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Management of Brazilian hardwood species (Jatoba and Garapa) wood waste biomass utilization for energy production purposes

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Abstract. In the Federative Republic of Brazil, Jatoba (*Hymenaea courbaril*) and Garapa (*Apuleia leiocarpa*) trees are intensively harvested. The yield of one log is approximately 45–55%, which indicates a great amount of produced wood waste biomass.Present research monitored the suitability of wood waste biomass from Jatoba and Garapa trees for bio–briquette for solid biofuel production. The research was focused on chemical parameters,and energy potential of such biomass kinds. Jatoba wood waste biomass was used for the production of bio–briquette fuel and its final mechanical quality was investigated by determination of their mechanical quality indicators. Results of chemical analysis (in wet basis) exhibited great level of ash content in case of both species (Jatoba – 0.31%, Garapa – 3.02%), as well as high level of energy potential; net calorific value equal to 18.92 MJ kg^{-1} for Jatoba and to 18.395 MJ kg^{-1} for Garapa. Analysis of elementary composition proved following levels of oxygen content: Jatoba – 41.10%, Garapa – 39.97%. Mechanical analysis proved bio–briquette samples volume density ρ equal to 896.34 kg m^{-3} which indicated quality bio–briquette fuel, while the level of rupture force RF occurred at a lower level – 47.05 N mm^{-1}. Most important quality indicator, the mechanical durability DU, unfortunately, occurred at a lower level; DU = 77.6% compared to the minimal level of bio–briquette fuels intended for commercial sales which must be > 90%. Overall analysis proved materials suitability for energy generation purpose with certain limitations which can improve by changing production parameters of briquetting.

Key words: Briquetting, direct combustion, renewable energy, waste management.

INTRODUCTION

Management is the process of reaching organizational goals and by hardwood species management we mean inte gration and coordination of series of actions towards the achievement of a specific objective. It follows value chain wood waste generated by wood processing industry.

Wood processing is a downstream activity of the forestry because it adds economic value to logs, diversifies the products and increases the incomes (Israel & Bunao, 2017).

All products and services have environmental impacts, from the extraction of raw materials to the production or manufacture, distribution, use, and disposal. However, wood is a renewable resource used in wood industry and for energy production (Jungmeier et al., 2002; Kim & Song, 2014). Wood waste is produced by a number of sectors as part of the municipal waste stream. The value chain of wood involves cutting logs, sawn into the timber and transported to manufacturers who transform and obtain outputs that generate wood waste (Kaplinsky, Memedovic, Morris, & Readman, 2003).

In the late 19th century, worldwide trade in wood furniture grew by 36%, faster than merchandise trade as a whole (26.5%), apparel and footwear (32%). Solid wood furniture represents one of the rawest materials for manufacturing high-end designed products (Kaplinsky et al., 2003). Wood waste from furniture, construction arises in different forms ranging from untreated, off-cuts, to treated wood containing preservatives and via a variety of post-consumer waste which can be used for feedstock or combustion (Owoyemi et al., 2016; Huron et al., 2017). The over-extraction of wood resources, linked with clearing for agricultural purposes and indiscriminate burning creates disorder which aggravates the wellbeing of the forests. In Brazil, many highly valued timber species occur at extremely low densities yet are intensively harvested with little regard for impacts on population structures and dynamics of forest (Schulze et al., 2008). For instance, Jatoba and Garapa wood are used for flooring, furniture, cabinetry, tool handles, boat building and other special items (Meier, 2015). The production, exploitation, and processing of wood represent one of the main pillars of Amazon economy. There are more than 71 zones of wood extraction which extracts about 14.2 million cubic meters of logs per year which generate 5.8 million cubic meters of lumber with about 59% of wood waste materials (Marchesan, 2012). The yield of one log of Jatoba, for instance, is approximately 45–55%, the remains fall into the category of by-products such as dust, sawdust, chips, barks, rags, trimmings, and tips.

