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Assessment of guava (*Psidium guajava L.*) wood biomass for energy purposes

Master's thesis

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Statutory declaration

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In Prague, 22nd of April 2016

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Amilkar H. Mendoza Hernández

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Abstract

Owing to the utilization of fossil fuels in excess, climate change, environmental impact and declining natural resources scientific research is being driven to original technical solutions. Timber and other wood products have, for ages, remained one of the major materials used for heating worldwide due to their renewable nature and availability in various types.

Biomass from guava (*Psidium guajava L.*), a common and well-dispersed tree, native to Latin America, had been analysed in order to determine the quality and opportunities for energy purposes.

Briquettes from guava biomass were produced and determinations of physical, chemical and mechanical parameters were made according to international standards. As a result, it is worth stressing that virtually imperceptible traces of heavy metals were found, with concentration of copper 2.65 mg/kg as the highest, a moisture content at 9.8% that comfortably fulfil the minimum standard, and a net calorific value 17.11 MJ/kg which meets the average of hardwood. However, nitrogen content exceeded the stated value for A1 and A2 fuel classes as well as sulphur content (0.063%) and ash content (3.74%) slightly exceeded the maximum allowed values of international standards.

Is concluded that guava briquettes did not fully fulfil the quality requirements stated by the standard EN 17225-3:2014 for graded wood biomass, nevertheless solid biofuels based on guava biomass are suitable for energy purposes, especially for industrial use. However, further studies are recommended with binder or with addition of other materials in order to improve the biomass characteristics and properties of final compacted fuel.

Keywords: biomass, bioenergy, briquetting, calorific value, combustion, guava (*Psidium guajava L.)* wood, moisture content, solid biofuel, elemental compositions.

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

1 Introduction

The phenomenon of global warming, caused by the excess emissions of greenhouse gases, has led in recent decades to an increased interest in the study of its causes. The most immediate and visible result of the warming has been a succession of climatic events which led to natural disasters and has generated countless human and economic losses (Berry, 2008).

Nowadays, the high demand and consumption of fossil fuels has made consider and recognise that oil is a finite resource and in the context of its forthcoming exhaustion, man must seek alternative sources of energy to meet their basic needs (Freibauer et al., 2011). Therefore, the use of biomass will become a real alternative to the scope of the human beings and especially without triggering adverse effects or for the planet, nor for living beings (Yokoyama, 2008).

In recent years, Ecuador has reflected on the need to adopt and implement strategies different to traditional energy related to the use of hydrocarbon in various forms. In 2013 thus many government institutions such as the Ministry of Electricity and Renewable Energy (MEER), Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP) and especially in educational institutions both public and private, have increased their research efforts to find energy alternatives to the different types of biomass, as was reported by Ministry of Electricity and Renewable Energy of Ecuador.

Biomass from fruit trees can be continuously harvested, being an entirely renewable resource ensuring sufficient supply of it (Martínez-Pérez et al., 2012). Furthermore, adverse impacts on the environment, especially emissions of carbon dioxide are widely offset by the carbon dioxide captured in growing plants, which mitigates to some extent the use and import of fossil fuels to the country, while biomass does not emit the pollutants sulphur or nitrogen, creates jobs and economic development in rural populations (Hertwich et al., 2010). Simply speaking, converting waste into a resource is a recycling process while contributing to environmental care and social improvement.

Psidium guajava L., commonly known as guava, belongs to the myrtle family, is native to tropical areas of the American continent, and is already spread all around the tropical areas of the world (Morton, 1987; Somarriba, 1988).

Within the province of Imbabura, in the Ibarra-San Lorenzo road, there are vast areas for guava plantations, where inappropriate management of residual biomass generated from the pruning of that species, is reported by Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP), triggering several problems. Such outdoor incineration resource emits significant amounts of greenhouse gases and generates forest fires. Consequently, the amount of energy released by combustion of wood that could be destined for the production of energy within a controlled environment is wasted.

This study aim to obtain reliable data of physical, mechanical and chemical properties of biomass and briquettes produced from *Psidium guajava L.* pruning. Measurements and calculations have been made with a sample from thirty trees spread in a parcel of one hectare in Ibarra, Ecuador.

2   Literature review

This chapter is divided into two main parts, 2.1 Guava (*Psidium guajava L.*) and 2.2 Energy.

2.1 Guava (*Psidium guajava L.*)

Psidium guajava L., commonly known as guava in English or guayaba is Spanish, or the equivalent in other languages belong to the myrtle family Myrtaceae, (Morton, 1987). It was reported in West Indies since 1526. Spanish and Portuguese colonists led to Guam and the East Indies (Little, 1964). It was adopted as a crop in Asia and hot areas of Africa; it is believed that from Egypt passage to Palestine, Algeria and the Mediterranean French coast (Anónimo, 2010). Based on archaeological evidence, it has been used widely and known in Peru since pre-Columbian times. It grows in all the tropical and subtropical areas of the world, adapts to different climatic conditions but prefers dry climates. (Fosberg and Sachet, 1975). This adaptability allows its spread all around the world with an extensive acceptance in countries such India and Pakistan becoming the biggest producers in the world (Shruthi et al., 2013).

