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Gross Heating Value of Various Shade-Trees Wood in Coffee Plantation in Costa Rica and Its Relation with Extractives and Specific Gravity

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Abstract

Shade-trees with energy use in coffee plantations are an important alternative to increase profitability in agroforestry systems. The aim of this study was to investigate gross calorific value (GCV) of 15 shade-tree species in coffee plantations in Costa Rica. The relationships between specific gravity and extractives content on GCV was evaluated. The results revealed that GCV varied from 15.9 to 21.9 MJ kg-1 for sapwood, and from 15.3 to 21.9 MJ kg-1 for heartwood. No consistency was observed regarding to relation of type of wood (sapwood or heartwood) and GCV. The highest GCV value was found in *Pinus caribae*a for sapwood and heartwood. However *Cupressus lusitanica*, presented high GCV in sapwood too. The lowest values were found in *Schizolobium parahyba* in sapwood and *Zygia longifolia* and *Eucalyptus globulus* in heartwood. Carbon content (C) and carbon/nitrogen ratio (C/N ratio) and extractives in sodium hydroxide and dichloromethane were correlated with GCV in sapwood and heartwood. Meanwhile extractives in hot water were correlated in heartwood, and nitrogen content (N) and extractives in cool water were too correlated in sapwood.

Keywords: Tropical species, extractives content, biomass, fuelwood

INTRO\DUCTION

In Costa Rica, although the use of wood as an energy source is not a major source, fuelwood represents approximately 5% of the energy sources (Moya & Tenorio, 2013). Currently, there is an interest for in exploiting all residues of sawing process and plantation residues as biomass (Chacón, 2012) for heat production. Traditionally the wood in this country comes from pruning in coffee plantations and tree crops associated with coffee, cocoa and paddocks plant and pruning in hedges (Beer *et al*., 2003).

Trees located in coffee plantations, which serve as shade (Beer *et al*., 1998) and nitrogen-fixing and storing carbon (Toledo & Mogel, 2012) are an energy source with the potential to exploit due to the large number of these associations with coffee plantation (Rojas *et al*., 2004). Is estimated that 4.0 m^{-3} of wood per hectare can be gained (Beer *et al*., 1998), equivalent to about 45600 MJ ha^{-1} as an energy source.

One of the limitations presented in coffee is the erratic prices, because of this, the sector seeks to apply technology to achieve high productivity and add other activities to the production system of coffee with other crops to provide additional value to the main economic activity (Mendez *et al*., 2010). The alternatives for incorporating trees in coffee plantations is as variable as the available space, the production system and the wished objective; fences as windbreaker, foliage, trees on boundaries, shadow, are existing alternatives for the design of a wooded-coffee plantation (Rojas *et al*., 2004).

The choice of shade-tree species should be accompanied with knowledge of the species (Moya, 2007; Tenorio & Moya, 2013a). If the purpose is energetic use, probably the species are different to the timber species, because when harvesting these species should be adequate to their energetic behavior and this determines the characteristics of density, calorific power, among others (Moya *et al*., 2017).

The objective of this work was to determine the energetic potential of trees used as shade in coffee plantation. As a secondary objective, to determine whether there is a relationship between gross calorific value with basic specific gravity and the percentage of soluble extractives in different solvents (ethanol, toluene, dichloromethane, cold water, hot water, sodium hydroxide) in sapwood and heartwood.

MATERIALS AND METHODS

The selected species are often used as shades for coffee plantation in the upper and middle basin of Reventazón river in Costa Rica. The species used in this study are presented in Table 1. The tree age was not possible to establish because the annual ring is indistinctive in this tree and the owners of coffee plantation did not register the years of planted. To collect the samples mature and healthy individuals were selected (3 trees for each species located within the same trial of coffee plantation). The removal thereof was made from the main stem of the tree to 1.3 m height and a piece of wood was extracted of about 8 cm thick. Although caloric values varied across the trunk and tree age, the 1.3 m height is usually the part of trees that represents to standard height with other species or other tress. In the case that the species presented visible heartwood, this was marked. When heartwood was not visible, it was assumed approximately 5 cm around the pith in order to ensure that the part corresponded to that tissue.

