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Potencial do bambu para fins energéticos

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Resumo

O bambu é uma matéria-prima renovável versátil e de rápido crescimento, com alta produtividade, baixo custo de manejo, alta capacidade de sequestrar carbono atmosférico e potencial para fins energéticos. O objetivo deste estudo é descrever o potencial do bambu para fins energéticos, por meio de diferentes alternativas de produtos. Foi realizado um estudo de revisão da literatura, para tabular dados relativos a diferentes alternativas energéticas para o bambu, considerando as seguintes perguntas de pesquisa (i) quais são produtos alternativos de bambu com potencial energético? (ii) quais os parâmetros tradicionalmente descritos em artigos científicos? Constatou-se o valor médio de 4.396, 6.994, 4.597 e 4.530 kcal.kg^{-1}, no poder calorífico superior (PCS) da biomassa, carvão vegetal, briquete e pellets de diferentes espécies de bambu, valores semelhantes ao verificado para a madeira do hibrido de *Eucalyptus grandis* x *Eucalyptus urophylla*. Os dados comprovam o potencial do bambu como fonte energética, podendo inclusive substituir espécies arbóreas tradicionalmente utilizadas.

Palavras-chave: Biomassa; Carvão vegetal; Briquete; Pellets; Poder calorífico superior.

Abstract

Bamboo is a versatile, rapidly growing renewable raw material with high productivity, low handling cost, high ability to sequester atmospheric carbon and potential for energy purposes. The paper aimed to describe the potential of bamboo for energy purposes through different product alternatives. A specific literature review was carried out to tabulate data related to different energy alternatives for bamboo, considering the following questions: (i) which are the alternative bamboo products with energy potential? (ii) what are the parameters traditionally described in scientific articles? The average value of 4,396, 6,994, 4,597 and 4,530 kcal.kg^{-1}, was found in the Gross Calorific Value (GCV) of biomass, charcoal, briquette and pellets of different bamboo species, values similar to those found for *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid wood. The data prove the potential of bamboo as a source of energy and may even replace tree species traditionally used.

Keywords: Biomass; Charcoal; Briquette; Pellets; Gross calorific value.

Resumen

El bambú es una materia prima renovable versátil y de rápido crecimiento con alta productividad, bajo costo de manipulación, alta capacidad de secuestrar carbono atmosférico y potencial para fines energéticos. El objetivo de este estudio es describir el potencial del bambú con fines energéticos a través de diferentes alternativas de productos. Se realizó un estudio de revisión de la literatura para tabular datos relacionados con diferentes alternativas de energía para el bambú, considerando las siguientes preguntas de investigación (i) ¿qué son los productos de bambú alternativos con potencial energético? (ii) ¿cuáles son los parámetros tradicionalmente descritos en artículos científicos? El valor promedio de 4.396, 6.994, 4.597 y 4.530 kcal.kg^{-1} se encontró en el mayor valor calorífico (MVC) de biomasa, carbón, briquetas y pellets de diferentes especies de bambú y híbrido *Eucalyptus grandis* x *Eucalyptus urophylla*. Los datos muestran el potencial del bambú como fuente de energía e incluso pueden reemplazar las especies arbóreas utilizadas tradicionalmente.

Palabras clave: Biomasa; Carbón vegetal; Briquetas; Pellets; Poder calorífico superior.

1. Introduction

The growing demand for energy in the world, especially sustainable, encourages the uses of renewable products instead of non-renewable ones. One option that stands out is bamboo, a fast-growing, high-yielding renewable material with low handling costs and a carbon sequestering capability (Sun et al., 2013; Hernández-Mena, Pécoraa, & Beraldo, 2014).

In Brazil, there are 232 native species where 134 are endemic, and other 20 were introduced. The total area covered by bamboo in the world is approximately 36 million hectares, 9.3 million are in Brazil (the largest area), followed by China and India, with 5,712,000 and 5,476,000 ha, respectively (Chaowana, 2013; FAO, 2010).

The native bamboo occurred in forests of the Brazil, particularly, for millions hectares of the specie Guadua spp. dominant, or in the understory, in the South-Western Amazon, especially in the states of Acre and Amazonas (Drumond & Wiedman, 2017). The commercial plantations cover 30 thousand hectares of *Bambusa vulgaris* in the Northeast, mainly in Maranhão, Paraíba, Pernambuco and Bahia (Guarnetti & Coelho, 2014). These regions have the potential to consolidate a productive chain for energy purposes.