Taxonomy:

Kingdom: Plantae

Order: Myrtales

Family: Myrtaceae

Subfamily: Myrtoideae

Genus: *Psidium*

Species: *Guajava*

Binomial name: *Psidium guajava Linn.*

2.1.1 Plant morphology and description

Usually a small tree from 3 m to 10 m high; but some can achieve even 20 or 30 m in height. It is an evergreen tree or shrub deciduous with 15 cm diameter to 1.5 m height with irregular tree top; while the trunk is usually twisted and very branched. Thick, upward and gnarled branches; typically with smooth cortex tinted in reddish brown or the grey scales with total thickness of 5 to 8 mm; flowers normally solitary up to 8 cm, sweetly perfumed, actinomorphic; sepals 4-5, green outside and white inside; 4-5 white petals; superficial root system and sexually is hermaphrodite (Amador, 1753; Morton, 1987).

Wood

Guava wood, which you can see in the Figure 1, is well known as being hard and durable, its colour can vary from pale yellow to soft red, it can weigh 650-750 kg/m^3; is durable indoors; used in carpentry and turnery (Norton and Hall, 2004). Guatemalans use guava wood to make spinning tops, and in El Salvador, it is fashioned into hair combs which are perishable when wet (Morton, 1987), also is recently used in Hawaii for smoked food such a raw chicken (Guava Wood Farmers Hawaii, 2016).

Figure 1 Guava wood
Source: (Author, 2015)

Leaves

Simple decussated leaves position with lanceolate, oblong or elliptical shape and size from 3 up to 13.5 cm; in local communities of Latin America it is well known as a medicinal plant; guava tea leaves are used for stomach disorders such diarrhea or as an anti-inflammatory, and are also used for pain relief and reducing fever (Gutierrez et al., 2008).

Fruit

The fruit is a type of berry from 4 cm up to 12 cm in diameter, formed from completely rounded to pear shaped with persistent calyx at the apex, fleshy, yellowish beige to pink, fragrant and bittersweet taste. When immature and until a very short time before ripening, it is green, hard, gummy within and very astringent, thin and soft yellow peel, when ripe. It is consumed as fresh fruit, canned in syrup, juices, jams, and jellies fruit containing many seeds (3 to 5 mm).

2.1.2 Environmental requirements

- **Pluviosity**

The optimum rainfall varies between 1,000 and 3,800 mm of annual precipitation, irrigation is also recommended during the dry season (Willan, 2001).

- **Altitude**

From 0 m above sea level to 1,100 m above sea level.

- **Temperature**

From 15.5 °C to 34 °C recommended for good yields inclusive, at temperatures below the 3.2 °C plant dies.

- **Soil**

To produce quality fruit, fertile, deep, rich soils are preferred; organic and well drained, although guava has excellent efficiency in almost any type of soil. The ideal pH soil between 6 and 7, even though it is known in soil from pH of 4.5 to 8.2.

2.1.3 Current distribution and production

Native to tropical America, probably from southern Mexico to South America, the range greatly extended beyond these areas through cultivation (Little, 1964). Spread and also naturalized in the Southern United States such as Florida and California around 1847 to the Brazilian Amazon where it is also native (Morton, 1987). It was also introduced in tropical and subtropical regions of the Old World and may refer to the new areas where guava can be found in countries like India who, along with Pakistan, is the biggest producer in the world (Lewandowski, 2015). The distribution of the total production is shown by percentage in the chart Chart 1.
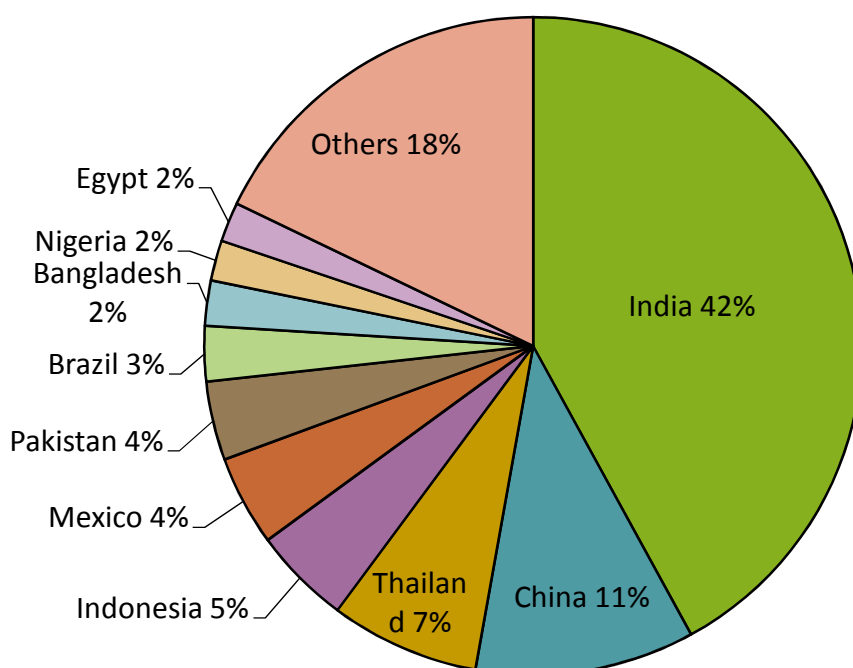
Chart 1 Top 10 biggest mangoes, mangosteens and guavas producers in 2013
Source: (FAOSTAT, 2016)

2.1.4 Uses

Main usage

Main commercial usage is summarized in the table below, it is worth mentioned that usage of wood does not include any energy purposes. It is mainly used for ornaments, decorations and accessories.

