, since the values of the parameters studied are within the limits prescribed in the international standards. By selecting these species for use as fuel from biomass, contributes inevitably to socio-economic development without compromising the existence of the resource, while providing care and the health of the environment for the welfare of the resident. But in terms of advantages, *A. wrightii* excelled by its high capacity of charcoal production, high fixed carbon content, more calorific value and low content of ash than others species studied.

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