Each cross section from sampled trees was extracted 5 chips approximately 6 cm wide and 1 cm in long from sapwood and heartwood separately. The chips were milled, separating in sapwood and heartwood for producing sawdust. The sawdust was sieved through 0.25 mm and 0.42 mm meshes (40 to 60 meshes, respectively), until approximately 8 g per test were obtained for energy properties determination. Specific gravity (SG) was determined using both sub samples. The volume of each sample was defined as the volume of water it displaced when submerged, according to ASTM D2395-02 standards (ASTM, 2013c).

The gross calorific value (GCV) was determined for free-water condition (moisture content of 0%). Moisture content was measured according to ASTM D-1442-92 norm (ASTM, 2013a) and GCV was determined using Parr calorimetric test through the D-5865-04 standard (ASTM, 2013b). Extractives were determined in water (hot and cool condition), in sodium hydroxide (NaOH), in an ethanol-toluene solution and in dichloromethane (CH_2-Cl_2) (ASTM 2013d). For each type of extractives, 3 samples were taken.

First, the assumptions of normal distribution, variance homogeneity and absence of extreme data of GCV, SG and extractives content in different solvent were verified. Proc Univariate procedure was applied of SAS 8.1 for Windows (SAS Institute Inc., Cary, N.C.). Second, the values of GCV were compared by ANOVA. The average differences were analyzed by Tukey test with 0.01 in significance in order to find which treatments varied. Third, a Pearson correlation matrix was used for determining the SG and extractives content in different solvent with GCV.

RESULTS AND DISCUSSION

Gross Caloric Power

The energetic potential of 15 shade-tree species in coffee plantations are presented in Table 1. It is observed that the highest value (over 20,000 kJ kg^{-1}) of GCV occurs in *P. caribaea*, both sapwood and heartwood. However, in the sapwood *C. lusitanica* species also showed a GCV greater than 20 MJ kg^{-1}. The lowest value of GCV was presented in *S. parahyba* in heartwood, but in sapwood, was presented in *Z. longifolia* and *E. globulus.* Regarding GCV values difference between sapwood and heartwood of each species, it was found that the species *E. globulus, G. liricidia sepium, P. guajava, T. havanensis* and *Z. longifolia* had significant difference between the two types of wood (Table 1). The remaining species showed no significant differences between the values of GCV and its sapwood and heartwood.

It is that GCV decrease with moisture content (Tenorio & Moya, 2013b), however this parameter was not measured in this study. However, the decreasing of GCV with moisture content can be modeled by Y= $\beta0$*X+ $\beta1$, detailed for different species by Tenorio & Moya (2013b)

Sapwood and Heartwood Comparison

Regarding the differences for the same type of wood (sapwood or heartwood) in different species, it was found that in the case of sapwood, *P. caribaea* presented significant differences with the other species and is the species with the highest GCV (Figure 1a). It also shows that three different groups in sapwood are formed, a group composed only of *P. caribaea*, a group of 15 species with intermediate values, ranging from 17.000 to 20.0 MJ kg^{-1}, and a last group consisting of *F. benjamina* and *prinoides, S. parahyba, E. globulus, Z. longifolia* and *T. havanensis* (Figure 1a). Furthermore, in the heartwood for different species (Figure 1b), three groups were newly introduced. The first group again *P. caribaea*, with the highest value of GCV, then a group of 9 species, with

Table 1. Shade-tree species studied, main characteristics and gross caloric power of sapwood and heartwood obtained for 15 shade-trees used in coffee plantation in Costa Rica