Table 1 Main commercial applications and most common uses for guava tree

	Usage	Country/Region	Resource
Fruit	Juice, jelly nectar, concentrated, stuffed of candies, gelatines, pastes, tinned products, confectionery	All countries	(Jimenez et al., 2001)
Wood and leaves	Carpentry and turnery use the leaves to make a black dye for silk	Southeast Asia	(Morton, 1987; Rodarte, 1994)
Wood	Engravings	India	(Rodarte, 1994)
Wood	Spinning tops	Guatemala	(Morton, 1987)
Wood	Hair combs	El Salvador	(Morton, 1987)
Wood	Construction of houses	Nigeria	(Lucas et al., 2006)
Leaves	Employed to give a black colour to cotton	Southeast Asia	(Rodarte, 1994)
Leaves	Serve to dye matting	Indonesia	(Rodarte, 1994)
Bark	Dyes, stains, inks, tattoos and mordants	Africa	(Burkill, 1985)

Source: (Gutierrez et al., 2008)

Related researches about guava biomass

The most relevant founded researches related directly to the subject of this study were the following two papers; Chemical composition of biomass generated in the guava tree pruning, written by Julio Camarena et al. (2015) reports ash content range from 1.8% to 8.2%, also a pH from 4.98 to 5.88, is important to mention that the measurement were calculated from a mix of leaves and branches; also from Mexico Ricardo Martinez (2012) wrote a comparative research about six varieties of common trees included guava, his study is limited to calorific value 4.076 kcal/kg and ash content 5.76%.

Medicinal effects

Generally, guava is used for traditional medicine, as it is reported by several authors. The table below shows compounds contained in guava resource and its effects.

Table 2 Compounds in guava and its pharmacological effects

	Compound	Effects	Resource
Leaves	Phenolic compounds, isoflavonoids, gallic acid, catechin, epicathechin, rutin, naringenin, kaempferol	Hepatoprotection, antioxidant, anti-inflammatory, antispasmodic, anti-cancer, antimicrobial, antihyperglycemic, analgesic	(Hui-Yin and Gow-Chin, 2007; Chen et al., 2010; Metwally et al., 2010; Nair and Chanda, 2007; Ojewole, 2006; Peng et al., 2011; Roy et al., 2006; Ryu et al., 2012)
Pulp	Ascorbic acid, carotecoids (lycopene, β-carotene, β-cryptoxanthin)	Antioxidant, anti-hyperglycemic, anti-neoplasic	(Bontempo et al., 2012; Huang et al., 2011; Oliveira et al., 2010; Thuaytong and Anprung, 2011)
Seed	Glycosids, carotenoids, phenolic compounds	Antimicrobial	(Castro-Vargas et al., 2010; Pelegrini et al., 2008)
Skin	Phenolic compounds	Endothelial progenitor cells and improvement of their intestinal absorption	(Felice et al., 2012; Nascimento et al., 2010)
Bark	Phenolic compounds	Strong antibacterial activity (against multi-drug-resistant *Vibrio cholera*), stomachache and diarrhea	(Rahim et al., 2010; Ryu et al., 2012)

Source: (Barbalho et al., 2012)

2.2 Energy

Before making an introduction to biomass it is imperative to know what it is part of, very briefly show an overview of energies, renewable energies, and bioenergies forward specifically about biomass and solid biofuels.

Some concepts are so fundamentals in life that they are difficult to explain with words; an example of this is energy, something so elemental in our world but so difficult to explain. In the dictionary it is defined as "*the property of matter and radiation that is manifest as a capacity to perform work (such as causing motion or the interaction of molecules)*" (Oxford Dictionary, 2016)*,* and from this definition it is possible to start. This ability to perform work which is not created or destroyed is called the law of conservation of energy. The first to discover or publish this law was the father of modern chemistry, the chemist Lavoisier in 1789 in his book Elements of Chemistry in a New Systematic Order Containing All the Modern Discoveries (original French title "*Traité élémentaire de chimie*"). It was adopted by Einstein when he discovered that matter was a type of potential energy. Humankind can obtain energy from many resources, and these resources are divided into two main groups according to the origin: Non-renewable and renewable; United Nations made a classification on its report 29E, on page 4 there is section E "New sources of energy" renewables are mentioned in the Table 3, (Gritsevskyi, 2006).

Table 3 Classification of energy

Type	Renewability		Renewable	Non-renewable
Conventional	**Commercial**		Hydropower (large scale) Geothermal Nuclear (breeder)	Fossil fuels Nuclear
	Traditional	**Other**	Solar (air drying) Hydro (mills, pumps) Wind (mills, pumps and sails) Animate (animal and human)	
		Biomass	Fuelwood "cropping" from natural forest/charcoal Twigs, leaves, sticks Crop residues (straw, husks) Animal residues (dung, tallow) Industrial residues (wood waste, sawdust)	Fuelwood "mining" Charcoal
Non-conventional	**Novel**		Plantation and marine crops (for distillation, pyrolysis) Biogas	
		Other	Solar (collectors, photovoltaic) Hydro (mini and micro) Wind (wind motors) Tidal, wave power Ocean thermal gradients Heat pumps	Nuclear Petroleum from coal, shale Synthetic natural gas

Source: (Gritsevskyi, 2006)

2.2.1 Bioenergy

According to the U.S. Department of Energy (2010), bioenergy is a type of energy coming from biological resources such as a waste wood, wood, straw, manure, and many others; this material is called biomass and its share is 11% of the global energy supply, see Chart 2.

Between 1990 and 2009 bioenergy supply increased from 38 to 52 exajoules (EJ) as a result of growing energy demand. New policies to increase the share of renewable energy and indigenous energy resources are also driving demand, as reported by World Energy Council (2013).