The importance of wood waste management is the worldwide spread of techniques focused on the reduction and re-utilization of these waste materials as regards the policies of each country (Jungmeier et al., 2002; European Commission, 2010; Bittencourt et al., 2015). Considering the need to reduce carbon emission, wood waste resources provide an alternative energy that helps to reduce the emission from landfill (Röder & Thornley, 2017). The utilization of most common products of wood waste for recycling and energy production using biomass has been highlighted in the field of energy and sustainability mainly for environmental conservation (Altafini et al., 2003; Daian & Ozarska, 2009a; Raud et al., 2014). Studies of awareness on wood waste utility, economic benefits, and energy consumption are summarised in Table 1.

One of the factors affecting the utilization of wood waste is the dependency on fossil fuel as a source of energy production. At a time when fossil fuels were much cheaper than wood, wood wastes were destroyed by burning (Top, 2015). The amount of carbon dioxide released into the atmosphere during burning or decomposition of wood is the same as that which a tree absolves during growth. In developing countries about 70% of energy is supplied from fossil fuels and the remaining 30% is from renewable sources. Environment impacts due to fossil fuel use include global warming, air quality deterioration, oil spills and acid rain (Ming et al., 2014; Patel, 2014). However, the use of wood pellets and briquettes from wood waste contributes less to air pollution than fossil fuel (Giuntoli et al., 2013; Kim & Song, 2014; Singh et al., 2016). Wood waste is considered a potential alternative for energy production. It does not compete with food and feed production with no direct impact on soil. Contrarily, it contributes to generating energy security for the local population in the places where wood waste originates from (Bergeron, 2016).

Classification of wood waste biomass varies from country to country. In European Union legislation, waste management option is ranked in order of environmental preference with the first priority being the reduction or avoidance of waste and the recovering of energy (Knauf, 2015; van Dam, 2013). However, the classification obeys three categories: *Clean untreated* wood (an e.g. pallet, wooden boxes, scraps lumber and, plywood) which can sometimes contain nails, bolts or screws (Fig. 1, c, d)*; slightly treated wood waste* (wood painted or coated) and *heavily treated* (impregnated wood waste).

Clean untreated wood waste biomass is widely used for commercial production of bio–briquette fuel due to its suitable chemical and mechanical parameters. The technology of high–pressure briquetting operates without using any external binders, thus, ensures a high level of bio–briquette final quality (Emerhi, 2011). Differences within energy potentials and level of suitability of specific wood types can be found between deciduous and coniferous trees, trees from tropical and temperate zones and even different parts of the trees (trunk, branch, bark).

In consequence, the aim of present paper is to state the potential of Jatoba and Garapa wood waste biomass for energy generation in the form of bio–briquette fuel. The aim was supported by chemical analysis of the wood waste biomass kinds (which contained of testing of basic chemical parameters and elementary composition of investigated samples) and subsequent mechanical analysis of bio–briquette samples produced from such materials (which contained of testing of mechanical quality indicators of investigated bio–briquette samples).

Figure 1. Different forms of wood waste biomass: a) pile of sawdust; b) wooden offcuts or scraps from lumber; c) wood chips; d) old pallets.

Table 1. Examples of studies on wood waste management: main features

Authors (year)	Country	Category	Methodology	Area of impact
Huron et al. (2017)	FRA	Treated wood waste	Lab analysis	Environmental awareness
Bergeron (2016)	CHE	Climate change	Review plus modeling	Wood waste utility
Tatàno et al. (2009)	ITA	Waste management	Lab analysis	Energy content
Kim & Sang (2014)	PRK	Climate change	LCA according to ISO 14040	Environmental awareness
Massote et al. (2013)	BRA	Waste management	CP methodology by UNEP	Wood waste utility
Hiramatsu et al. (2002)	JPN	Waste management	Lab analysis	Wood waste utility
Moreno & Font (2015)	ESP	Untreated waste management	Lab analysis	Wood waste utility
Joshi et al. (2015)	USA	Waste management	Questionnaire survey	Wood waste utility
Top (2015)	TUR	Waste management	Questionnaire survey	Economic awareness
Knauf (2015)	DEU	Energy policy	A review of LCA methodology	Environmental awareness
Röder et al. (2014)	UK	Waste management	LCA according to ISO 14040	Environmental awareness
Warnken (2008)	AUS	Waste management	LCA methodology	Environmental awareness
Daian & Ozarska, (2009b)	AUS	Waste management	Questionnaire survey	Economic awareness

