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Balduino Junior, Ailton Leonel; Yurgen Balduino, Thalles; Friederichs, Gustavo; Bayestorff da Cunha, Alexsandro; Brand, Martha Andreia
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Energetic potential of bamboo culms for industrial and domestic use in Southern Brazil

Potencial energético de colmos de bambu para uso industrial e doméstico na região sul do Brasil

Ailton Leonel Balduino Junior[I] Thalles Yurgen Balduino[II] Gustavo Friederichs[II] Alexsandro Bayestorff da Cunha[III] Martha Andreia Brand[III*]

ABSTRACT

*This study aimed to determine the energetic quality of the **Bambusa vulgaris** culms for combustion (in natura) and as a charcoal. Five individuals (culms) of **Bambusa vulgaris** of 3 years of age were analyzed, gathered in the city of Florianópolis, Santa Catarina. In the in natura culms it was determined the moisture content freshly gathered (39%); basic density (0.624gcm^{-3}); the chemical composition (total extractive content (16.26%) and lignin content (25.76%)); the proximate chemical composition (volatiles content (82.25%); fixed carbon content (15.26%) and ash (2.49%)) and gross calorific value (4571kcalkg^{-1}). In the charcoal, produced in the laboratory, the determined properties were the gravimetric yield (36.40%);the apparent density (0.372gcm^{-3}); volatiles content (27.55%); fixed carbon content (67.32%); ash (5.12%) and gross calorific value (7431kcalkg^{-1}). The Bambusa vulgaris species has potential for use in the energy generation either in natura, as chips for burning in boilers or in the charcoal form for domestic use, it can be used to broaden the base of biomass for energy generation and to replace the timber species of Pinus and Eucalyptus gender used for this purpose in the Southern region of Brazil.*

Key words: ***Bambusa vulgaris***, *biomass energy, chips for boiler, charcoal.*

RESUMO

*Este trabalho teve como objetivo determinar a qualidade energética de colmos de **Bambusa vulgaris** para queima direta (in natura) e na forma de carvão vegetal. Foram analisados cinco indivíduos (colmos) de **Bambusa vulgaris** com 3 anos de idade, coletados na cidade de Florianópolis, Santa Catarina. Nos colmos in natura foram determinados o teor de umidade recém coletado (39%); massa especifica básica (0,624gcm^{-3}); a composição química (teor de extrativos totais (16,26%) e teor de lignina (25,76%)); a composição química imediata(teor de voláteis (82,25%); teor de carbono fixo (15,26%) e cinzas (2,49%)) e poder calorífico superior (4571kcalkg^{-1}). No carvão vegetal, produzido em laboratório, foram determinados o rendimento gravimétrico (36,40%); a densidade aparente (0,372gcm^{-3}); teor de voláteis (27,55%); teor de carbono fixo (67,32%); cinzas (5,12%) e poder calorífico superior (7431kcalkg^{-1}). A espécie Bambusa vulgaris tem potencial para utilização na geração de energia tanto na forma in natura, como cavacos para a queima em caldeiras,como na forma de carvão vegetal para uso doméstico, podendo ser utilizada para ampliar a base de biomassa para geração de energia e até substituir as espécies madeireiras do gênero Pinus e Eucalyptus utilizadas para este fim na região sul do Brasil.*

Palavras-chave: ***Bambusa vulgaris***, *energia de biomassa, cavacos para caldeira, carvão vegetal.*

INTRODUCTION

In 2011, it was established in Brazil the Law n. 12.484, which regulates the national policy to encourage sustainable management and the cultivation of Bamboo (PNMCB). This law aims the development of bamboo culture in Brazil through government actions and private enterprises. Among other actions, the federal government intends to work on the implementation of the incentive for research and technological development focused on sustainable management, cultivation, environmental services and applications of

[I]Programa de Pós-graduação em Engenharia Florestal, Centro de Ciências Agroveterinárias, Universidade do Estado de Santa Catarina (UDESC), Lages, SC, Brasil.
[II]Curso de graduação em Engenharia Florestal, Centro de Ciências Agroveterinárias, Universidade do Estado de Santa Catarina (UDESC), Lages, SC, Brasil.
[III]Departamento de Engenharia Florestal, Centro de Ciências Agroveterinárias, Universidade do Estado de Santa Catarina (UDESC), Av. Luiz de Camões, 2090, 88520-000, Lages, SC, Brasil. E-mail: martha.brand@udesc.br. *Corresponding author.