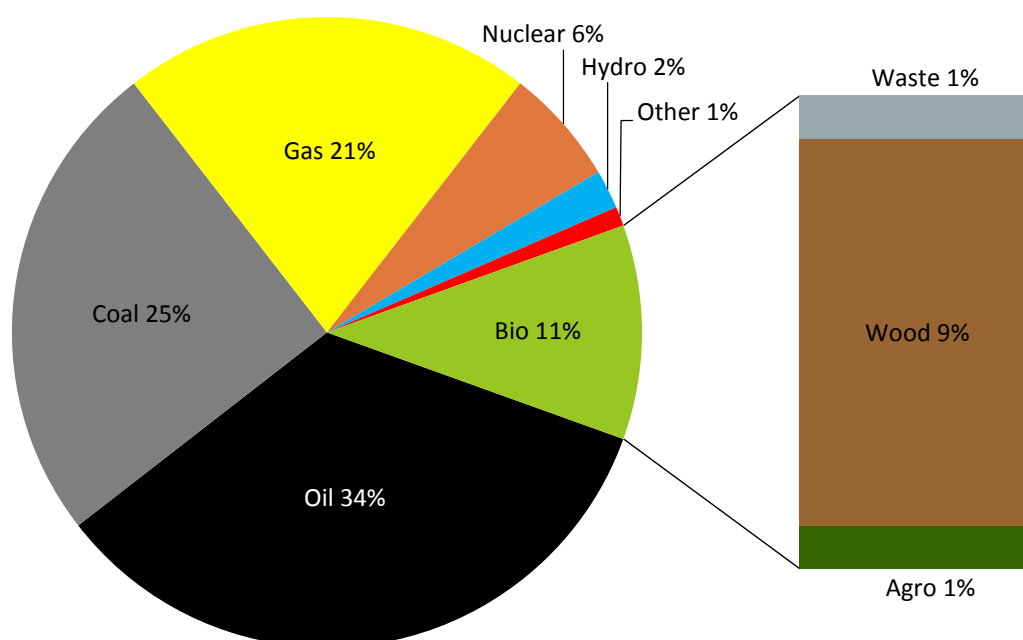**Chart 2 Share of bioenergy on global energy supply**
Source: International Energy Agency (IEA) (2009) www.iea.org

Biomass classification according to the origin

- **Natural**

Produced in natural ecosystems.

- **Residual**

Forest residues comprising forestry treatments and cuts of timber;

Agricultural waste: including trimmings, crop residues;

Waste Forest Industry representing sawmills, pulps, papers;

Waste agricultural industries including husks, skins, shells, vinasse, and bones;

Biodegradable waste referring to the slurries, manures, sludges from sewage treatment plants, bones, tallow.

- **Energy crops**

Woody species shifts 3-4 years and 10,000 feet/ha (Populus);

Herbaceous species (Miscanthus, Ciara);

Crops for ethanol production (wheat, corn, artichoke, sweet sorghum);

Crops for biodiesel (rapeseed, sunflower, linseed).

- **Agricultural**

Excess of biomass to complete the non-food crops and biofuels and partially replacing fossil fuels (oil, cottonseed oil, soybean oil, safflower oil).

This biomass classification was interpreted from (Delagado, 2008).

- **Residual biomass**

Residual biomass can be well-defined as the biomass materials generated in the activities of production, processing and consumption in the context in which they are generated and have no economic value (McKendry, 2002).

- **Agricultural waste**

Agricultural waste includes all parts of the food or industrial crops that are not consumable or marketable. They are a highly heterogeneous series of products with the common denominator of a great difficulty of removal, having as already mentioned, in many cases a high polluting potential, (Johnson, 2008). Agricultural waste can be classified into three types: firstly, **roots, leaves and unusable fruit**, these residues are incorporated into the soil and contribute to significantly improve the physical and biological properties of the soil and to a lesser degree to increase the nutrient content of the soil (OECD and EUROSTAT, 2007). Secondly, **stems or branches**, waste energy potential interest, these are generally lignocellulosic waste that are usually burned in their farmland. This category of waste includes straws of grain cereals and stover corn, some industrial crops such as textiles and oilseeds (sunflower, cotton) and annual pruning fruit trees and vineyards that in the past were used as domestic fuel but now they constitute a disposal problem; the branches are generally used as fuel in boilers, furnaces. Thirdly, **forest residues,** with the annual logging led to

the recovery of lumber and logs uncorked, while bark, branches, and leaves (about a third of the tree) remains on the ground to appear as waste (IFA, 2006; Nations, 2003).

Advantages and disadvantages of biomass

- **Advantages**

Biomass is a renewable source of energy, and its use does not contribute to accelerating global warming; in fact, it reduces levels of carbon dioxide and waste conversion processes (Australian Institute of Energy, 2004; UNIDO, 2010); captures of methane from agricultural waste and landfills, and acts as a replacement of petroleum, helping to mitigate the greenhouse effect and pollution of aquifers. Biomass fuels contain insignificant levels and do not contribute to sulphur fumes causing "acid rain"; combustion of biomass produces less ash than coal and can be used as input in organic soils (McKendry, 2002). Also, biomass is a local resource that is not subject to fluctuations in energy prices, caused by changes in the international market of fuel imports. In developing countries, its use would reduce the economic pressure imposed on imports of petroleum products (The Global Commission on the Economy and Climate, 2014); and use of biomass resources may stimulate rural economies, creating more job options and reducing economic pressures on agricultural and forestry productions as reported by the International Energy Agency.