Bamboo is grass specie but has a set of characteristics that make it an alternative raw material to traditional woody materials, such as pine and eucalyptus planted forests. It is able to meet the emerging demands of various industry sectors, due to its high biomass production per hectare/year, easy handling in harvesting and cutting, it is an perennial specie, has excellent edaphoclimatic adaptation to most Brazilian conditions and provide comparable calorific value to species commonly used for energy purposes.

In Brazil, it is estimated that half of the woody biomass harvested is destined for energy purposes (Hernández-Mena, Pécoraa, & Beraldo, 2014) being the world's largest producer and consumer of charcoal, mainly used for the production of steel, pig iron and ferroalloys. However, it was because of a combination of stricter environmental regulation and increased enforcement that most of this production source from planted forests, especially eucalyptus (Yazdani, Hamizan, & Shukur, 2012; Nisgoski et al., 2014).

The gravimetric yield in coal is directly influenced by the process temperature, the higher final temperatures result in reduced charcoal yield due to greater volatilization of organic matter (Vieira et al., 2013; Jesus et al., 2017). Thus, intense thermal degradation is not recommended to avoid compromising charcoal production.

The briquetting process optimizes combustion and favors efficient energy production by compressing biomass into a uniform, processed fuel that be burned can as an energy source (Antwi-Boasiako & Acheampong, 2016).

In Brazil, the production of briquettes and pellets is still small scale. One aspect that has stimulated the increase in the production of this product is related to the prohibition from 2014 on the disposal of untreated industrial co-products, as defined in the National Solid Waste Policy

(Brasil, 2010). This legislation encourages the use of secondary products from logging activities, through their mechanical compaction aiming at their use for energy purposes, and their direct disposal in landfills is not allowed.

Density is an important physical property when evaluating a material for energy purposes because interferes with the question of transportation and dimensioning of energy conversion machines and equipment.

On the other hand, the concept of density depends on how it is measured and, in the case of wood and bamboo, on the moisture content. Therefore, for standardization purposes, the terms used in this study were basic density, apparent density and bulk density. Basic density refers to the ratio of the material dry mass to its volume saturated in water (Brandt et. al., 2019). Apparent density refers to the ratio of the material mass to its volume at determined moisture content (in general 12%) and bulk density refers to the mass of granulated or ground material that occupy the a container (Eisenbies et. al., 2019).

Comparatively, the average annual increment (AAI) in biomass was 20, 54 and 35 tons.ha^{-1}.year^{-1} for Eucalyptus (traditional cycle), Eucalyptus (short cycle) and Bamboo (Escobar & Coelho (2014). However, it is necessary to focus not only on the context of the available raw material, but as a priority, on the results achieved with the innovation and technological training developed for different uses.

This study seeks to disseminate the potential of bamboo for energy purposes. For this, the following questions were considered: What are the alternative bamboo products with energy potential and the parameters traditionally described in scientific papers? The methodology used for this literature review research considered the databases of the Portal de Periódicos da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), considering the period between 2013 and 2019. For the survey of scientific papers, searches were performed considering the use of double terms, always using the term “bamboo” and another related to the energy context, such as: “energetic”, “fuel”, “biomass”, “coal”, “briquette” and “pellets”.

Considering Pereira et al. (2018), this research used the quantitative method, from the data collection with their respective units, generating a set of tables, which allowed analysis through mathematical techniques such as the case of average values, total sums, percentages and in generation of applicable mathematical equations and/or formulas.

In view of the demand for new sources of biomass and the suitability for energy use, this literature review paper aimed to describe the potential of bamboo for energy purposes.

2. Alternative Energy Uses For Bamboo

The initial study, to generate tables, considering different energy alternatives for bamboo covered 175 scientific papers, but this research used a final bibliography of nine papers were used for data compilation. These selected papers are from the following journals: Agricultural Research in the Tropics; BioResources; Bioscience Journal; Chemical Engineering Transactions; Ciência Rural; International Journal of Current Research; Renewable Energy and Scientia Forestalis that presented coherent content or data relevant to the purpose of this research. The list of scientific articles selected for this study were listed in Table 1, composed by the title, objective, authors and year of publication:

Table 1. List of analyzed papers.

