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Potencial energético de biomassa e carvão de bambu

Energy potential of bamboo biomass and charcoal

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Resumo: A biomassa sempre foi utilizada pela humanidade como fonte de energia. Atualmente, devido aos problemas decorrentes da utilização de combustíveis fósseis, a biomassa volta a despertar interesse. Devido a produtividade, o bambu pode se tornar uma alternativa sustentável. Sendo assim avaliou-se potencial energético da biomassa e de carvão de quatro espécies de bambu. As espécies estudadas foram *Phyllostachys aurea* A. C. Rivière *(*bamboo golden*), Chusquea gracilis* Mcclure & Smith (*criciúma*), *Chusquea mimosa* Mcclure & Smith (*caratuva*) and *Merostachys multiramea* Hackel (*taquara lixa*). Estas são encontradas na Meso Região Centro Sul do estado do Paraná, Brasil. O bambu foi avaliado quanto ao conteúdo de água, massa específica, análise imediata e poder calorífico. A massa específica da *Phyllostachys aurea* foi de 0,63 g cm^{-3} in natura e 0,41 g cm^{-3} após carbonizada. A espécie *Phyllostachys aurea* in natura apresentou poder calorífico superior de 18,91 MJ kg^{-1} e conteúdo de cinzas de 4,90 g kg^{-1}, enquanto seu carvão chegou a um poder calorífico do 25,05 MJ kg^{-1} e conteúdo de cinzas de 12,40 g kg^{-1}. O poder calorífico superior do carvão da espécie *Chusquea mimosa* foi de 25,55 MJ kg^{-1}, porém com grande quantidade de cinzas geradas, 79,30 g kg^{-1}. A espécie *Chusquea mimosa* apresentou potencial para ser utilizada in natura e a espécie *Phyllostachys aurea* como carvão.
Palavras-chave: *poder calorífico, análise imediata, bioenergia, desenvolvimento sustentável*

***Abstract**:* Biomass has always been used by the humankind as source of energy. Nowadays, due to the problems resulting from the use of fossil fuels, it is seen with great interest. Due to its productivity, bamboo might become a sustainable alternative. Thus, this paper aimed at evaluating the energy potential of four bamboo species *in natura* and as charcoal. The species investigated were *Phyllostachys aurea* A. C. Rivière *(*bamboo golden*), Chusquea gracilis* Mcclure & Smith (*criciúma*), *Chusquea mimosa* Mcclure & Smith (*caratuva*) and *Merostachys multiramea* Hackel (*taquara lixa*)*,* found in the center-south of the state of Parana/Brazil. The bamboo was evaluated regarding its water content, specific mass, proximate analysis and upper calorific value. The specific mass of *Phyllostachys aurea* was 0.63 g cm^{-3} *in natura* and 0.41 g cm^{-3} after charred. The species P*hyllostachys aurea in natura* presented 18.91 MJ kg^{-1} calorific value and 49.00 g kg^{-1} ash content, while its charcoal presented 25.05 MJ kg^{-1} and 12.40 g kg^{-1}, respectively. The calorific value of the species *Chusquea mimosa* was 25.55 MJ kg^{-1}, however, it generated great amount of ash. The bamboo species *Chusquea mimosa* present energy potential to be used *in natura*, and the species *P. aurea* presented energy potential when turned into charcoal.
Keywords: calorific value, immediate analysis, bioenergy, sustainable development

1 Introduction

The dependence on energy originated from finite fossil sources and the environmental problems caused by their use are issues of global concern. This raises great interest in the search for alternative sources of renewable energy (Esteban et al., 2008, Zhu et al., 2011, Buratto et al., 2021 e Rosa et al., 2022).

Bioenergy is the most widely used source of renewable energy in the world, with 14% of the 18% renewable energy employed. Wood represents 68% of the supply of biomass primary energy, followed by the vegetable charcoal with 10% (wood is the source of over 52 million tons of the charcoal used). Around 2.6 billion people depend directly on the biomass energy (World Energy Council, 2016).