Species	Traditional used of tree	Tree for lumber	Heartwood distinctive	Gross caloric values (MJ kg^{-1})		
				Sapwood	Heartwood	Average
Acnistus arborescens	Fence/Foliage	-	-	17.66A	18.11A	17.88
Cordia alliodora	Boundaries/Timber	+	+	18.71A	18.63A	18.67
Coutarea latifolia	Fence/Foliage	-	-	18.30A	18.66A	18.48
Cupressus lusitanica	Boundaries/Timber	+	+	20.43A	18.25B	19.34
Eucalyptus deglupta	Boundaries/Timber	+	+	15.88A	18.46B	17.17
Eucalyptus saligna	Shade/Timber	+	+	18.94A	18.37A	18.65
Ficus benjamina	Fence/Foliage	-	-	17.10A	16.47A	16.79
Ficus prinoides	Fence/Foliage	-	-	16.33A	16.42A	16.38
Gliricidia sepium	Fence/Foliage	-	+	18.34A	14.92B	16.63
Pinus caribaea	Boundaries/Timber	+	+	21.91A	21.95A	21.93
Psidium guajava	Fence/Fruit	-	-	18.23A	16775B	17.50
Schizolobium parahyba	Boundaries	+	-	16.16A	15.28A	15.72
Syzygium malaccense	Shade/Fruit	-	-	18.69A	19.51A	20.0
Trichilia havanensis	Shade	-	+	14.93A	19.48B	17.21
Zygia longifolia	Bounderies	-	+	15.79B	17.7B	16.75

Legend: The averages in sapwood and heartwood for a same species with different letters present significant differences. Determined at P-value >0.01.

values from 17.0 up to 20.0 MJ kg^{-1}, and the last group with the lowest values and form by *F. benjamina* and *F. prinoides, P. guayava, S. parahyba, E. globulus, Z. longifolia* and *T. havanensis* (Figure 1b).

The variation range (14.9 to 21.9 MJ kg^{-1}) found in the GCV of the 15 shade-tree used in coffee plantation in Costa Rica (Table 1) agrees with values found for other tropical species growing in Costa Rica (Moya & Tenorio, 2013) and India (Kumar *et al*., 2011), but growing in pure plantation and natural condition, respectively. Likewise, for species that present sapwood and heartwood, the lack of clarity of which type of wood has higher GCV, has also been brought up by other authors (Moya & Tenorio 2013, Kumar *et al*., 2011). They have found that in some species, sapwood has a higher GCV than heartwood, while for other species the opposite results were found, as heartwood had a higher GCV. Similar results were obtained in the present study (Table 1).

According to GCV values found (Table 1), *C. lusitanica* and *P. caribaea* are the species that scored the highest GCV both its average and sapwood and heartwood, which places them as important species from the energetic point of view. Conversely, *S. parahyba* in heartwood and sapwood of *Z. longifolia* and *E. globulus* are species with the lowest values of GCV, therefore, species of low potential as energy source. The other tree species as coffee shade generally have similar values of GCV and this condition would allow if necessary the mixture of species without altering power conditions.

Specific Gravity and Extractives Correlation

The average values of the specific gravity and the amount of extractives in the different solvents are presented in Table 2. The correlation analysis between the values of GCV with SG in the wood of sapwood, heartwood and the average of the two types of wood was not statistically significant (Figure 1, Table 2). As with the carbon positive and highly correlated (P-value<0.01) to the GCV in the two types of wood and the average of the two types of wood. The amount of nitrogen was negatively significant (P-value<0.05) with the GCV in sapwood and the average of the two types of wood, but with the heartwood was not significant to GCV. The C/N ratio was positively significant (P-value<0.05) with GCV in both types of wood and the average of them (Table 2). The lack of relation between SG and GVC is typical, because the fuel properties present strong relation with chemical and extractives components (Senelwa & Sims, 1999).

Regarding extractives, it was found that sodium hydroxide extractives and dichloromethane were correlated with GCV of sapwood, heartwood and the average of the two types of wood. Extractives of sodium hydroxide were negatively correlated with GCV, but dichloromethane extractives were positively correlated (Table 3). While extractives in the ethanol-toluene solution were not correlated to the GCV in the different types of wood and the average of them. Extractives in hot water was negatively correlated in the heartwood (Value-P > 0.05), but these extractives with cold water were negative and highly correlated (P-value > 0.01) with the GCV in the sapwood and the average of the two types of wood (Table 3).