- **Disadvantages**

By their nature, biomass has relatively low energy density; that is, its availability is required in large volumes to produce power, compared with fossil fuels, so the transportation and handling are expensive and net energy production is reduced. The key to this problem is to place the conversion process near the sources of biomass production, such as mills, sugar mills, and farms, where sawmill waste, bagasse, and animal excreta are present (Balan, 2014). Furthermore, its incomplete combustion produces organic matter, carbon monoxide (CO) and other gases and if combustion is used at high temperatures. Nitrogen oxides are also produced. On a domestic scale, the impact of these emissions on family health is important (Jacob, 2013). Additionally, there is no generalized economic and political platform to facilitate the development

of biomass technologies in terms of taxes, subsidies, and policies covering, in general, any regulations worldwide (Schock et al., 2007).

Biomass composition

Lignocellulose is the botanical term used for biomass from wood, being a combination of cellulose, hemicellulose, and lignin; the ratio of the components may vary from different species (Sims et al., 2008), even between roots, stems and trunk. Other factors which have influence are age and stage; but generally cellulose and hemicellulose comprise 50% up to 75% of the biomass and 20-25% lignin (Jeffries, 1994; Tullus et al., 2010). So it is possible to infer that the ratio/relation is Cellulose:Hemicellulose:Lignin; is 2:1:1, as it shows the chart below.
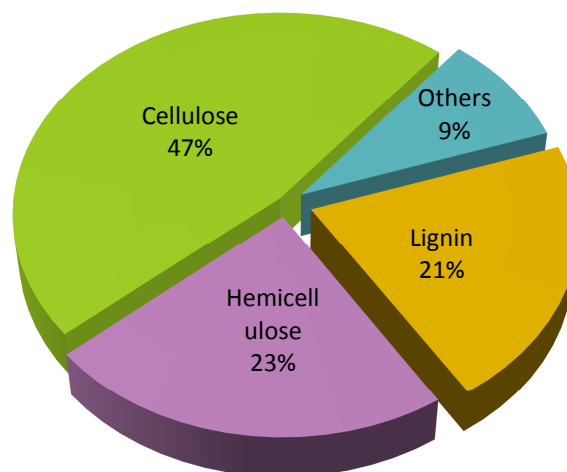
Chart 3 Biomass composition
Source: (Author, 2015)

- **Cellulose**

Is the main component of biomass, is a polysaccharide composed linked by β-1.4, being each glucose molecule reversed about each other (Yokoyama, 2008), the linearity of the structure enables a strong bond between the microfibrils. The crystallinity confers resistance to hydrolysis due to the absence of water in the structure and the strong bond between the glucose chains prevents hydrolases (Basso et al., 2013).

- **Hemicellulose**

Usually this is the second most abundant compound, and is the linking material between cellulose and lignin. The C5 and C6 sugars, linked through 1.3, 1.6 and 1.4 glycosidic bonds and often acetylated, form a loose, very hydrophilic structure that acts as a glue between cellulose and lignin (Bon and Ferrara, 2010). Wood hemicelluloses are short (degree of polymerization within 100 to 200), refers to a group of homopolymers and heteropolymers consisting largely of anhydrous-b-(1→4)-D-xylopyranose, mannopyranose, glucopyranose, and galactopyranose main chains with some substituents (Jeffries, 1994; Reid, 1995). Depending on the predominant sugar type, the hemicelluloses are referred to as mannans, xylans or galactans.

- **Lignin**

Lignin is a polymer of aromatic subunits usually derived from phenylalanine (Whetten and Sederoff, 1995)**,** furthermore, is anamorphic three-dimensional and highly disperse (Reid, 1995). Chemically, lignin is not a strictly defined molecule, being characterized by a significant amount of variation in its chemical composition however its structure have been described in softwood lignin, e.g. dibenzodioxin structures (Tullus et al., 2010).

Characteristics of the biomass

There are six important properties of biomass related to thermal conversion: moisture content, bulk density, ash content, calorific value, volatile matter content; elemental composition; in the following paragraphs a brief explanation of each of these thermal properties will be given. However, because there are different ways of being calculated, the only formulas that follow in this study are those that refer to standards, and are given through methodology.

Also in the Table 4 is summarized the effects of biomass properties related to the thermal conversion.

- **Moisture content**

The moisture content of biomass basically is the amount of water in the material and is given as a percentage of the weight material (Canadian Biomass Energy Research L, 2010), this weight can refer on **wet basis** in this case the total weight means total sum

of: water + ash + ash free dry matter, on the other hand moisture content on **dry basis** in this instance the total weight means total sum of: ash + ash free dry; finally, the moisture content can be expressed as a percentage of the content of ash-free dry matter. In the latter case, the weight of water is related to the weight of the dry biomass. Because the moisture content affects the value of the biomass fuel, based on which the moisture content is measured to be always specified (Govett et al., 2010).

- **Bulk density**

Bulk density refers to the mass of material per unit of volume. To this biomass, it is usually expressed on a dry basis (moisture content; MC = 0%) or on a basis as is received, with a corresponding indication of the moisture content (MC). Similar to the moisture content of biomass, biomass bulk densities show an extreme variation lows of 150-200 kg/m^3 for cereal grain straw and high of 600-900 kg/m^3 for solid wood. Together, the calorific value and bulk density determine the energy density, the potential energy available per unit volume of biomass. In general, the densities of biomass energy are about one tenth of fossil fuels such as oil or coal with high quality (McKendry, 2002).