The Bambuseae Kunth ex Dumort. (Bambusoideae) is one of the main non-timber forestry products. Due to the presence of a woody tissue in its physiological structure, it shows energy potential (FAO, 2007). Botanically speaking, it is not a tree, and that is the reason why it is omitted in some discussions about forests related to climatic changes, however, it is already known as a source of bioenergy in many countries. Bamboo presents a great yield potential (Mognon et al., 2014; Sanquetta et al., 2015).

China and India are the greatest bamboo producers, estimates show that annually 5 million tons of bamboo are processed in each country (Klein, 2015). The European Union (UE), United States of America (USA) and Japan altogether consume over 56% bamboo and rattan commodities in the global market (Benton et al., 2011).

Theoretically, bamboo is already recognized in Brazil. In 2011, the National Law nº 12.484/2011 was passed, which provided for the institution of a National Incentive Policy to the sustainable management and cultivation of bamboo (PNMCB) (Brasil, 2011).

The productivity of bamboo biomass is high all over the country, however, in practice the recognition of its potential is still limited and it is used on a large scale by one company only, to be burnt in boilers in the paper recycling process (Guarnetti and Coelho, 2014).

Aiming at the sustainable rural development, alternative techniques of products and productions for the peasant farming are sought as well as ways of aggregating value to these products. Within this scope, the study of bamboo energy potential and characterization of its biomass becomes very relevant.

2. Material and methods

The bamboo was collected in the municipality of São Mateus do Sul, state of Parana, Brazil. That city shows a wavy and gentle wavy relief crossed by floodplains (Flores and Garrastazu, 2010). Its Köeppen climatic classification is Cfb, subtropical with rainfall events distributed throughout the year, mild summers and frequent frost in winter (Caviglione et al., 2000).

The main classes of soils found in the region are Argisols (Podzolic), Gleysols and Latosols (Flores and Garrastazu, 2010). The city belongs to the Rio Iguaçu watershed and its original vegetation is Mixed Ombrophilous Forest whose symbol is the *Araucaria angustifólia* (Bertol.) Kuntze. (Maack, 1968).

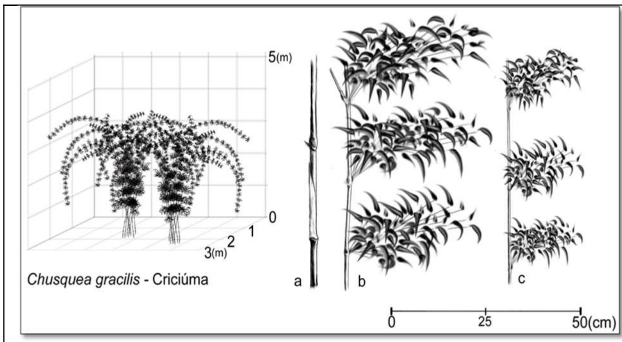
Fragments of stalk, leaves and roots were collected to be compared exsiccate from the herbarium at the State University of Ponta Grossa (UEPG) in Paraná State - Brazil, the Municipal Herbarium at the Botanic Garden in Curitiba, Paraná State- Brazil, and virtual herbaria (Reflora Virtual Herbarium; American Austral Virtual Herbarium; Flora and Fungi Virtual Herbarium).

Three landrace species were collected; *Chusquea gracilis*, *Chusquea mimosa* and *Merostachys multiramea*, and one exotic species, *Phyllostachys aurea*. The landrace specie *Chusquea gracilis* is popularly known as *criciúma, cará-de-var and, bengala* (Figure 1). The collection was carried out at the UTM coordinates 562,296 m and 7,133,663 m, grid 22J, 787 m altitude. The sample was 7.2 m long and presented 28 nodes. Eight nodes from the base were used. This species was collected in the flowering phase.

