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Assessment of Guava (*Psidium Guajava* L.) Wood Biomass for Briquettes' Production

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Abstract: Residual biomass from guava (*Psidium guajava* L.), a common and widespread fruit tree native to Latin America, has been analyzed in the present research in order to determine the biomass quality and its potential use for energy purposes. Obtained biomass was grinded and compacted into the form of fuel briquettes. Determinations of solid biofuel parameters, i.e., physical, mechanical and chemical properties such as calorific value, moisture, ash content, volatile matter, mechanical durability, contents of the main chemical elements and heavy metals were performed according to international standards. As a result, not inconsiderable traces of heavy metals were found, with a concentration of zinc 4.57 mg kg^{-1} as the highest. Guava's moisture content (9.8%) comfortably fulfilled the minimum standard requirements and the net calorific value as received (17.11 MJ kg^{-1}) met the average value of a wood. However, measured sulphur content (0.063%) as well as ash content (3.74%) exceeded the maximum allowed limits for the graded wood briquettes and, therefore, guava wood briquettes should be rather categorized as non-woody A class briquettes. The results of the study can contribute significantly to the knowledge of guava wood properties and its potential as renewable solid fuel since there is little published data about it.

Keywords: bioenergy; calorific value; densification process; solid biofuel

1. Introduction

High demand and consumption of fossil fuels have forced the global population to consider and recognize that the oil is a finite resource, and in the context of its forthcoming exhaustion humans must seek alternative sources of energy to meet their basic needs [1]. Therefore, the use of biomass is becoming a real possibility and, moreover, without triggering adverse effects for the planet nor for living organisms [2].

In recent years, Ecuador has reflected on the need to adopt and implement strategies different from traditional energy, i.e., related to the use of hydrocarbon in various forms [3]. According to data of the Intenational Energy Agency (IEA) [4] the total energy production of Ecuador in 2016 was 36.77 Mtoe, where the share of crude oil was 76.37%, oil products 16.15%, natural gas 1.63%,

hydropower 3.7%, solar/tide/wind 0.03% and biomass 2.12%. Thus, many government institutions such as the Ministry of Electricity and Renewable Energy (MEER), Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP) and especially educational institutions both public and private have increased their research efforts to find energy alternatives primarily in different types of biomass, as was reported by MEER [3] and Mendoza Hernández [5].

Biomass pruned from fruit trees can be continuously harvested, being an entirely renewable resource ensuring sufficient biomass supply [6]. Furthermore, negative impacts on the environment, primary caused by carbon dioxide emissions, are widely offset by the carbon dioxide captured in growing plants, which mitigate to some extent the use and import of fossil fuels to the country, while biomass does not emit pollutants such as sulphur or nitrogen, and creates jobs and economic development in rural populations [7]. Simply speaking, it is about converting waste into a resource by a recycling process while contributing to environmental care and social improvement.

According to MAGAP [8], within the province of Imbabura (northern Ecuador), on the Ibarra-San Lorenzo road, there are vast areas of guava plantations, where inappropriate management of residual biomass generated from the pruning is frequently creating a number of problems: common outdoor burning of this biomass emits significant amounts of greenhouse gases and generates forest fires. Consequently, the amount of energy released by the burning of wood that could be destined for the production of energy within a controlled environment is wasted. Proper utilization of excess and relatively abundant residual guava biomass seems to be a promising way to obtain clean alternative energy. In general, due to a very good climate adaptability, the guava tree is nowadays widely spread in tropical and subtropical regions around the world [9,10]. According to Gutiérrez et al. [9] in different countries, where guava is cultivated the wood is used for engraving (India), spinning tops (Guatemala), hair combs (El Salvador) or the construction of houses (Nigeria) as published by Lucas et al. [11], or either for application in traditional medicine [12–17]. However, the energy application of guava wood has not been mentioned. The most relevant founded publications dealing with the analysis of guava biomass characteristics are the research of Camarena-Tello et al. [18], which measured some chemical composition of guava leaves and branches including ash content, and the research of Martínez-Pérez et al. [6], which is limited to the calorific value and ash content of guava bark. This study aims to obtain an overall evaluation of the physical, mechanical and chemical properties of biomass and briquettes from *Psidium guajava* L. pruning in order to assess its energy value.