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the products and bamboo by-products; encourage the cultivation and the use of bamboo by family farming, stimulate the internal and external market of bamboo and its by-products (BRASIL, 2011).

In Brazil, the bamboo species are found in almost all regions, either at sea level as in the mountainous regions (PRESZNHUK, 2004). Beyond that, there is potential for planting native and exotic species of bamboo. Relative to the exotics, the species with the greatest potential are ***Dendrocalamus giganteus, D. Latiflorus*** e ***D. asper***, and the genders ***Phyllostachys*****e** ***Bambusa***. In the gender ***Bambusa,*** one of the species with greatest economic importance is the ***Bambusa vulgaris***, used in the production of bioenergy (charcoal) cellulose and paper (GRECO & CROMBERG, 2011; GUARNETTI, 2013), being in the list of the priority species of bamboo for research in the world (NATIONAL TROPICAL BOTANICAL GARDEN, 2014). Greater attention has been given to ***Bambusa vulgaris*** due to the high growth rate, the short renewal period under various conditions of soil and climate and the easy propagation (SUN et al., 2013).

The ***Bambusa vulgaris*** is originally from Asia and came to Brazil brought by the Portuguese, widespread in the country and used on farms for several purposes. According to GUARNETTI (2013), in the Northeast, the João Santos group has a production of 30 thousands hectares of ***Bambusa vulgaris*** for biomass use, and the Penha group explores 3 thousands hectares meant for energy purposes, where biomass is used in the form of chips, burned in boiler.

Bamboo species are potential candidates for bioenergy production, due to its high content of cellulose and hemicellulose, high gross calorific value and low ash content, constituting promising energy cultures for use in biorefineries, in Brazil (RAMBO et al., 2015).

However, in southern Brazil, the area of bamboo plantations bamboo are small, and in regions where there is nofrost, as the coastal region, the ***Bambusa vulgaris*** is a promising species, but it requires technical information to support investors who are interested in expanding the supply base of biomass for energy generation in this region.

Considering that in Southern Brazil, the biomass for energy generation is basically coming from species of ***Pinus*** and ***Eucalyptus*** gender and that besides the energy supply chain, these species may be present in other production chains (cellulose and paper and mechanical transformation), the inclusion of bamboo can be strategic in the segments of the energy use of biomass, as in the industry (use *in natura* as chips in boilers) and in domestic use as charcoal for cooking and heating (fireplace).

In this context, the determination of the energetic quality of this biomass is important to strengthen its use as a reliable energetic source in southern Brazil. Thus, this study aimed to determine the energetic quality of culms of ***Bambusa vulgaris*** for combustion (*in natura*) and as charcoal.

MATERIALS AND METHODS

Five individuals (culms) of ***Bambusa vulgaris*** of 3 years of age were analized, gathered in the Experimental Farm Ressacada of the Federal University of Santa Catarina, in Florianópolis (27º41'03.7"S 48º32'33.8"W). Each individual had the DBH and the total high measured (9.0cm and 18.0m, 10.5cm and 13.0m, 7.3cm and 12.0m, 10.5cm and 16.0m and 11.0cm and 16.5m DBH and total height, respectively), and portions of 1m of length were collected at the base, middle and top of the culms.

The energetic quality of the specie was analized *in natura* and after the charcoal production. Samples were made from the culms *in natura* to determine the basic density (BD), using the maximum moisture content method, according to the equation 1:

$$G_f = \frac{1}{\left(\frac{M_m - 0,346}{M_o}\right)}$$

where: M_m is the mass of water-saturated wood in grams after the removal of the surface water with a damp cloth, (gcm^{-3}); M_o is the oven dry weight, achieved by oven drying at 105°C±3°C until constant weight ($g\ cm^{-3}$); $1/G_s$=0.346, assuming that the average density of the wood substance is 1.53g cm^{-3}.