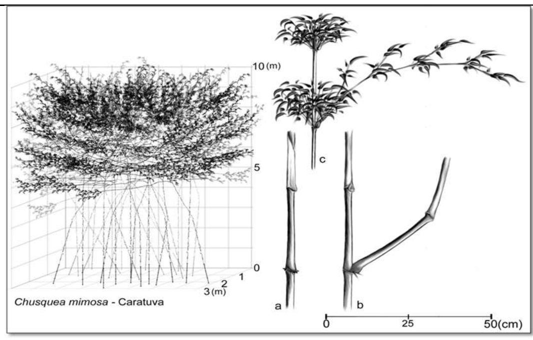
The landrace specie *Chusquea mimosa* is popularly known as *caratuva, cará-mimoso, cará-de-vara, cará-de-caniço, cará-de-bengala* and *carafá* (Figure 1). Samples were collected at the coordinates UTM 570,944 m; 7,148,482 m, grid 22J, 782 m altitude. This sample was 11m long and presented 45 nodes. Thirteen nodes from the base were used in the analyses.

The third landrace specie collected was *Merostachys multiramea*. This specie is popularly known as *taquara, taquara lixa, taquara mansa, taquara poca* and *taquaricé* (Figure 1). The collection was carried out at the UTM coordinates 556,210 m; 7,133,972 m, grid 22J, 816 m altitude. The sample used was 13.9 m long and had 37 nodes. Sixteen nodes from the base were used in the analyses.

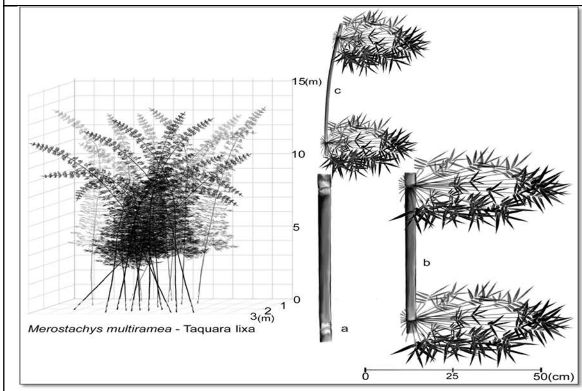
The exotic species *Phyllostachys aurea* is popularly known as *bambu dourado, bambuzinho amarelo* and *bambuzinho chinês* (Figure 1). This species is considered and invasive plant by the rural producers in the region. It was collected at the UTM coordinates 564,835 m; 7,143,693 m, grid 22J, 804 m altitude. The sample was 7.3 m long and had 51 nodes along the stalk. Fifteen nodes from the base were used in the analyses.



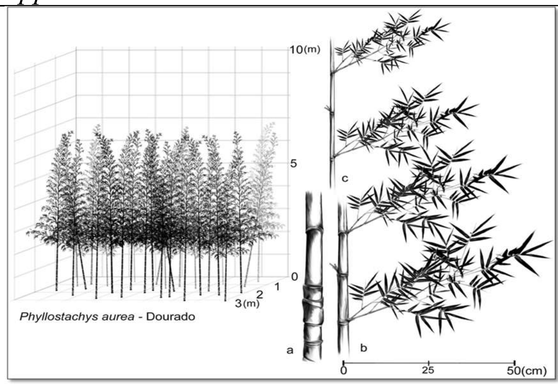
C. gracilis and (a) lower (b) middle, and (c) upper stem



C. mimosa and (a) lower (b) middle, and (c) upper stem



M. multiramea and (a) lower (b) middle, and (c) upper stem



P. aurea and (a) lower (b) middle, and (c) upper stem

Figure 1 – Graphical representation of the species studied. Design: Gilson Yugo Ueno Funaki

To characterize the biomass, physic and chemical analyses were performed: water content, specific mass, proximate analysis (fixed carbon, volatile material and ash content) and upper calorific value. In addition, the bamboo biomass pyrolysis was carried out to obtain charcoal. The charcoal was characterized through the determination of water content, specific mass, proximate analysis (fixed carbon, volatile material and ash content) and upper calorific value.