2. Materials and Methods

2.1. Origin of Material, Preparation of Analysis Sample and Production of Briquettes

Measurements and calculations have been made on a representative sample (15 kg) of *Psidium guajava* L. (wood biomass including bark), collected from 30 trees spread throughout a parcel of one hectare in the parish of Lita, which is located about 100 km far from the city Ibarra in the Ibarra canton of Imbabura province, Ecuador (see Figure 1).

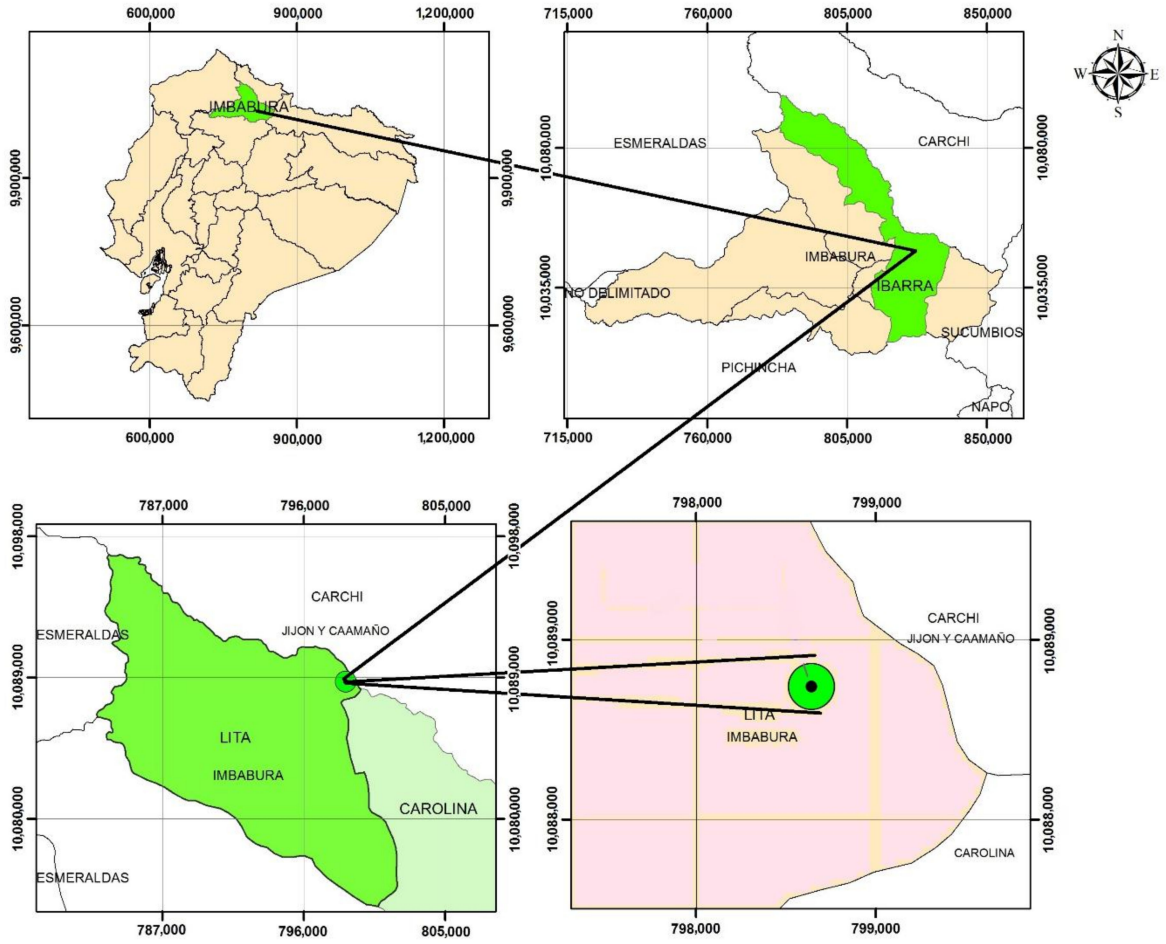

Figure 1. Location of the material's collection area: Ecuador, Imbabura province, Ibarra cantor, Lita parish.