- **Ash content**

Ash is the inorganic compound consisting of minuscule particles released after combustion it can be either structural or extractable; structural ash is bound in the physical structure of the biomass while extractable ash is inorganic material that can be removed by washing or extracting the material (Sluiter et al., 2004). Ash, as the moisture content can be expressed on a wet, dry, or dry ash free basis. The ash content is usually expressed on a dry basis. Ash behaviors during combustion are closely related to the characteristics of biomass. For example the melted ash may cause problems in reactors combustion and gasification (Shao et al., 2012), nevertheless is possible to release the ash on soil, to help return the mineral content to the ground, however owing to the potentially very high concentration of minerals it is important that this is done with caution. In particular, if there is the potential presence of heavy metals or arsenic in ash, it must be checked before the ash is used in this way. Alternatively, ash may be used in the manufacture of construction blocks and cement (Verheijen et al., 2010).

- **Calorific value**

The gross calorific value is the most important measurement in biomass for the reason that it indicates the amount of energy contained in the mass (weight) and is released as heat in its complete combustion with oxygen in a calorimeter standardize. It is defined as the amount of heat energy released during the full combustion of a unit mass of biomass (Moka, 2012). The calorific value of fuel is an indication of the energy chemically bound in the fuel concerning a standardized environment; it is measured in joules by the amount of matter (Trasnco, 2008).

It is considered that the calorific value of the biomass can vary between 3,000-3,500 kcal/kg for ligno-hemicellulose waste, 2,000 to 2,500 kcal/kg for municipal waste and 10,000 kcal/kg for fuel liquids from energy crops (Kalembkiewicz and Chmielarz, 2012). Calorific value can be: firstly, gross calorific value (GCV), also denominated as higher heating value (HHV), measured in a calorimeter, and is defined as the heat remaining in all elements of combustion once it is cooled down to the original pre-combustion temperature. The heat of water condensation is included in this calculation. Secondly, net calorific value (NCV), also called low heating value (LHV), is calculated by deducting the heat of water evaporation from the GCV, (Aliapur, 2014; Owens and Cooley, 2013). NCV is generally used or measured in solid biofuels because they usually contain some amount of water prior to burning; GCV is relevant for gas burnt in condensing boilers which condense the water vapour produced by combustion (Baskar et al., 2012).

- **Volatile matter content**

Volatile matter content is defined as a mass loss when fuel is heated (400 °C to 500 °C) out of contact with air under specific temperature; the biomass decomposes into volatile gases and coal burning solid. The biomass typically has a high volatile matter content (up to 80%), whereas coal have a low volatile matter content (below 20%) (Lee, 2007; Riva et al., 2012; Sorathia et al., 2012).

- **Elemental composition**

The composition of the free organic component biomass is relatively uniform. The main components are carbon which usually from 44% up to 49% for wood; oxygen, and hydrogen. Most biomass also contains a small proportion of nitrogen (Marie-rose et al., 2008). For example is relevant to determine ash content because it can be

released to the atmosphere. Also, the content of sulphur may affect the furnace, causing corrosion (Stolarski, 2008).

Table 4 Effects of different elements during process of biomass into energy

	Properties	Effects
Physical	**Moisture content**	Storage durability
		Dry-matter losses
		Low NCV
		Self-ignition
	Bulk density	Fuel logistics (storage, transport, handling) costs
	Ash content	Dust, particle emissions
		Ash utilization/disposal costs
	Particle dimension and size distribution	Determines fuel feeding system
		Determines combustion technology
		Drying properties
		Dust formation
		Operational safety during fuel conveying
Chemical	**Carbon, C**	GCV (positive)
	Hydrogen, H	GCV (positive)
	Oxygen, O	GCV (negative)
	Chlorine, Cl	Corrosion
	Nitrogen, N	NOx, N_2O, HCN emissions
	Sulphur, S	SOx emissions, corrosion
	Fluor, F	HF emissions
		Corrosion
	Potassium, K	Corrosion (heat exchangers, superheaters)
		Lowering of ash melting temperatures
		Aerosol formation
		Ash utilization (plant nutrient)
	Sodium, Na	Corrosion (heat exchangers, superheaters)
		Lowering ash melting temperatures
		Aerosol formation
	Magnesium, Mg	Increase of ash melting temperature
		Ash utilization (plant nutrient)
	Calcium, Ca	Increase of ash melting temperature
		Ash utilization (plant nutrient)
	Phosphorus, P	Increase in ash meting point
		Ash utilization (plant nutrient)
		Emissions of pollutants
	Heavy metals	Ash utilization and disposal issues
		Aerosol formation

Source: (Malisius et al., 2000), (Van Loo and Koppejan, 2007)

Processes of biomass conversion into energy

From the standpoint of energy efficiency, the biomass is characterized by a low carbon content as was mentioned before; around 45% in comparison for example with coal, which is approximately 85%; and a high oxygen content and volatiles. These volatile compounds are concentrating much of the calorific value of the biomass (Wood and Branch, 1986). The calorific value of the biomass depends on the type of biomass considered and the moisture content. Moreover, normally these calorific values of biomass can occur on a dry or wet basis. These features, together with the low sulphur content of biomass, make it a particularly attractive product to be exploited for energy. Notably, from the environmental point of view, the energy use of biomass does not contribute to increased greenhouse gases, since the balance of CO_2 emissions into the atmosphere is neutral, (Stelte, 2011).

In effect, the CO_2 generated by the combustion of biomass is reabsorbed by photosynthesis in growing plants necessary for their production and, therefore, does not increase the amount of CO_2 in the atmosphere. On the contrary, in the case of fossil fuels, the carbon released into the atmosphere is one that is fixed to the earth for millions of years, (Agroindustrial Ministry of Argentina, 2011).