Water content determination was carried out following the norm NBR 14660 (ABNT, 2004). Mass was determined in semi-analytical balance (Shimadzu – model BL 3200H, 0.01 g accuracy). Specific mass was measured using the Archimedes Method, according to D2395 (ASTM, 2014).

The samples were prepared for the immediate analysis according to NBR 14660 (ABNT, 2004). A muffle furnace, brand Quimis, model Q318 M24 was used according to D3172 (ASTM, 2013).

The upper calorific value (UCV) of the samples was determined using a digital calorimetric pump (brand IKA Works, model C 5000) according to D5865 (ASTM, 2013).

The pyrolysis of the bamboo biomass was carried out using a muffle furnace (brand Quimis, model Q318 M24). After the charcoal mass was determined using a semi-analytical balance (Shimadzu - Model BL 3200H, 0.01 g accuracy), the charcoal gravimetric yield was calculated on a dry basis. The fixed carbon yield was calculated according to Vale et al. (2011). The energy yield was calculated according to Park and Jang (2012) and Park et al. (2012).

3 Results and discussion

The water content in the biomass influences the calorific value, presenting an inverse relation (Vale et al., 2011). Table 1 shows mean values of the water content in the portions base, middle and top of the bamboo stalk. Higher water content was observed in the stalk base, a fact that is in accordance with the findings by Berndsen et al. (2010).

In addition to the influence of transportation, high water content results in longer time to eliminate water in the initial phase of charring, causing an increase in the process endothermal phase, thus reducing yield (Roffael and Schaller, 1971). The values for the stalk base (Table 1) are compatible (Armandei et al., 2015), however, these values might vary depending on the time of the year (Beraldo et al., 2004).

Another variable to be taken into consideration is specific mass, the wood used in the conversion of thermal energy presents values between 0.45 and 0.65 g cm^{-3} (Foelkel, 1978).

Table 1 – Water content in the lower, middle, and upper stem of bamboo species.

Species	Stem part	Water content (g kg^{-1})	CV (%)
Merostachys multiramea	Lower	604,7	3,01
	Middle	595,5	0,66
	Upper	488,2	7,60
Chusquea gracilis	Lower	570,2	1,75
	Middle	423,1	12,45
	Upper	304,0	4,26
Phyllostachys aurea	Lower	432,0	0,37
	Middle	422,8	0,25
	Upper	304,0	7,89
Chusquea mimosa	Lower	788,7	0,30
	Middle	776,9	1,74
	Upper	706,0	1,67

The species *C. gracilis* and *P. aurea* presented specific mass values that were similar to those already reported (Table 2). They also presented higher values after charred, which tends to be related to the calorific value. Species of the genus *Eucalyptus* sp. presented specific mass around 0.47 and 0.58 g cm^{-3} (Brito et al., 1983).

Table 2 – Specific mass of bamboo species in natura and its charcoal.

	Specific mass (g cm^{-3})			
Specied	*In natura*	CV (%)	Charcoal	CV (%)
Merostachys multiramea	0,40	10,40	0,32	54,06
Chusquea gracilis	0,46	15,42	0,26	32,82
Phyllostachys aurea	0,63	2,76	0,41	15,40
Chusquea mimosa	0,20	13,88	0,10	38,40

The species *C. mimosa*, with 0.20 g cm^{-3} specific mass, was far below the species of the genus *Eucalyptus* sp. Some bamboo species also presented specific mass low values, such as *D. asper* with 0.25 g cm^{-3} (Brito et al., 1983). Other bamboo species had upper specific mass values, 0.54 – 0.65 g cm^{-3} (Marafon et al. 2019). The 0.41 g cm^{-3} found in the charcoal of the species P. aurea was close to the charcoal specific mass found for the bamboo species Bambusa vulgaris Schr. and Dendrocalamus giganteus Wall. Ex. Munro, 0.42 g cm^{-3} (Brito et al., 1987).