In accordance with the tree growing calendar, the pre-harvesting pruning and renovation pruning is done twice a year each; usually in January and July (pre-harvesting), and in April and October (renovation) [5,8]. On average, 12.5 kg of waste wood biomass is produced per tree [5]. For the purposes of this research, the biomass was harvested within the spring renovation pruning. All harvested biomass was firstly cut into large pieces and then the representative sample was gathered based on the standard sampling methodology BS EN 14778:2011 [19]. Small amounts of freshly cut biomass were used for determination of moisture content. The whole obtained representative biomass sample was dried naturally during three months in the conditions of Ecuador and, thereafter, sent to the Czech Republic for further processing and laboratory tests.

A portion of the representative sample material (200 g) was separated based on the standard BS EN 14780:2011 [20] and was used for preparation of analysis samples as follow: firstly, it was crushed into pieces of about 20 mm and then ground by laboratory hammer mill IKA® MF 10.1 (IKA, Staufen, Germany), afterwards it was homogenised in a knife mill Grindomix GM 100 (Retsch GmbH, Haan, Germany) up to the particle size of 1 mm. The rest of the material was used for briquettes' production through several steps: (1) the guava wood biomass was cut by the shredder AL-KO New Tec 2400R (AL-KO, Kötz, Germany) into pieces of 20–30 mm; (2) thereafter, the pieces were ground by the hammer mill 9FQ-40C (Green Energy Machine Product, Vlčnov, Czech Republic) with sieve holes' of a diameter of 6 mm; and (3) the ground biomass was briquetted by the hydraulic piston press BrikStar CS50 (Briklis, Malšice, Czech Republic) with the diameter of the pressing chamber of 50 mm, under the working pressure of 18 MPa.

Figure 2 below illustrates the guava plantation with the details of the tree before and after the renovation pruning as well as the final product (guava briquettes).

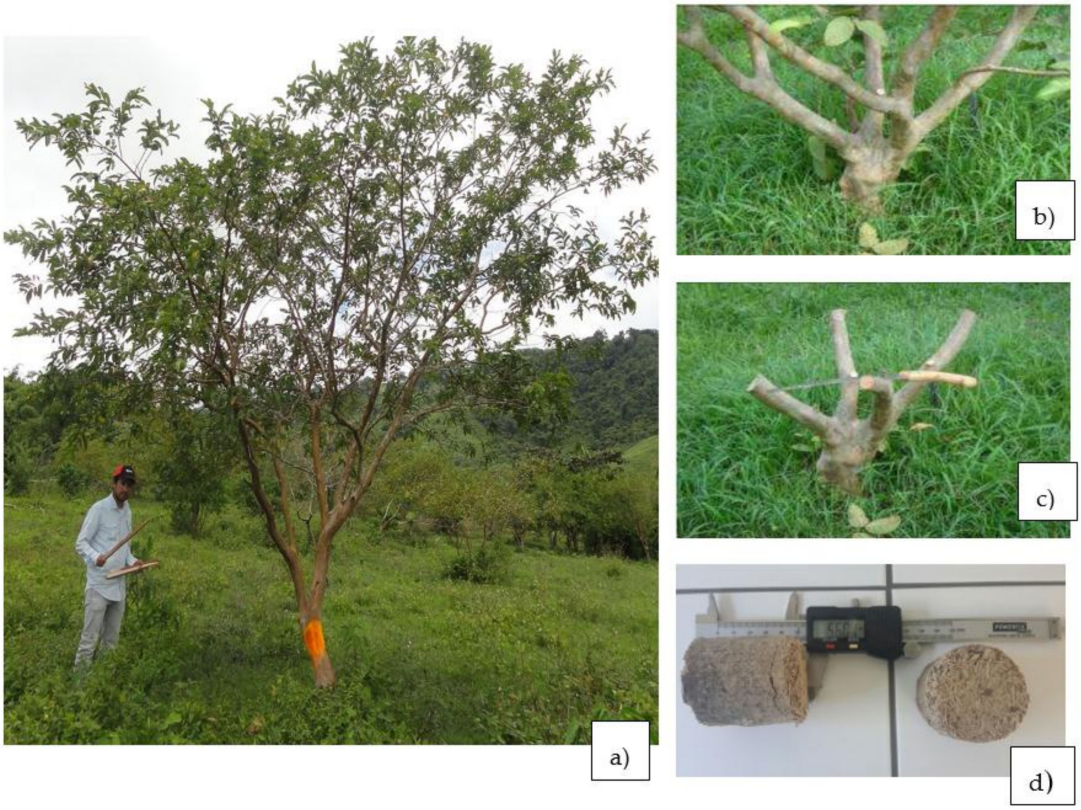

Figure 2. *Psidium guajava* L. (guava): (**a**) guava plantation in the Lita area; (**b**) guava tree before the renovation pruning; (**c**) guava tree after the renovation pruning; (**d**) briquettes produced from guava.