Some studies, as those carried out by Singh & Khanduja (1984) and Goel & Belh (1996), indicated that species with high SG, which have high GCV values, also present a slow burn, making them more convenient for fuel. However, species' fuel capacity is also dependent on its moisture content and chemical compositions (Senelwa & Sims, 1999). The present study found though that

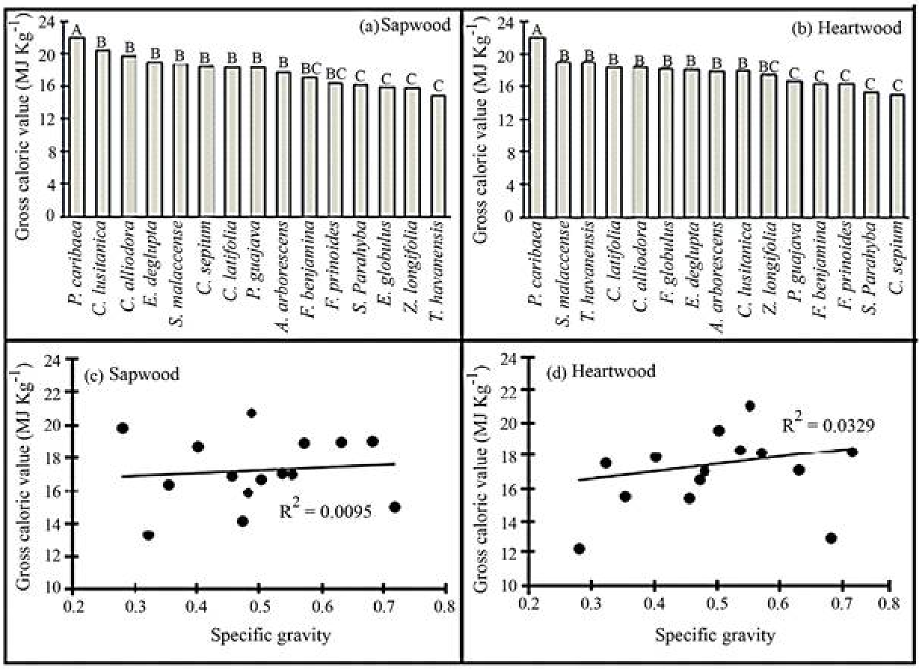

Figure 1. Comparisons of gross caloric power among the species for sapwood (a) and heartwood (b) and relation between specific gravity of sapwood (c) and heartwood (d) with the net caloric power in 15 shade-trees used in coffee plantation in Costa Rica

Table 2. Specific gravity and extractives in different solvent in 15 shade-trees used in coffee plantation in Costa Rica

Species	SG	NaOH	CH_2Cl_2	Et-Tol	H_2O_C	H_2O_F	N	C	N/C
Acnistus arborescens	0.57	12.52	2.59	2.82	3.80	5.71	0.43	46.0	113
Cordia alliodora	0.40	11.99	3.61	2.12	3.94	2.87	0.27	45.9	172
Coutarea latífolia	0.56	10.35	3.22	4.27	5.01	4.15	0.31	46.1	150
Cupressus lusitanica	0.48	12.12	4.26	3.59	5.31	2.02	0.10	47.4	314
Eucalyptus globulus	0.54	10.73	3.11	3.35	2.95	4.39	0.19	46.8	242
Eucalyptus deglupta	0.49	8.72	2.82	0.35	2.14	3.33	0.09	45.8	397
Ficus benjamina	0.32	13.50	2.97	1.37	3.76	4.19	0.21	46.3	263
Ficus prinoides	0.35	12.35	3.15	5.22	8.20	9.21	0.24	45.9	192
Gliricidia sepium	0.55	11.27	3.76	3.00	4.80	4.50	0.40	46.3	115
Pinus caribaea	0.47	9.97	3.58	2.70	3.36	2.69	0.16	48.3	290
Psidium guajava	0.68	8.93	3.87	3.48	5.56	7.45	0.22	45.6	207
Schizolobium parahyba	0.28	12.97	2.36	2.38	3.72	4.89	0.35	45.3	133
Syzygium malaccense	0.50	11.17	3.44	3.62	3.71	4.91	0.32	46.5	150
Trichilia havanensis	0.63	11.39	3.04	3.22	3.56	5.04	0.31	45.3	148
Zygia longifolia	0.72	11.85	3.51	3.86	3.06	5.68	0.28	46.2	163
General Total	0.50	11.32	3.29	3.02	4.19	4.74	0.26	46.3	203

Legend: SG: Specific gravity, NaOH: sodium hydroxide, CH_2Cl_2: dichloromethane; Et-Tol: ethanol-toluene, H_2O_C: hot water; H_2O_F: cool water; N: nitrogen content (%); C: carbon fraction; N/C: carbon/nitrogen ratio.

both SG were not correlated to any of the fuel characteristics evaluated (Table 3). This result suggests that the fuel characteristics of the shade-tree in studied are most influenced by extractives.