From the energy point of view biomass is convenient to divide into two groups:

- **Dry biomass**

Dry biomass with a tenor of less than 60% moisture, such as wood, straw. This type is better suited to be used as energy by thermochemical processes or by-products in the form of gaseous, solid, liquid (Sun and Cheng, 2002);

- **Wet biomass**

Wet biomass when moisture content excesses 60%, such as in the remaining plant, manure, or aquatic vegetation. It is particularly suitable for treatment by chemical processes, obtaining liquid and gaseous fuels (Rodriguez Perdigón, 2014).

Biomass resources can be converted into energy by three different types, biological conversion, chemical conversion and thermal conversion. These three types are subsequently divided into different methods which are mentioned in the following picture.
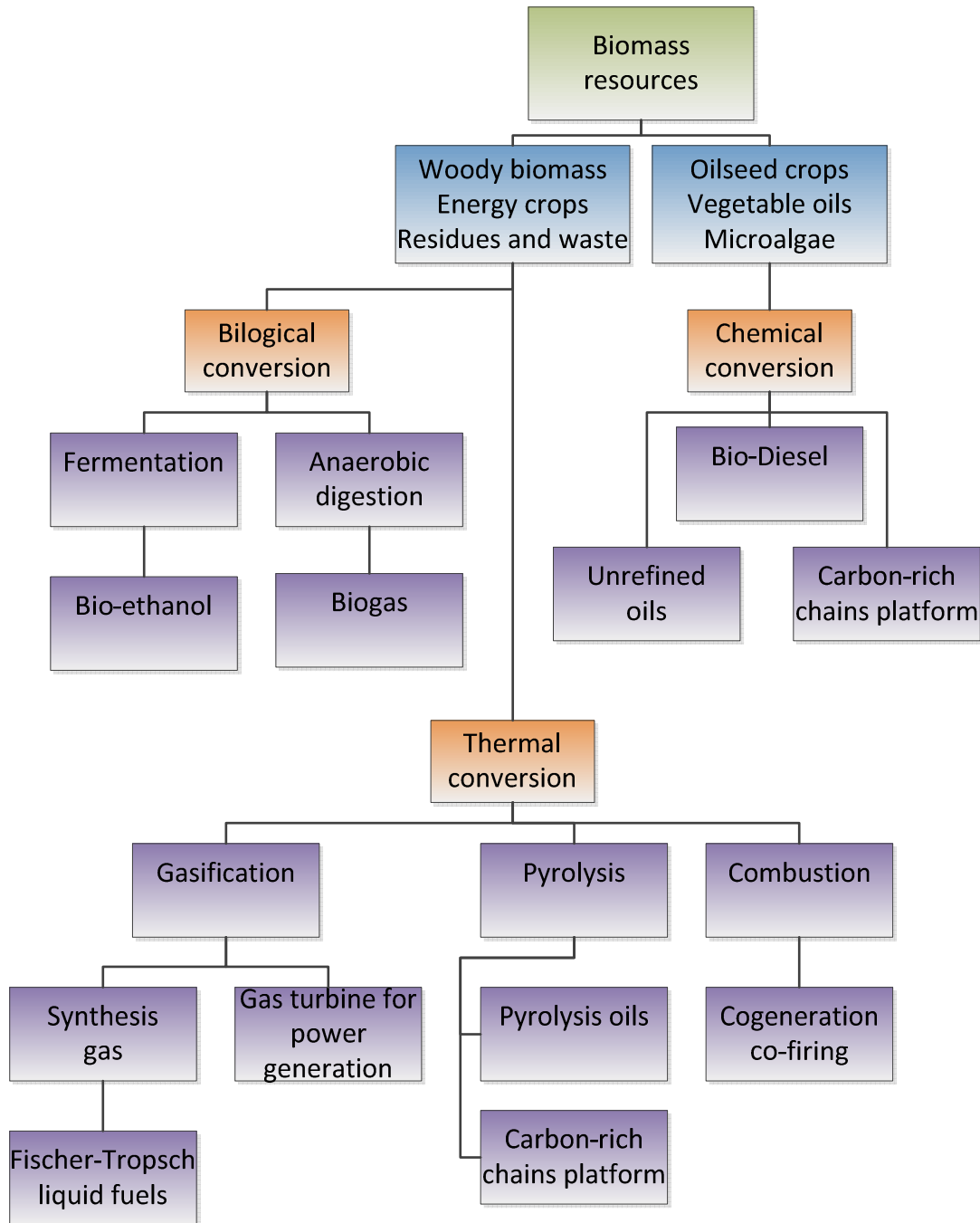
Figure 2 Conversion options for bioenergy
Source: (Johnson, 2008)

Thermochemical processes

There are three: combustion, gasification, and pyrolysis, and there is, still in the development stage, liquefaction (Sims et al., 2008).

- **Combustion**

Combustion is the simplest and most widely used, both past and present. It allows for thermal energy, either for domestic or industrial purposes, for example cooking, heating, steam in a boiler, or steam mechanical energy using a machine. The technologies used for direct combustion of biomass cover a broad spectrum from the simple open fire still used for cooking to high-efficiency boilers used in industry (Uhlenberg, 2009).