2.2. Bulk Density

The bulk density of cut biomass was determined under the standard BS EN ISO 17828:2015 [21]; once the container was weighed and its volume measured, the material was poured into the container until a cone shape was formed, then the container was hit three times and afterwards more material was poured into the container until it was not possible to add any more, then any outstanding material was removed using a scantling. The bulk density was calculated according to the following equations:

$$BD_{ar} = \frac{(m_2 - m_1)}{V}, \text{ kg m}^{-3} \quad (1)$$

$$BD_d = BD_{ar} \times \frac{(100 - M_{ar})}{100}, \text{ kg mm}^{-3} \quad (2)$$

where: BD_{ar}—is the bulk density as received in kg m^{-3} BD_d—is the bulk density of the sample on a dry basis in kg m^{-3} M_{ar}—is the moisture content, as received, as percentage by mass (wet basis); m_1—is the mass of the empty container in kg; m_2—is the mass of the filled container in kg; V—is the net volume of the measuring container in m^3.

2.3. Moisture Content

The measurement of moisture content was performed in accordance with international standard BS EN ISO 18134-3:2015 [22]. The analysis sample was introduced into the drying oven Memmert 100–800 (Memmert GmbH, Schwabach, Germany) at 105 °C for about 3 h. After the drying the sample was weighed; subsequently, the process was repeated n times until the difference between procedure n

and $n - 1$ stood equal or less than 0.2%. The resulting moisture content was calculated as the mean of duplicate determinations using the following equation:

$$W = \frac{m_w - m_d}{m_w} \times 100, \ \% \tag{3}$$

where: W—is the moisture content in %; m_w—is the mass of the baker and sample before drying in g; m_d—is the mass of the baker and sample after drying in g.

2.4. Ash Content

In concordance with the standard BS EN ISO 18122:2015 [23], approximately 1 g of analysis sample that had been dried at 105 °C beforehand and spread on the bottom surface of a crucible was placed in a cold furnace (muffle furnace, LAC LH 06/13, LAC, Rajhrad, Czech Republic) and heated from ambient temperature to 250 °C over a period of 30 min, then retained at this temperature for a further 60 min; the temperature was raised once again to 550 °C over a period of 30 min and kept for a period of 120 min; afterwards, the sample was removed from the furnace, left at ambient temperature to cool down, and weighed. Ash content on a dry basis was calculated from several repetitions with respect to repeatability precision by the following equation:

$$A_d = \frac{(m_3 - m_1)}{(m_2 - m_1)} \times 100 \times \frac{100}{100 - M_{ad}}, \ \% \tag{4}$$

where: A_d—is the ash content in anhydrous condition in %; m_1—is the mass of the empty container in g; m_2—is the mass of the container plus the test sample in g; m_3—is the mass, of the container plus ash in g; M_{ad}—is the moisture content of the test sample used for determination in %.

2.5. Calorific Value

Calorific value was determined under the standard BS EN 14918:2009 [24]. Around 1 g of the material compressed in an unbreakable test piece was placed into a bomb (lower part); the fuse was attached to the ignition wire in contact with the sample and water was added. Having readied all components, the bomb was assembled and placed into the calorimeter (IKA 6000, IKA, Staufen, Germany), which was configured with the required information such as sample weight, hydrogen content in the material and other. Gross calorific value was then measured automatically. For the calculation of a net calorific value the following equation was applied:

$$Q_{net} = Q_{gr} - 24.42 \times (w + 8.94 * H^a), \ \mathrm{J\ g^{-1}} \tag{5}$$

where: Q_{net} —is the net calorific value in J g^{-1}; Q_{gr}—is the gross calorific value in J g^{-1}; 24.42—is the coefficient corresponding to 1% of the water evaporated from the sample at 25 °C; w—is the moisture content in the sample in %; 8.94—is the coefficient for conversion of hydrogen to the water; H^a—is the hydrogen content in the sample (%).