FR – France; NGA – Nigeria; CHE – Switzerland; ITA – Italy; PRK – Republic of Korea; BRA – Brazil; JPN – Japan; ESP – Spain; USA – United States of America; TUR – Turkey; DEU – Germany; UK – United Kingdom; AUS – Australia.

MATERIALS AND METHODS

The present chapter is divided into three subchapters sorted chronologically in accordance with the experimental measurements process. Nevertheless, the whole process of biomass definition investigated materials selection; preparation and subsequent testing performed according to international technical standards requirements. Specifically, we used following technical standards requirements: EN 14918 (2010), ISO 1928 (2010), EN 15234–1 (2011), EN 643 (2014), EN ISO 16559 (2014), EN ISO 17225–1 (2015), EN ISO 17831–2 (2015), EN ISO 18122 (2015), EN ISO 18134–2 (2015), EN ISO 16948 (2016) and EN ISO 18123 (2016).

Investigated samples

The samples used for this paper originated from Brazil in form of rough sawn lumber, kiln dried (KD) at 10–12%, fumigated and then processed in the Czech Republic into profiles for furniture industries. The samples investigated came from trees harvested in 2015 and processed in 2017. The callected waste samples are produced during the cutting of boards in the form of fine dust, during drilling and milling operations for production of outdor furnitures.

Generated biomass was primarily processed in the effort to meet the requirements for bio–briquette production; such preparation mainly contained from drying (suitable moisture content < 10%) and milling and grinding (suitable particle size < 10 mm). Investigated samples in prepared suitable form are expressed in Fig. 2.

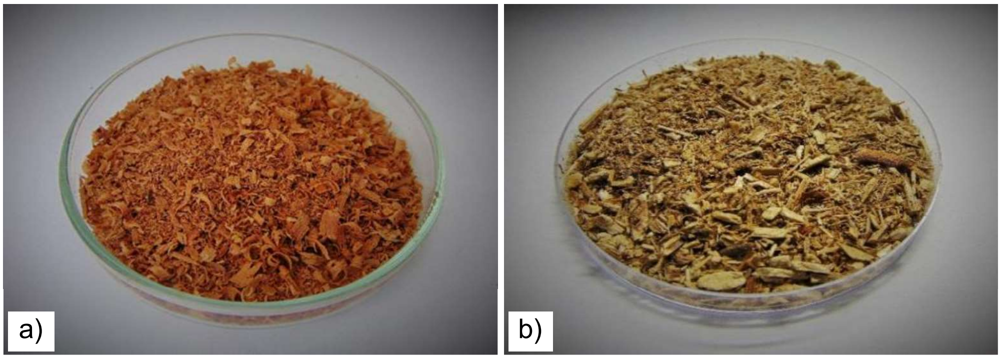

Figure 2. Investigated wood waste biomass samples prepared for testing: a) Jatoba; b) Garapa.

Chemical quality indicators

Experimental measurements performed within the chemical analysis stated the safety and suitability of investigated wood waste biomass for direct combustion (energy generation). Following laboratory testing was performed. The measurements were repeated; at least three reliable results were acquired for every sample with respect to the reliability of obtained results and to the behavior of the sample during testing.

Moisture and ash content

Determination of investigated samples moisture content M_c (%) was performed according to the mandatory technical standard EN 18134–2 (2015) by using of thermo-gravimetric analyser LECO, type TGA 701 (Saint Joseph, United States). Ash content A_c (%), was determinate using the same equipment in accordance to the mandatory technical standard EN ISO 18122 (2015). Primarily, the samples were dried at 107 °C and further, the samples were burned at 550 °C until their constant weight.