The charcoal specific mass values followed the trend of the specific mass of bamboos *in natura.* The species *C. gracilis*, *M. multiramea* and *P. aurea* presented values that were consistent with that of the *Eucalyptus urophylla* ST Blake charcoal specific mass, 0.25 g cm^{-3} (Brito et al., 1987) and from 0.27 to 0.34 g cm^{-3} of *Eucalyptus* sp. hybrid clones (Castro et al., 2013). The *Eucalyptus pellita* F. Muell charcoal, submitted to different charring processes, ranged between 0.35 and 0.38 g cm^{-3} (Oliveira et al., 2010).

Regarding proximate analysis (Table 3), the species *C. mimosa* presented higher fixed carbon content, 236.8 g kg^{-1}. This value is close to that of the species *Dendrocalamus asper* (Schutz.) Back. ex. Hyne, 230.0 g kg^{-1} (Sette Junior et al., 2016). The charcoal fixed carbon values were close but below those reported for the Eucalyptus sp. and other bamboo species, from about 574.0 to 908.0 g kg^{-1}, the charcoal of the species *M. multiramea* presented the lowest fixed carbon content, 584.0 g kg^{-1}. The values (Table 3) were close to those found for the *Eucalyptus* genus, charred at 400 °C (Jesus et al. 2017).

Table 3 – Immediate analysis of bamboo species in natura and its charcoal

Species	Form	Fixed carbon	CV	Volatile material	CV	Ash	CV
M. multiramea	*in natura*	211,8	0,74	748,7	0,44	39,5	4,32
	charcoal	584,0	1,70	361,8	2,74	54,2	0,57
C. gracilis	*in natura*	195,9	0,36	776,4	0,60	27,6	0,91
	charcoal	621,4	2,20	314,3	4,27	64,3	1,12
P. aurea	*in natura*	193,4	2,81	801,7	1,07	4,9	9,92
	charcoal	641,2	1,61	346,4	3,16	12,4	9,65
C. mimosa	*in natura*	236,8	1,79	714,2	0,26	49,0	4,84
	charcoal	627,4	0,74	293,3	1,06	79,3	5,91

Bamboos *in natura* presented high content of volatile material. The species *P. aurea* showed the highest volatile material value, 801.7 g kg^{-1}, being close to the hybrid *Eucalyptus urograndis*, 822.0 g kg^{-1} (Sette junior et al., 2016). The values of volatile material content of the biomass *in natura* were close to those referenced (Sette Junior et al. 2016).

The volatile material content values of the charcoal of different bamboo species were similar to those presented in the literature, the charcoal of the species *C. mimosa* showed the lowest content of volatile material, 293.3 g kg^{-1}, value greatest than that found for the species *B. vulgaris* (Lestari et al. 2018).

Ash content is usually associated to the presence of minerals coming from the soil (Teixeira do Vale, 2011) and is also inversely related to the fixed carbon content. Regarding ash content, the species *P. aurea* was the only one observed to present a value below 10 g kg^{-1}, this value is usually found in energy woods and considered as reference for biomass with this purpose (Sette Junior et al., 2016; Simetti et al. 2018). The species *C. gracilis, in natura*, presented 27.6 g kg^{-1} and was close to values already reported for the bamboo species *B. vulgaris*, 25 g kg^{-1} (Sette Junior et al., 2016).

As regards charcoal, the species under study presented ash content above the value found in Eucalyptus sp. charcoal, except for the species *P. aurea* that presented low ash content, close to the *Eucalyptus pellita* charcoal (18.6 g kg^{-1}) (Oliveira et al., 2010). The highest charcoal ash content was found for the species *C. mimosa*, 79.3 g kg^{-1}, which is a high value, however, similar to those of other bamboo species (Lestari et al. 2018).