2.6. Volatile Matter Content

The measurement was performed based on the BS EN ISO 18123:2015 [25]. The crucible and lid were placed into the muffle furnace (ELSKLO MP5, Elsklo Ltd., Desná v J. h., Czech Republic) at 900 °C for 7 min. Once the time had passed they were removed from the furnace, cooled down and weighed. Then, the test sample was poured into the cold crucible and placed into the furnace for a further 7 min at the same temperature. After this period the sample was removed, cooled down to the temperature

30 °C to 50 °C and weighed once again. The measurements were repeated and the calculation was carried out according to the equation below:

$$V_d = \left[\frac{100\ (m_2 - m_3)}{m_2 - m_1} - M_{ad}\right] \times \left(\frac{100}{100 - M_{ad}}\right),\ \% \quad (6)$$

where: V_d—is the volatile matter in %; m_1—is the mass of the empty crucible and lid in g; m_2—is the mass of the crucible, lid and the test portion before heating in g; m_3—is the mass of the crucible, lid and the test portion after heating in g; M_{ad}—is the moisture, as a percentage by mass, in the general analysis sample.

2.7. Content of Carbon (C), Hydrogen (H) and Nitrogen (N)

C, H, N elements' analysis was done by an automatic device (LECO CHN628, LECO Corporation, Saint Joseph MI, USA) according to the standard BS EN ISO 16948:2015 [26]. Calibration of the determiner was undertaken beforehand, then 0.1 g of analysis sample wrapped in aluminium foil and prepared in three replicates was placed into the carousel and combusted in the furnace of the device at 100% oxygen and temperature around 1050 °C. The results were calculated automatically.

2.8. Content of S, Cl, Ca, Fe, P, K, Si, Cr, Mo, Sb, Rh and Zr

Determination of these chemical components was performed by the X-ray fluoresce method (XRF) based on the standard BS EN ISO 16967:2015 [27]. A dry sample of 30 g was used; it was placed in a standard 32 mm XRF sample cup; then, following the user guide, the analysis area was set up on the screen, which took less than 30 s; XRF was calibrated; afterwards, the sample was analysed for a total of 90 s (30 s main, 30 s low, 30 s high), and results were shown on the screen in %.

2.9. Content of Cd, Co, Cu, As, Hg, Ni, Pb and Zn

Determination was carried out following the standard BS EN ISO 16968:2015 [28]. The freeze-dried and homogenised sample was decomposed based on a microwave-assisted wet digestion system with focused microwave heating. A solution of the sample (~0.3 g of dry matter, in 3 replicates) was weighed in a vessel (volume 35 mL) and 6 mL of concentrated nitric acid was added; the mixture was heated to maximum power 300 W, temperature 180 °C, and maximum pressure 21 bars for 12 min. After cooling, the solution was quantitatively transferred to polyethylene containers and filled with 30 mL of purifying water. Elements' contents in the digests were measured by inductively coupled plasma mass spectrometry (ICP-MS, Agilent, Santa Clara, CA, USA) using non-gas mode or a collision cell mode to reduce potential interference.

2.10. Mechanical Durability

The measurement was conducted in accordance with the standard BS EN ISO 17831-2:2015 [29] using the rotating durability drum. Each portion of briquettes with the weight of approximately 2 kg was placed into the drum and rotated 105 times for 5 min. Afterwards, the abrasion was sieved and the mechanical durability of the briquettes was calculated as follows:

$$DU = \frac{m_A}{m_E} \times 100,\ \% \quad (7)$$

where: DU—is the mechanical durability (%); m_E—is the mass of pre-sieved briquettes before the drum treatment in g; m_A—is the mass of sieved briquettes after the drum treatment in g.

The number of measurements/replications within the determination of each parameter was strictly in accordance with the appropriate standard and the stated repeatability precision was respected.