Elementary composition

The content of Carbon C (%), Hydrogen H (%), Nitrogen N (%), Sulphur S (%) and Oxygen O (%) was determined by using of laboratory instrument LECO, type CHN628+S (Saint Joseph, United States) which used helium as carrier gas. The process of testing is completely defined by the mandatory technical standard EN ISO 16948 (2016). Investigated samples were burned in Oxygen while produced flue gases were analyzed.

Calorific values

The results values of gross calorific value GCV (MJ kg^{-1}) were obtained during experimental measurement described in mandatory technical standard EN 14918 (2010) by using of isoperibol calorimeter LECO, type AC 600 (Saint Joseph, United States). However, the results of net calorific value NCV (MJ kg^{-1}) were calculated according to the mandatory technical standard ISO 1928 (2010).

Mechanical quality indicators

Set of experimental practical tests was used for determination of the final mechanical quality of produced bio–briquette samples. Together, the result values of following tests describe the efficiency of such densification process, thus, the suitability of investigated materials for bio–briquette production and appropriateness of such bio–briquette samples for commercial sale.

Volume density

The dimensions of produced bio –briquette samples were used for the statement of their volume density ρ (kg m^{-3}). Following formula (1) was used for its calculation:

$$\rho = \frac{m}{V} \quad (1)$$

where ρ – volume density (kg m^{-3}); m – bio–briquette samples mass (kg); V – bio–briquette samples volume (m^3).

Mechanical durability

Mechanical durability DU (%), the most important indicator of bio–briquette samples mechanical quality, as stated by the mandatory technical standard EN ISO 17831–2 (2015). A dustproof rotating drum (Fig. 3) was used for experimental part of the testing; the bio–briquette samples was primarily weighted and then placed into the drum and then subjected to the controlled impacts due to the drum rotation.

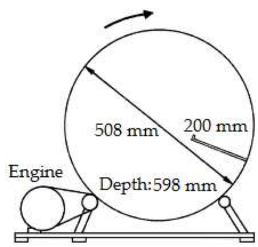

Figure 3. Scheme of a mechanical durability equipment testing DU (CULS, 2013).

After a precisely stated time of rotation, the tested bio –briquette samples were removed from the drum and weighted.The following formula (2) was used to calculate mechanical durability DU (%) level of the samples.

$$DU = \frac{m_a}{m_e} \cdot 100 \quad (2)$$

where DU – mechanical durability (%); m_a – samples weight after testing (g); m_e – samples weight before testing (g).

Rupture force

Statement of rupture force RF (N mm^{-1}) is not stated by any mandatory technical standards, but it is based on previous experimental testing of Brožek et al. (2012) and (Brožek, 2015). The principle of the test (as shown in Fig. 4) consists in the loading of the force to the bio–briquette sample and subsequent measurement of the maximal force before samples disintegration.

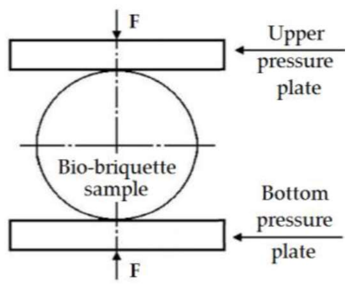

Figure 4. The principle of rupture force (RF) testing.

RESULTS AND DISCUSSION

Present chapter reports and evaluates obtained observations and result values of specific experimental tests. In respect to the 'Materials and Methods' chapter distribution, there are also three subchapters related to the specific biomass or bio–briquette samples parameters.

Investigated samples

The experimental part of present research related to the bio–briquette samples production is unfortunately represented only by the utilization of the Jatoba wood waste biomass.

The process of bio–briquette samples production was not possible in case of Garapa wood waste biomass due to its limitations. Mentioned limitations were related to the area of materials origin and its transportation. The available amount of material did not correspond to the required quantity material necessary for bio–briquette samples production and testing. Nevertheless, utilization of Jatoba wood waste biomass for bio–briquette production resulted in bio–briquette samples expressed in Fig. 5.