The upper calorific value of all species *in natura* (Table 4) was similar to the results found in the literature (Sette Junior et al., 2016).

Regarding the vegetable charcoal UCV values, the values found were below those already reported, both for bamboo and energy cultures (Lestari 2018). The highest values were found for the charcoal of the species *C. mimosa*, 25.55 MJ kg^{-1} and *P. aurea*, 25.05 MJ kg^{-1}. The species *M. multiramea*, 22.36 MJ kg^{-1}, was close to that of the bamboo species *B. multiplex*, 23.00 MJ kg^{-1} after charred at 280ºC (Bada et al., 2014).

As expected, species *in natura* with higher ash content presented lower biomass SCP (Brand, 2010 and Petroff and Doat, 1978). When the charcoal was investigated, this did not occur, the species *C. mimosa* presented high UCV value, when compared to ash content (Table 3).

Table 4 – Upper calorific value (UCV) of bamboo species in natura and its charcoal.

	In natura		Charcoal	
Species	UCV (MJ kg^{-1})	CV (%)	UCV (MJ kg^{-1})	CV (%)
M. multiramea	17.80	1.31	22.36	0.20
C. gracilis	18.07	1.10	20.96	3.35
P. aurea	18.91	1.33	25.05	1.19
C. mimosa	17.20	0.22	25.55	2.70

Considering immediate analysis and upper calorific value, the species *C. mimosa* presented energy potential to be used *in natura*.

As a complement for the energy potential analysis, fixed carbon, energy and charcoal gravimetric yields were determined (Table 5).

Table 5 – Gravimetric yield on charcoal (GYC) and yield on fixed carbon (YFC) and energetic (YE).

Species	GYC (g kg^{-1})	YFC (%)	YE (%)
M. multiramea	466.5	9.88	58;60
C. gracilis	403.4	7.90	46.81
P. aurea	387.7	7.50	51.35
C. mimosa	413.0	9.78	61.36

Yield and quality in charcoal production depend on the chemical constitution of the biomass, specific mass, calorific value and water content (Paludzysyn Filho, 2008). The charcoal gravimetric yield values (Table 5) were above those reported for bamboos, however, within the band 28-50% reported for the genus *Eucalyptus* sp. (Brito; et al., 1987 and Balduino Junior, 2016).

The fixed carbon yield presents directly proportional relation to the extractive contents and biomass specific mass (Oliveira et al., 2010). Thus, when associated to the specific mass content and lignin content, it results in a charcoal with higher gravimetric yield (Pastore et al., 1989), this can also be explained by the carbon content (Petroff and Doat, 1978).

The species *C. mimosa* presented values that are considered poor for the energy potential *in natura* such as high-water content, low specific mass and lower SCP than those of other species, however, after the thermal process that reduce water content and relative content of volatile materials, both SCP and thermal yields increased considerably, showing the energy potential of this species.

4 Conclusions

Based on the calorific value and ash content, it can be concluded that the *in natura* biomass of the species *P. aurea*, an exotic species, presented the highest thermal potential. Another advantage of this species is its low water content. In relation to charcoal, it had one of the highest fixed carbon contents, but one of the lowest gravimetric yields of charcoal. This biomass has the capacity to be used as an energy source when compared to commercial biomass. The values presented are close to some bamboo species and also for the genus *Eucalyptus* spp.

The *in natura* biomass of *C. mimosa*, a native species, was the one that presented one of the lowest calorific values, being compatible with a high water content. However, its charcoal was the one that presented one of the highest calorific values, although the *in natura* density and of the charcoal produced was one of the smallest.

The lowest calorific value of charcoal was for *C. gracilis*, a native species, which contains a high ash content. It also presented one of the lowest energy yields.

The native species *M. multiramea*, a native species, although with high gravimetric yield and high fixed carbon content, presented low calorific value for both natural biomass and charcoal.

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