After obtaining samples, excess of material was ground in a hammer mill and from de sawdust a sample was gathered to determine the moisture content (MC). The remaining material was placed in a climatic chamber. For the energetic and chemical analyses of sawdust, the material used was the one which remained in the 60 mesh sieve. Physical, chemical and energetic analyzes of *in natura* material are in table 1, along with the used standards and the experimental design adopted in the study.

The same samples used for the determination of the basic density were wrapped in aluminium foil and charred in a laboratory muffle, without air intake. Carbonization was the total time of 6 hours and 30 minutes with a final temperature of 450ºC in the last 30 minutes, heating rate variable and descending along the carbonization.

Table 1 - Standards used to determine the physical and energetic properties in culms of ***Bambusa vulgaris***.

Analized propertie	Standard	N	NP	R	Total
Moisture Content	NBR 14929 (ABNT, 2003)	5	3	3	45
Basic density	Maximum Moisture Content method	5	3	10	150
Gross calorific value	DIN 51900 (DIN, 2000)	5	1	3	15
Proximate analysis	ASTM 1762 (ASTM, 2013)	5	1	3	15
Chemical analysis	NBR 7989 (ABNT, 2010)	5	1	4	20

N = number of individuals analyzed; NP = number of positions (3: base, middle and top; 1: for the mixing of the three positions); R = number of repetitions for each property analyzed in each position and individual.

After de carbonization, the apparent density of the charcoal was determined, through the volume and weight measurements of the specimens, and the gravimetric yield of carbonization by the reaction between the dry weight of charcoal and the absolutely dry weight of the specimen, before carbonization. The charcoal was ground and used for the determination of: moisture content, according to the standard NBR 14929 (ABNT, 2003), gross calorific value, according to the standard DIN 51900 (DIN, 2000) and the proximate analysis according to the standard ASTM 1762 (ASTM, 2013).

The F-test was applied to check the variation between the treatments and then the Tukey test at 5% of probability.

RESULTS AND DISCUSSION

The moisture content of the evaluated species is close to the desired maximum for the energy generation that is 30% (Table 2), constituting an advantage when using the culms for direct burning, with statistically significant differences between the evaluated individuals. For mature culms of this species, with more than three years, ROUSSET et al. (2011) reported values of 20.19% of humidity.

Timber species, such as the gender ***Eucalyptus*** and ***Pinus***, are commonly used for energy generation in the study area, in southern Brazil. These in turn, show high moisture content in freshly harvested material, compared to bamboo. BRAND (2013) analyzing the logs moisture content

Table 2 - Physical and chemical properties of culms *in natura* and charcoal of ***Bambusa vulgaris***.

Culms *in natura*	---Analized Individuals---					Mean
	1	2	3	4	5	
MC (%)	34 c	36 c	54 a	39 b	31 d	39
BD (gcm^{-3})	0.752 a	0.612 b	0.403 d	0.678 c	0.676 bc	0.624
TE (%)	16.52 a	16.22 a	15.46 a	16.37 a	16.71 a	16.26
L (%)	25.79 a	25.74 a	25.80 a	25.75 a	25.60 a	25.76
FC (%)	16.31 a	14.21 a	15.07 a	15.74 a	14.96 a	15.26
VC (%)	82.49 a	82.40 a	81.98 a	82.54 a	81.87 a	82.25
AC (%)	1.19 b	3.39 a	2.95 a	1.72 b	3.17 a	2.49
GCV ($kcalkg^{-1}$)	4585 b	4702 a	4599 ab	4452 c	4517 bc	4571
Charcoal	1	2	3	4	5	Mean
AD (gcm^{-3})	0.415 b	0.345 c	0.258 d	0.382 bc	0.463 a	0.372
GY (%)	34.38 d	36.49 bc	38.10 a	35.74 c	37.31 ab	36.40
VC (%)	27.31 b	26.68 b	30.72 a	27.33 b	25.73 b	27.55
FC (%)	68.63 a	67.52 a	62.99 b	68.48 a	69.01 a	67.32
AC (%)	4.06 c	5.81 a	6.30 a	4.19 cb	5.26 ab	5.12
GCV ($kcalkg^{-1}$)	7568 a	7340 ab	7207 b	7507 ab	7532 ab	7431

Note: Means IN LINE followed by the same letter do not differ statistically between them at 5% of probability by Tukey test.