Figure 5. Produced bio–briquette sample before experimental testing.

The observation of produced bio–briquette samples dimensions (expressed in Table 2) was important for further calculations and evaluation of subsequent experimental tests.

Table 2. Dimensions of produced Jatoba bio–briquette samples

Bio–briquette sample	Mean height (mm)	Mean diameter (mm)	Mean weight (g)
Jatoba	54.51 ± 9.15	51.45 ± 0.39	101.78 ± 13.26

± – standard deviation.

Chemical quality indicators

Data obtained during chemical analysis described the suitability of investigated materials for direct combustion that ensured environmental conservation but also described energy potential and burning efficiency of such biofuels. The detailed values are noted in Table 3 and Table 4.

Table 3. Chemical parameters of investigated wood waste biomass samples (w.b.)

Waste biomass sample	W_c (%)	A_c (%)	GCV (MJ kg^{-1})	NCV (MJ kg^{-1})
Jatoba	7.46	0.31	20.16	18.92
Garapa	7.77	3.02	19.61	18.39

W_c – moisture content; A_c – ash content; GCV – gross calorific value; NCV – net calorific value; w. b. – wet basis. All values expressed here are average values.

Table 4. The chemical composition of investigated wood waste biomass samples in dry basis (w.b.)

Biomass sample	C (%)	H (%)	N (%)	S (%)	O (%)
Jatoba	52.62	5.71	0.23	0.03	41.10
Garapa	51.16	5.60	0.23	0.02	39.97

C – Carbon; H – Hydrogen; N – Nitrogen; S – Sulphur; O – Oxygen.

As the specific value indicates, it is obvious that the level of ash content A_c (%) occurred at a high level (required result) in cases of both samples. Moreover, in the case of Jatoba wood waste biomass, the values proved extremely good results. The mandatory technical standard states maximal level of ash content $A_c < 10\%$ in case of bio–briquette fuel intended for commercial sale (EN 15234–1. (2011)).

The values of net calorific values NCV (MJ kg^{-1}) proved the extremely high level of materials energy potential. Such results are highly recommended if consider the mandatory technical standard of the level of net calorific value NCV > 15 MJ kg^{-1} within the commercial bio–briquette production (EN ISO 17225–1. (2015)).

Within the elementary composition of fuel intended for direct burning, the content of Oxygen O (%) is considered as an important indicator of materials ability to burn; the higher content of Oxygen O (> 40%) can cause problems during the fuel burning. The evaluation of obtained data indicates a satisfactory level of the monitored chemical parameter in both cases; in case of Jatoba, the values occurred only slightly above the theoretical maximal level. The expression of the chemical analysis in dry ash Free State form was also used (noted in Table 5) for the evaluation of precise values of selected chemical parameters without the influence of the presence of the ash.

Table 5. Chemical composition of investigated wood waste biomass samples in dry ash free state (d.a.f.)

Biomass sample	C (%)	H (%)	N (%)	S (%)	O (%)	GCV (MJ kg^{-1})	NCV (MJ kg^{-1})
Jatoba	52.79	5.73	0.23	0.03	41.22	20.23	18.98
Garapa	52.75	5.77	0.24	0.02	41.21	20.22	18.97

C – Carbon; H – Hydrogen; N – Nitrogen; S – Sulphur; O – Oxygen; GCV – gross calorific value; NCV – net calorific value; d.a.f. – dry ash free state.

Mechanical quality indicators

Present chapter provides the evaluation of the mechanical quality of investigated bio–briquette samples produced from Jatoba wood waste biomass; detail values of specific experimental measurements are noted in Table 6.

Table 5. Mechanical quality indicators of Jatoba bio–briquette samples

Bio–briquette sample	W_c (%)	ρ (kg m^{-3})	RF (N mm^{-1})	DU (%)
Jatoba	5.61	896.34 ± 105.93	47.05 ± 18.78	77.60

W_c – moisture content; ρ – volume density; RF – rupture force; DU – mechanical durability; ± – standard deviation The values in Table 5 represent only average values.