3. Results and Discussion

3.1. Classification by Origin and Source

According to the standard BS EN ISO 17225-1:2014 [30] related to the raw material classification of solid biofuels, which is based on their origin and source, the residual biomass from guava is classified as 1.1 Forest, plantation and other virgin wood. Stating origin and source is mandatory for all solid biofuels [30].

3.2. Bulk Density

Bulk density is an important variable for economic reasons in relation to transport and storage costs which are substantial in terms of energy use [31]. The bulk density (BD_{ar}) of cut guava biomass determined by the present research was 227.72 kg m^{-3} and bulk density BD_d was 205.40 kg m^{-3}. Between the typical bulk densities of unprocessed biomass materials is included hardwood with an average value of 330 kg m^{-3}, which is considerably higher than guava biomass; in comparison with a coal of 700 kg m^{-3} [32] the material is 3 times less dense. According to BS EN 14778:2011 [19] the typical bulk density of wood chips ranges between 250–400 kg m^{-3}.

3.3. Moisture Content

Biomass moisture content is one of the most decisive parameters for briquettes' production. If the moisture exceeds 20%, biomass does not densify well and the produced briquettes are of very poor mechanical quality [33]. According to Huhtinen [34], biomass moisture also significantly affects the calorific value of the fuel, i.e., the higher the moisture, the lower the calorific value. Lucas et al. [11] reported a green moisture content in guava biomass of 84%, and Camarena-Tello et al. [18] declared guava's green moisture content to be 68%. The moisture of freshly harvested biomass from the plantation in Lita was 38.2%. In general, according to Ivanova et al. [35] the moisture content in wood biomass depends on the climatic conditions of a cultivation area and the time of the year when harvesting takes place; thus, the differences between the published and the research data can be explained. Comparing the aforementioned values of green guava biomass and the moisture content of the field dried material used in this research, it is possible to affirm a significant moisture reduction, which means that if the wood is firstly dry, then the moisture content may be 9.8% depending on the relative air humidity and other drying conditions. In comparison with other materials for energy purposes, for example, energy grass Rumex OK 2 contained moisture of 7.75% [36] and pine sawdust of 10.35% [37], and thus guava biomass moisture content fulfils the requirements for the range recommended by other authors. According to BS EN ISO 17225-3:2014 [38], the maximum moisture content of wood briquettes is 12% for the highest-quality A1 class and 15% for A2 and B classes.

3.4. Ash Content

Ash content can affect behaviours during combustion and play a major role in optimising furnace/boiler design for enhanced combustion efficiency and eliminate operational problems [39]. The ash content value in guava bark stated by Martínez-Pérez et al. [6] was 5.76%. In this experiment the total guava wood biomass (mixture of core with bark) was used and obtained a result of ash content of 3.74%. The percentage of core and bark is unknown for guava biomass; however, according to Fengel and Wegener [40] the bark share generally ranges from 5% to 8%, but the amount can vary depending on factors such as age, location, species, etc. As published by Karampinis et al. [41], the ash content tends to be different in different parts of the plant. Compared with other biomass materials, the ash content in guava wood is, for example, the same as in a flax straw with 3.7% ash [42], however that material is classified as a herbaceous biomass. Taking into account ash content's limits given by BS EN ISO 17225-3:2014 standard [38], i.e., ash content $\leq$ 1% for A1 class, $\leq$ 1.5% for A2 class and $\leq$ 3% for B class, it can be seen that guava wood does not fulfil the requirements for graded wood biofuel.

Nevertheless, the standards for non-woody briquettes (ash content $\leq$ 6% for A class, $\leq$ 10% for B class) are easily achieved (BS EN ISO 17225-7:2014 [43]).

3.5. Calorific Value

According to Tang et al. [44], calorific value is the main factor that determines the usefulness of biomass as an energy source. The result of gross calorific value of guava wood of 18.42 MJ kg^{-1} is slightly below the average of hardwood 19 MJ kg^{-1} [42]. The guava's net calorific value of 17.11 MJ kg^{-1} is comparable with the gross calorific value of straw residual biomass such a barley straw 17 MJ kg^{-1} [45] and covers 74% of the net calorific value of coal 25 MJ kg^{-1} [46]. The net calorific value of guava was catalogued to the highest-quality class A1 of graded wood briquettes ($\geq$15.5 MJ kg^{-1}) as compared with international standard BS EN ISO 17225-3:2014 [38].