Title of papers	Objective	Source
Energetic potential of bamboo culms for industrial and domestic use in Southern Brazil	Determine the energy quality of *Bambusa vulgaris* stalks for combustion (*in natura*) and as charcoal	1
Potential of bamboo species for the production of briquettes	To evaluate the potential use of four bamboo species in briquettes production	2
Evaluation of briquettes from bamboo species produced under different temperatures	To evaluate the quality of briquettes produced from bamboo species biomass under different temperature conditions	3
Slow pyrolysis of bamboo biomass: analysis of biochar properties	Determine biochar yield in slow pyrolysis of *D. giganteus* Munro bamboo as a function of final reactor temperature	4
Bamboo-Derived Fuel from *Dendrocalamus latiflorus*, *Phyllostachys makinoi*, and *Phyllostachys pubescens* Waste	Fuel production from bamboo waste and the addition of engine oil	5
Improved bulk density of bamboo pellets as biomass for energy production	To investigate the effect of mixing bamboo and pine particles on pellet properties	6
Bamboo species potential as an energy source	To evaluate the biomass and charcoal energetic characteristics of bamboo species	7
Production and characterization of bamboo pellets	To evaluate the potential use of bamboo species biomass in pellet production	8
Characterization of biomass, charcoal, and briquette of *Phyllostachys aurea* Carr. ex A. & C	Perform the energetic and physical-mechanical characterization of *Phyllostachys aurea* biomass, coal and briquettes	9

Source: [1] Balduino Junior et al. (2016); [2] Brand et al. (2019); [3] Freitas et al. (2016); [4] Hernández-Mena et al. (2014); [5] Lin et al. (2016); [6] Liu et al. (2016); [7] Santos et al. (2016); [8] Sette Jr et al. (2016) and [9] Sette Jr et al. (2017).

It is important to note in Table 1 that papers from the most current research were used. These studies describe the characteristics of the biomass originating from bamboo plantations, as well as the characteristics and properties of the products that can be obtained from this biomass.

From this scientific papers, were tabulated data and information about the energy use of bamboo, both in relation to biomass and in processed products such as briquettes, pellets and charcoal. In Table 2, are shown the chemical composition, basic density and Gross Calorific Value (GCV) of the biomass of different bamboo species and of the *Eucalyptus* sp. wood.

Table 2. Chemical composition, basic density and Gross Calorific Value of the biomass of different bamboo species and the *Eucalyptus* sp. wood.

Species	BaD	LC	EC	VC	AC	FC	GCV	Source
Bambusa tuldoides	0,421	---	---	75.2	3.0	21.8	4,515	4
Bambusa vulgaris	0,624	25.76	16.26	82.25	2.49	15.26	4,571	1
Bambusa vulgaris *	0,462	---	---	74.7	2.5	22.8	4,663	4
Dendrocalamus asper	0,604	---	---	75.0	2.1	23.0	4,526	4
Dendrocalamus giganteus	---	26.25	4.90	70.31	2.57	17.75	4,116	2
Dendrocalamus latiflorus	---	26.19	2.93	---	2.96	---	4,139	3
Phyllostachys makinoi	---	28.78	1.69	---	1.75	---	4,285	3
Phyllostachys pubescens	---	28.80	4.30	---	1.73	---	4,356	3
Bamboo average	0,527	27.16	6.02	75.49	2.39	20.12	4,396	-
Eucalyptus grandis x *urophylla* hibrid	0,482	27.5-30.2	2.1-2.5	82.2	0.3	17.5	4,658	4,5

BaD = Basic density ($g.cm^{-3}$); LC = Lignin content (%); EC = Extractive content (%); VC = Volatile content (%); AC = Ash content (%); FC = Fixed carbon content (%); GCV = Gross calorific value ($kcal.Kg^{-1}$). *Var. Vittata.
Source: [1] Balduino Junior et al. (2016); [2] Hernández-Mena et al. (2014); [3] Lin et al. (2016); [4] Santos et al. (2016); [5] Zanuncio et al. (2013).

In Table 2, it can be seen that the mean gross calorific value of the different bamboo species is lower than that of the reference eucalyptus. On the other hand, the average basic density of bamboo is higher. With regard to chemical properties, a higher content of extractives and ash is a negative factor for many uses as an energy material, but a lower content of volatiles and a higher fixed carbon content may be an advantage.

The production of bamboo biomass in two cutting cycles of three years each, can reach 180 tons per hectare and consider 30 $tons.ha^{-1}.year^{-1}$ of IMA (Hernández-Mena et al., 2014). This biomass (in natura) has a lower content of volatiles and higher content of extractives, ash and fixed carbon than was registered in the wood of *Eucalyptus grandis x urophylla* hybrid. Another relevant aspect is that 3,313 GJ per hectare of energy can be used in the period of six years, using the estimate of production (180 tons) and the average value of 4,396 kcal.kg^{-1} relative to the GCV of different bamboo species (Table 2). In addition, considering a basic density of 0,482 g.cm^{-3} and GCV of 4,658 kcal.kg^{-1} of the *Eucalyptus grandis x urophylla* hybrid (Santos et al., 2016), it would be necessary to produce 352.4 m^3 per hectare of this wood to obtain the same amount of energy, in the same period.