Volume density ρ ($kg \cdot m^{-3}$) of investigated bio–briquette samples occurred at a satisfactory level (ISO 13061-2, 2014) which indicated the suitability of such material for densification process and proved the efficiency of such bio–briquette production. Results of rupture force RF ($N\ mm^{-1}$) and mechanical durability DU (%) described the strength of the bio–briquette samples and their resistance to the handling, transportation or long-term storage. The conditions of the bio–briquette samples after mentioned tests are expressed in Fig. 6. It ought to be mentioned, that both of the tests are destructive, thus, the destruction of tested bio–briquette samples is necessary for obtaining the required data.

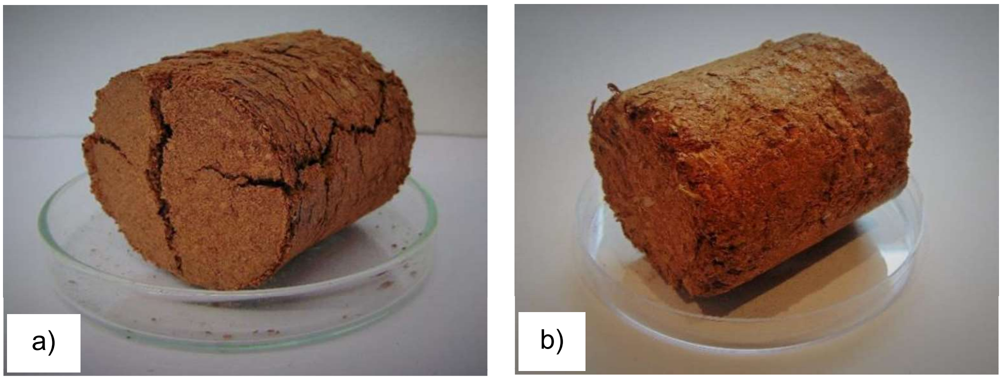

Figure 6. Jatoba wood waste bio–briquette samples after testing: a) Rupture force RF; b) Mechanical durability DU.

Namely, the specific result of rupture force RF indicated a satisfactory level of such indicator if compare with other previously published results of bio–briquette samples produced from the wood waste biomass under the same conditions with the same diameter (Brožek, 2013; Brožek, 2016). However, the values of mechanical durability DU represented negative results of present research. The minimum level of mechanical durability DU required for commercial bio–briquette production must be > 90% and is stated by mandatory technical standard EN ISO 17831-2 (2015). Obtained result of mechanical durability DU equal to 77.60% is insufficient. Nevertheless, such result can be improved by changing of one or more specific production factors related to the densification process; e.g. increasing of briquetting press pressure, decreasing of feedstock materials moisture content or mixing of Jatoba wood waste biomass with other feedstock materials or external binders. All of those factors can positively influence final mechanical durability DU produced bio–briquette samples.

CONCLUSIONS

Overall evaluation of obtained data within the chemical and mechanical parameters of investigated wood waste biomass from Jatoba and Garapa tree species proved its suitability for direct combustion, thus, its suitability for energy generation. The main advantages of their utilization for such purposes were the great results of ash content A_c (%) and their high level of energy potential expressed by the NCV ($MJ\ kg^{-1}$). Focused on the efficiency of bio–briquette samples produced from Jatoba wood waste biomass, their volume density ρ (kg m^{-3}) and rupture force RF (N mm^{-1}) indicated that it is high-quality biofuel, but the result of mechanical durability DU (%) expressed unsatisfactory level. Nevertheless, as was mentioned in 'Result and Discussion' chapter, such result can be easily influenced by changing of production parameters of such bio–briquette production. The energy use of wood waste products for biomass combustion should start from harvesting process and follow the all chain of custody to avoid the unnecessary burning of these waste materials. The harvesting plans of these species should contain a specific chapter that state how the wood waste post-harvest will be processed to guarantee that sawmills are sustainably harvesting and make the use of the wood waste as energy potential.

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