The analysis of the effect of chemical composition on GCV of the species studied revealed that the effects on sapwood and heartwood were lightly consistent (Table 3). Kumar *et al.* (2011) points out that a relation-

Table 3. Coefficient of correlation between net caloric power with specific gravity and extractives in different solvent in 15 shade-trees used in coffee plantation in Costa Rica.

Characteristics		Sapwood	Heartwood	Average
Specific gravity		0.01 NS	0.22 NS	0.038 NS
Carbon content		0.58 **	0.48 **	0.54 **
Nitrogen content		-0.32 *	-0.220 NS	-0.29 *
C-N ratio		0.34 *	0.32 *	0.34 *
Extractives in	Sodium hidroxide	-0.39 *	-0.51 **	-0.45 **
	Hot water	-0.027 NS	-0.39 *	-0.21 NS
	Cold water	-0.54 **	-0.22 NS	-0.40 **
	Dichloromathane	0.40 **	0.39 *	0.38 *
	Ethanol-toluene	-0.24 NS	0.11 NS	-0.05 NS

Note: *statistically significant parameter to 95% and **statistically significant parameter at 99%. Maximum CV = calorific power at 0% of MC, green CV = calorific power at the maximum MC of wood.

ship exists between a species percentage of C content and GCV. Although, C was correlated with GCV (Table 3), the multiple stepwise correlation analysis showed that C was the variable most important in the variation GCV in sapwood and the average of two types of wood (sapwood and heartwood), but this element is second variable in heartwood (Table 4). Similarly, extractives in dichloromethane and cool water were important in GCV in sapwood, but not in heartwood (Plomion *et al.*, 2000). These results indicate that C content effected GCV in sapwood, but this effect of C content becomes less important in heartwood, probably influenced by high extractives content, which is the main factor on caloric value.

In general, it has been noted that extractives increase the fuel capacity of biomass (Senelwa & Sims, 1999). Nevertheless, the present study found that fuel characteristics were little affected by the presence of extractives. In heartwood, GCV was positively affected by dichloromethane extracts, but negatively in sodium hydroxide and hot water extracts (Table 3). In sapwood, cold water and sodium hydroxide extracts negatively affected NCV and dichloromethane extracts affected again positively NCV. In this regard, Senelwa and Sims (1999) indicate that the lack of correlation among extractives and some fuel characteristics may be explained by the nature of the components and the relative quantities present in the fuel.

The objective of this work is to determine the energetic potential of trees used as shade in coffee plantation. As a secondary objective, to determine whether there is an relationship between gross calorific value with basic specific gravity and the percentage of soluble extractives in different solvents (ethanol, toluene, dichloromethane, cold water, hot water, sodium hydroxide) in sapwood and heartwood.

CONCLUSIONS

The species utilized as shade trees in coffee plantation presented good energetic potential because their GCV are high and the variation range (14.9 to 21.9 MJ kg^{-1}) found in the GCV agrees with values found for other tropical species growing in Costa Rica. However, there are some differences among species. The highest values in GCV, are found in *C. lusitanica* and *P. caribaea*, then the following is a group with by *A. arborescens, C. alliodora, C. latifolia, E. globulus* and *deglupta, P. guajava, S. malaccense, T. havanensis*, and at last, at the other end, with the lowest values, a group of *F. benjamina, F. prinoides, G. sepium, Z. longifolia* and *S. parahyba*. In general, it has been noted that some extractives increase the fuel capacity of biomass and carbon content, but the effect of extractives depend of sapwood and heartwood presence. Then this behavior indicate that fuel characteristics of shade trees in coffee plantation of may be explained by the nature of the components and the relative quantities present of extractives in sapwood or heartwood.

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