Abbreviations: MC = wet basis moisture content; BD = basic density; TE = total extractives; L = lignin content; FC = fixed carbon content; VC = volatiles content; AC = ash content; GCV = gross calorific value; AD = apparent density; GY = gravimetric yield.

of ***Pinus taeda*** (loblolly pine) and ***Eucalyptus dunnii*** (white gum) meant to energy generation, harvested at different times of the year, observed values ranging from 55 to 65%, with an average of 59% for pine with bark and 50 to 58% with an average of 54% of humidity for eucalyptus logs with bark freshly harvested, in the South of Brazil.

The basic density mean of ***Bambusa vulgaris*** culms can be classified as medium and it was similar to the values obtained by other authors, including the statistical variation that occurred between individuals of the same species. For culms of approximately four years of age, MELO et al. (2015) obtained $0.630gcm^{-3}$. MOREIRA (2012) obtained average values of $0.646gcm^{-3}$, while BRITO et al. (1987) reported $0.687gcm^{-3}$, for the three years of age individuals. Compared to timber species used for energy generation, the density of ***Bambusa vulgaris*** is similar to those reported by PROTÁSIO et al. (2011) ranging from $0.471gcm^{-3}$ to $0.619gcm^{-3}$ for different species of ***Eucalyptus*** sp.

The extractive and lignin content were high, with no significant variation among the evaluated individuals. Values observed were compatible with other authors. Regarding to the extractives, BRITO et al. (1987) obtained 16.2% of total extractives. For the lignin content, RAMBO et al. (2015) obtained 17.60% and MACEDO et al. (2014) reported 25.8%, of total lignin, for the one year of age species; ROUSSET et al. (2011) obtained 26.65% of lignin, for culms with more than three years; and for the age of three years, MOREIRA (2012) reported 23.11% and BRITO et al. (1987) 17.5%.

Comparing the bamboo and wood chemical composition, the bamboo has higher extractives content, and lower lignin content. BASSA et al. (2007) obtained values of 2.37% and 2.50% for total extractives and 31.18% and 28.54% for lignin content for ***Pinus taeda*** and for the hybrid ***Eucalyptus grandis x E. uroplylla***, respectively.

The chemical composition characterized by larger amounts of extractives is positive for the energy generation, since these components have a higher calorific value compared to cellulose and polyoses, giving biomass a higher gross calorific value. However, lower lignin contents implies in a reduction of calorific value.

The volatile content was higher when compared to that observed by authors like MACEDO et al. (2014),which analyzed the volatile content of the species with one year of age and obtained 78.30%; RAMBO et al. (2015) obtained 81.08%, MOREIRA (2012) 78.14% and ROUSSET et al. (2011) 80.13%. Conversely, the fixed carbon values were lower when compared to that reported by other authors: 17.20% (RAMBO et al., 2015); 19.60% (MACEDO et. al., 2014); 17.67% (MOREIRA, 2012); 17.75% (ROUSSET et al., 2011). Both, volatiles and fixed carbon did not show a statistical variation between the individuals.

The ash content values obtained by ROUSSET et al. (2011) were 2.12% and RAMBO et al. (2015) obtained 1.71%. According to MOREIRA (2012), the ash content tends to rise with the increasing of the age due to the accumulation of siliceous bodies. There was statistical variation between the individuals analyzed, constituting two groups of similarity.