In Table 3, are compared the characteristics of the bamboo charcoal of different carbonization studies with the characteristics of the charcoal of *Eucalyptus grandis x urophylla* hybrid.

Table 3. Characteristics of the charcoal of different bamboo species and of the charcoal of *Eucalyptus grandis x urophylla* hybrid.

Species	T	BaD	GY	VC	AC	FC	GCV	Source
Bambusa tuldoides	550	0.32	34.1	21.7	6.1	72.3	6,752	3
Bambusa vulgaris	450	0.37	36.4	27.5	5.1	67.3	7,431	1
Bambusa vulgaris *	550	0.34	34.7	23.6	3.0	73.4	6,777	3
Dendrocalamus asper	550	0.48	36.9	26.5	1.9	71.5	6,640	3
Dendrocalamus giganteus	500	---	---	8.10	3.9	81.5	7,372	2
Bamboo average	520	0.38	35.5	21.5	4.0	73.2	6,994	-
Eucalyptus grandis x urophylla hybrid	550	0.36	30.8	29.1	0.4	70.4	6,670	3

T = Temperature (°C); BaD = Basic density (g.cm^{-3}); GY = Gravimetric yield (%); VC = Volatile content (%); AC = Ash content (%); FC = Fixed carbon content (%); GCV = Gross Calorific Value (kcal.Kg^{-1}). *Var. Vittata.
Source: [1] Balduino Junior et al. (2016); [2] Hernández-Mena et al. (2014); [3] Santos et al. (2016).

According to Table 3, the gravimetric yield in charcoal and the average GCV for bamboo species was higher than that of eucalyptus wood, at similar temperatures of carbonization. Bamboo also has a higher content of fixed carbon, but less of volatiles, and this makes it possible to obtain a denser coal, however with a high ash content after burning. Considering the estimated productivity of 180 ton.ha^{-1} of bamboo biomass in the period of six years, in addition to the average yield of 35.5%, we would have 63.9 tons of bamboo charcoal, per hectare in the same period. Using the average GCV of bamboo charcoal, 6,994 kcal.kg^{-1}, we would have 1.87 GJ per hectare in these cycles.

When using the average values of 0,482 $g.cm^{-3}$ of the eucalyptus wood basic density (Table 2), and 30.8% of the gravimetric yield and 6,670 $kcal.kg^{-1}$ of GCV of the charcoal this wood (Santos et al., 2016), it will be necessary to produce 451.3 m^3 per hectare of this wood, over a 6-year period, to obtain the same amount of energy.

In Table 4 are shown the average levels of volatiles, ashes, fixed carbon and gross calorific values, as well as the apparent density, verified in briquette of different bamboo species and in the wood briquette of the *Eucalyptus grandis x urophylla* hybrid.

Table 4. Composition of the briquettes of different bamboo species and of the wood briquettes of the *Eucalyptus grandis x urophylla* hybrid.

Species	BD	VC	FC	AC	GCV	Source
Bambusa tuldoides	1.13	-	-	-	4,515	2
Bambusa vulgaris	1.11	82.2	15.3	2.5	4,571	1
Bambusa vulgaris	1.14	-	-	-	4,663	2
Dendrocalamus asper	1.20	-	-	-	4,526	2
Phyllostachys bambusoides	1.17	81.9	17.3	0.9	4,694	1
Phyllostachys edulis	1.22	80.6	19.0	0.4	4,670	1
Phyllostachys nigra	1.24	79.0	20.2	0.8	4,716	1
Phyllostachys aurea	1.16	81.5	17.6	0.9	4,424	3
Bamboo average	1.17	81.0	17.9	1.1	4,597	-
Eucalyptus grandis x urophylla hybrid	1.15	-	-	-	4,657	2

BD = Bulk density ($g.cm^{-3}$) of briquetes; VC = Volatile content (%); FC = Fixed carbon content (%); AC = Ash content (%); GCV = Gross Calorific Value ($kcal.Kg^{-1}$).
Source: [1] Brand et al. (2019); [2] Freitas et al. (2016); [3] Sette Júnior et al. (2017).