3.6. Volatile Matter Content

Fractional contribution heat presented by volatile substances in biomass is approximately 70% [47]. So, the higher the volatile matter content, the more heat produced by the biomass. The measured value of 77.43% corresponds to three-quarters of the original guava's sample weight. In general, the highest content of volatile matter in biomass is approximately 80% [48] and guava biomass volatile matter almost reaches this level. Besides, the high content of volatile matter produces a rapid combustion of the material [49]. On the other hand, lower volatile matter causes more smoke and releases toxic gasses [48].

3.7. Nitrogen, Carbon, Hydrogen, Sulphur and Chloride

The content of nitrogen (0.68%) in guava wood is relatively low and it is similar to other wood biofuels, where the N value is typically less than 1% [50], while the N content is much higher in cereals and especially in beans [51]. For example, the N content in Jatropha seed cakes is around 4% [52]. However, in accordance with strict limits for graded wood briquettes the N content is $\leq$0.3% for A1 class, $\leq$0.5% for A2 class and $\leq$1% for B class, and thus guava wood fulfils only B class requirements (BS EN ISO 17225-3:2014 [38]). In general, nitrogen has a direct impact on formation of harmful nitrogen oxides (NO_x) during fuel combustion.

Guava biomass content of carbon (49.64%) is similar to carbon in *Salix dasyclados* [53] and coniferous trees [50]—both around 50%; and is slightly below other tropical trees, the average percentage of which is around 52 [54].

Hydrogen is now considered an "energy vector" of enormous potential. Its combustion produces water and 27 kcal g^{-1} of energy. The H content in some shrub willow species is on average 7% [53], in comparison with guava H content of 5.99%. Typically, woody biomass has hydrogen content of around 6%.

Sulphur content in guava biomass is considerably lower (0.063%) in comparison with sulphur content in coal, which ranges between 0.4% and 0.7% [55]; nevertheless, guava S content is high in contrast with the limits for graded wood briquettes ($\leq$0.04% for A1 and A2 classes and $\leq$0.05% for B class, EN ISO 17225-3:2014 [38]) and it fulfils the limits of A class non-woody briquettes ($\leq$0.2%, BS EN ISO 17225-7:2014 [43]). Generally, higher sulphur content in fuels tend to generate corrosion and deterioration of combustion equipment [56,57].

Chloride content (0.020%) has fulfilled the maximum A1 level allowed by the standard BS EN ISO 17225-3:2014 [38]. Camarena-Tello et al. [18] have reported much higher Cl content range in guava branches from 0.08% up to 0.71% and Cl content was found to increase with growing altitude.

3.8. Other Chemical Compounds

Results from the determination of chemical compounds are shown in Table 1 below. Generally, guava biomass has a low concentration of heavy metals and other harmful elements.

Table 1. Contents of major and minor elements in guava wood biomass.

Element	(mg kg^{-1})	Element	(mg kg^{-1})
Co	0.020	Ca	1.155
Ni	0.212	P	0.036
Cu	2.652	K	2.137
Zn	4.570	Mo	0.002
As	0.012	Cr	0
Cd	0.001	Zr	1.002
Hg	0.005	Rh	0
Pb	0.035	Si	0.213
Fe	0	Sb	0.003

Contents of some elements in guava rather differs from the results of Camarena-Tello et al. [18], where phosphorus (P) varies from 4.90 mg kg^{-1} to 8.88 mg kg^{-1}, potassium (K) from 43.11 mg kg^{-1} to 52.10 mg kg^{-1}, calcium (Ca) from 26.17 mg kg^{-1} to 33.44 mg kg^{-1}, and silicon (Si) concentration is comparable with a range from 0.15 mg kg^{-1} to 0.40 mg kg^{-1}. Maximum amounts of As, Cd, Cr, Cu, Pb, Hg, Ni and Zn are also stated by the standard BS EN ISO 17225-3:2014 [38]. As compared to the standard, all measured concentrations are negligible and fully within the limits.