Considering the energy use, the wood showed material volatile content between 75 and 85%, and fixed carbon content between 15 to 25%. Therefore, the bamboo had higher ash content, and volatile content equivalent to that observed for different wood species and groups. Thus, the bamboo can be considered of rapid combustion, where most of its mass is burned in the form of gases and the smallest proportion in the solid form (residual carbon).

The gross calorific value of ***Bambusa vulgaris*** can be considered similar to that obtained by others authors: $4378kcalkg^{-1}$ (RAMBO et al., 2015); $4000kcal.kg^{-1}$ (GUANNETTI, 2013); $4370kcalkg^{-1}$ (MOREIRA, 2012) and $4216kcalkg^{-1}$ (BRITO et.al, 1987). QUIRINO et al. (2005) evaluating the calorific value of different timber species reported values between 3888 and $5263kcalkg^{-1}$, wherefore the bamboo is within the values observed for wood. There was statistical difference among the analyzed individuals.

The apparent density of the ***Bambusa vulgaris*** charcoal was highly variable among the analyzed individuals, showing from low to high values of density, 0.258 to $0.463gcm^{-3}$. According to BRITO et al. (1987), the value of the apparent density of ***Bambusa vulgaris*** charcoal was $0.418gcm^{-3}$. The highest basic density values, presented by bamboos, are highly favourable in terms of their use for charcoal production because they will result in denser coals, which is desirable in terms of quality of this product (BRITO et al., 1987).

The gravimetric yield (GY) was high, with a lot of variation between the individuals. XIONG et al. (2014) observed a yield around 31% for bamboo carbonization with a temperature of 450°C. MAIA et al. (2013), for the same temperature, producing charcoal with ***Phyllostachys aurea*** obtained GY of 34.3%. COSTA (2004) obtained 32.54%; however, the average maximum temperature used in the carbonization was 400°C. BRITO et al. (1987) obtained the average value of GY of 29.6%, with a final temperature of 550°C.

The volatile content for the charcoal was high, compared to those observed by MACEDO et al. (2014) when they examined the volatile content of the ***Bambusa vulgaris*** of one year of age, which was 21.30%. XIONG et al. (2014) reported 22%;MAIA et al. (2013) 36.5%; COSTA (2004) 16.00%; and BRITO et al. (1987) 16.75%. Only the third individual was statistically different from the others. High values of volatile content may be related to the carbonization ramp used, since the temperature, the carbonization rate and the time of the carbonization influence the quality of the charcoal obtained (COSTA, 2004).

The fixed carbon content was low for charcoal, compared to the literature values and showed a statistical difference just between the third individual and the others. MACEDO et al. (2014) obtained 78.30%; COSTA (2004) 78.00%, and BRITO et al. (1987) 86.30%. Only XIONG et al. (2014) and MAIA et al. (2013) reported lower values than those presented, 65% and 57.4%, respectively.

The average ash content was high, and with a lot of variation among the individuals, compared to the results of Maia et al. (2013) (2.7%); COSTA (2004) (3.28%); BRITO et al. (1987) (3.5%). Only XIONG et al. (2014) reported 13% of ash content.

ZANUNCIO et al. (2014) determined for charcoal of various species of ***Eucalyptus*** the values 19.33 to 26.93% of volatiles; 72.70 to 80.22% of fixed carbon, 0.21 to 1.88% of ashes, demonstrating that the quality of the charcoal obtained from ***Bambusa vulgaris,*** in the carbonization ramp adopted, was low regarding to the proximate chemical composition.

The gross calorific value of ***Bambusa vulgaris*** charcoal was high. The values obtained in the literature ranged from 7969kcalkg^{-1} (COSTA, 2004) to 7785kcalkg^{-1} (BRITO et al., 1987), being higher than those observed in this study.

CONCLUSION

The energetic quality of bamboo culms, either *in natura* or in charcoal form is similar to other species traditionally used for energetic generation in the study region.

The ***Bambusa vulgaris*** species has potential for use in the energy generation either *in natura* as chips, for burning in industrial boilers, or in the form of charcoal for domestic use. Besides that, the species can be used to increase the base of biomass for energy generation and even to replace the timber species used for this purpose in the study region.

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