Bamboo waste can be used in the briquette and pellet production process. Regarding the parameters of the briquettes (Table 4), the raw material of different species of bamboo and wood of the *Eucalyptus grandis x urophylla* hybrid, allowed a similar numerical value in relation to apparent density and gross calorific value.

Considering the productivity of 180 tons of bamboo biomass in the interval of six years and the briquette average GCV of 4,597 $kcal.Kg^{-1}$ (Table 4), 3.46 GJ per hectare of energy would be obtained in this period. With density of 0,482 $g.cm^{-3}$ and the GCV of 4,657 $kcal.kg^{-1}$ of the eucalyptus briquette (Freitas et al., 2016), it would be necessary to produce 368,6 m^3 per hectare of this wood, to obtain the same amount of energy in the same period of time.

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Table 5 describes the percentages of moisture content, diameter, length, bulk density, ash content and the gross calorific value of pellets of different bamboo species and wood of the *Eucalyptus* sp.

Table 5. Main parameters in the production of bamboo and wood pellets from *Eucalyptus* sp.

Species	MC	D	L	BD	AC	GCV	Source
Bambusa tuldoides	7.7	6.1	28.4	0.65	3.0	4,515	2
Bambusa vulgaris	7.5	6.1	29.8	0.61	2.5	4,663	2
Dendrocalamus asper	8.2	6.0	28.9	0.60	2.1	4,526	2
Phyllostachys heterocycla	6.1	6.0	13.9	0.54	1.6	4,417	1
Bamboo average	7.4	6.05	25.6	0.60	2.3	4,530	-
Eucalyptus grandis x urophylla hybrid	7.9	6.2	28.0	0.67	0.3	4,658	2

MC = Moisture contente (%); D = Diameter (mm); L = Length (mm); BD = Bulk density (ton.m^{-3}); AC = Ash content (%); GCV = Gross Calorific Value (kcal.Kg^{-1}).
Source: [1] Liu et al. (2016); [2] Sette Júnior et al. (2016).

For the parameters of the pellets (Table 5), the raw material of different species of bamboo provide a similar values of moisture content, diameter, bulk density and gross calorific value that eucalyptus wood, however, the ash content it is superior. The pellets presented shorter length in bamboo, which may be due to the matrix used.

For the same period of time (six years) and productivity of bamboo biomass, with the average GCV of 4,530 kcal.Kg^{-1} (Table 5), 3.41 GJ per hectare of energy would be obtained. For eucalyptus pellets, with GCV of 4,658 kcal.kg^{-1} (Sette Júnior et al., 2016), it would be necessary to produce 363.2 m^3 per hectare of this wood, to obtain the same amount of energy in the same period of time.

In view of this, when comparing the need for biomass of different bamboo species and eucalyptus hybrids for the production of the same volume of energy, it can be concluded that requiring production of 352.4; 451.3, 368.6 and 363.2 m^3 per hectare, for fresh biomass, charcoal, briquette and pellet, over a 6-year period.

Bamboo is a renewable material that has satisfactory calorific value, when compared to the species most used for energy purposes, its biomass can be used both in raw form (in natura) and for the production of charcoal, it also allows the use of its waste in the briquette and pellet production process. Another relevant aspect is related to the reduction of environmental impacts in native forest areas, due to its high capacity for biomass production, thus retaining carbon from the atmosphere, being characterized as a renewable energy source.

3. Final Considerations

Bamboo presents as a viable material alternative for energy use, both through natural biomass and in the production of briquettes, pellets and charcoal.

Biomass of that material has a lower content of volatiles and higher extractives and fixed carbon than in the wood of the eucalyptus hybrid, however it shows a higher ash content and less gross calorific value.

In carbonization, under similar conditions, the yield in bamboo charcoal was higher, compared to that verified for the wood. There were found similarity between the moisture content, width, length, bulk density and gross calorific value of the wood pellets and different bamboo species.

The gross calorific value verified in briquettes, pellets and bamboo charcoal is similar to that produced with forest species wood currently used for these energetic purposes, such as the eucalyptus hybrid.

In the energy use of bamboo, the main barrier found is of an economic nature, as the technologies used are still in the development process, with high implementation costs. This is the context related to the use of bamboo biomass for energy purposes, as until now, the existence of scientific studies that address barriers to the implementation of this system has not been verified.

Recommend to develop new experiments comparing the energy production of biomass, coal, briquettes and pellets of different bamboo species, with wood species traditionally used for these energy purposes.

Conflict of interests

There is no conflict of interest between authors.

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