3.9. Mechanical Durability

Mechanical durability is the main indicator of solid biofuels' mechanical quality (strength). The briquettes of poor durability are characterised by high crumbling that contributes to losses during handling and transportation [33,58]. Determined mechanical durability of guava briquettes (88.25%) is lower than the average values for briquettes from wood biomass stated by Brožek et al. [59]: 91.3% for briquettes made of spruce sawdust, 92.2% for briquettes from wood shavings (a mixture of 90% spruce and 10% pine biomass) and 94.3% durability for briquettes from poplar chips. Lower durability can be explained by the presence of bark in the guava wood sample, as the durability of briquettes made of pure bark is poor, e.g., 72.8% in the case of pine bark [59].

3.10. Evaluation of Guava Wood Briquettes According to the Standards' Requirements

Table 2 summarizes the research results indicating the main properties of guava briquettes in comparison with the limits given by the standards for graded wood briquettes of different classes [38] and graded non-woody briquettes [43].

Table 2. Comparision of the properties of the solid fuel from quava with the standard limit values.

Parameters	Units	Graded Wood Briquettes			Non-Woody Briquettes	Guava Briquettes
		A1 Class	A2 Class	B Class	A Class	
Diameter (D), Lenght (L)	mm mm	to be stated			to be stated	D 52.025 L 50.806
Moisture, M	w-% ar	≤12	≤15	≤15	≤12	9.8
Ash, A	w-% d	≤1.0 †	≤1.5 †	≤3.0 †	≤6.0	3.74
Net calorific value, Q	MJ kg^{-1} ar	≥15.5	≥15.3	≥14.9	≥14.5	17.11
Nitrogen, N	w-% d	≤0.3 †	≤0.5 †	≤1.0	≤1.5	0.680
Sulphur, S	w-% d	≤0.04 †	≤0.04 †	≤0.05 †	≤0.20	0.063
Chlorine, Cl	w-% d	≤0.02	≤0.02	≤0.03	≤0.10	0.020
Arsenic, As	mg kg^{-1} d	≤1	≤1	≤1	≤1	0.012
Cadmium, Cd	mg kg^{-1} d	≤0.5	≤0.5	≤0.5	≤0.5	0.001
Chlorimum, Cr	mg kg^{-1} d	≤10	≤10	≤10	≤50	0
Copper, Cu	mg kg^{-1} d	≤10	≤10	≤10	≤20	2.652

Table 2. *Cont.*

Parameters	Units	Graded Wood Briquettes			Non-Woody Briquettes	Guava Briquettes
		A1 Class	A2 Class	B Class	A Class	
Lead, Pb	mg kg^{-1} d	≤10	≤10	≤10	≤10	0.035
Mercury, Hg	mg kg^{-1} d	≤0.1	≤0.1	≤0.1	≤0.1	0.005
Nickel, Ni	mg kg^{-1} d	≤10	≤10	≤10	≤10	0.212
Zinc, Zn	mg kg^{-1} d	≤100	≤100	≤100	≤100	4.570

ar—as received, d—dry basis; A (A1) is the higher-quality class; †, values were not fulfilled by guava briquettes.

4. Conclusions

According to the literature review, residual guava wood biomass lacks suitable utilization; furthermore, accumulating large amounts of pruning waste and burning this in open fields has negative environmental impacts. The research results have found that guava wood is a good source of fuel and can be utilized in the form of briquettes. Taking into account the parameters that assure the quality of solid biofuels and their minimum/maximum acceptable values, which are stated by the international standards, it can be concluded that guava fuel is characterized by relatively high calorific value, low moisture content and very low contents of heavy metals and other trace elements, i.e., these properties correspond to the most strict limits of A1 class graded wood briquettes. However, the content of nitrogen was found to be more than twice as high as the maximum for the best A1 class wood briquettes and fulfils only the B class wood requirements. The weakest parameters of guava-based solid biofuel are sulphur and ash contents, which exceed maximum values for graded wood, even by several times in case of ash, but easily meet the best limits for non-wooden fuels. To sum up, while the overall quality of tested guava wood from Ecuador is closer to the graded wood and much better compared to typical non-wooden materials, due to higher sulphur and ash content in case of commercialization it should be categorized as a non-woody fuel. Nevertheless, taking into consideration availability and significant amounts of pruning residues together with its positive fuel properties, its utilization as a biofuel will contribute to the energy situation, waste management and other associated problems, especially in rural areas.

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