- **Gasification**

Gasification involves the burning of biomass in the presence of oxygen in a controlled manner so as to produce a combustible gas called "lean gas" for its low-calorie content in relation, for example, natural gas; about 25%. The gas is carried out to a closed basin, known gasifier, in which fuel and a smaller quantity of air introduced. The gas obtained can then be burned for thermal energy in a boiler to produce steam or be cooled and packaged for use in an internal combustion engine (Wood and Branch, 1986).

- **Pyrolysis**

Similar to the gasification process, but the combustion occurs in the absence of oxygen and is performed to obtain as a product a variable combination of charcoal, liquids, and treated gas. Commonly, the main product of pyrolysis is charcoal, with liquids and gasses considered by-products of the process. The pyrolysis products took full advantage of its great height before the massive spread of oil, since that was the only source of certain substances (acetic acid, methanol) (Jeong et al., 2014), which are now produced by the petrochemical process. Today, only the production of charcoal is of quantitative importance. Charcoal as a solid fuel has advantages over biomass; it has a higher caloric value orfor a lower weight for the same amount of power; allowing easier transport. However, it should be noted that the carbonization represents a major loss of energy present in the raw material because the process consumes large amounts of it, (Agroindustrial Ministry of Argentina, 2011).

Densification process

Biomass, in its natural form, is difficult to successfully use as an energy resource in large-scale applications because its density is low, has a high moisture content wet, and is naturally dispersed (Wright et al., 2010). The densification process embodies optimization of converting wasted biomass into biofuel. Densification technology includes processes such as pelleting, briquetting, or agglomeration, which improves characteristics of the materials for transportation, storage, burning. Pellets and briquettes have been used for many years in several regions of the world. William Smith was the first to be issued a United States patent (1880) for biomass densification. Using a steam hammer (at 66 °C), Smith compacted waste from sawmills (Grover and Mishra, 1996).

It is well known that one of the major disadvantages of biomass is its low bulk density, typically ranging from 70-100 kg/m^3 for agricultural straw and grasses and 150-200 kg/m^3 for woody biomass, like wood chips (Tumuluru et al., 2011). The low bulk densities of biomass usually represent a problem for transport storage and use. Low density is a problem if the biomass is using as a co-firing, facing problems for feeding the fuel into the boiler and with reduced burning efficiency. Densification is one promising option for overcoming these limitations. During densification, biomass is mechanically compressed, increasing its density. Generally, densification of biomass is performed using pellet mills, other extrusion processes, briquetting presses, or roller presses in order to help overcome feeding, storing, handling, and transport problems (Tumuluru et al., 2011; Mitchell, 2013; Miao et al., 2015).

- **Pelleting**

In a pellet mill, which basically consists of a cylinder with press channels and roller that push the material into the canal; by rotation the friction between the steel surface and the biomass in the press channel produce high pressure to the biomass, on the other side of the channel the biomass already pressed flows out of the system, and the endless material is cut by knife or a sharp surface called die, forming the pellets (Obernberger and Thek, 2004; Stelte, 2011).

- **Briquetting**

Briquetting is one type of compaction technology in the category of densification. Densification of biomass aims to improve its bulk density, reduce the size, uniform the shapes between pieces and homogenize properties (Cosgrove-davies, 1985). Flow chart of the briquetting particular sub processes is displayed in the following picture.
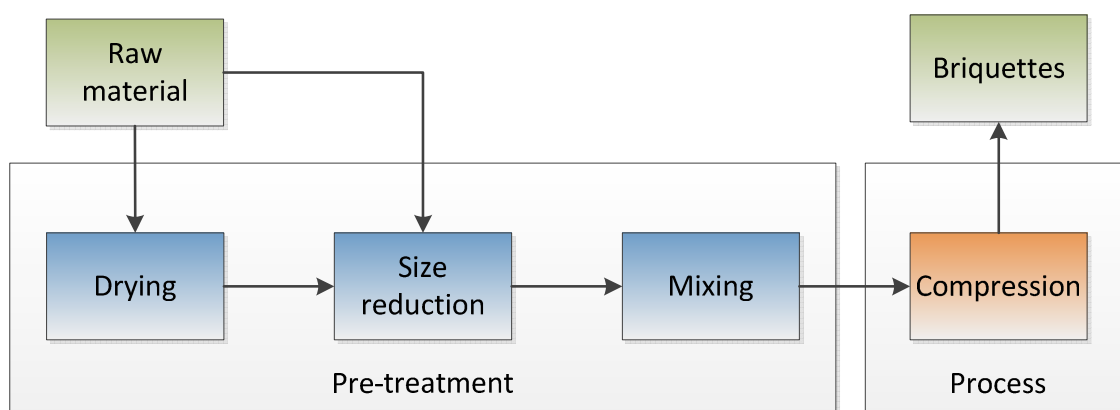
Figure 3 Briquetting process
Source: (www.briquette-machine.com, 2016)

There are two types of biomass briquetting technology. The EU and the United States have the piston press and the screw press, while Japan and South Asia has developed screw press technology. Nonetheless, both technologies have their advantages and disadvantages; it is universally accepted that the screw pressed briquettes are far superior to the ram pressed solid briquettes in terms of their storability and combustibility, (Grover and Mishra, 1996), but in using any of the two types of technology the flow process is the same.

Source: (Author, 2016)

Once the raw material is collected, it must be located in a close location to the briquets machine for processing; this place must be covered to prevent ambient influence such as rain, soil contact (which causes contamination), moisture content raising and so on. The method of pretreatment depends on the particular properties of the material being briqueted. (Adapa et al., 2009).

- **Pelleting and briquetting differences in properties**

Briquette processing, in contrast to pelleting, can be more efficient because the biomass materials do not necessarily have to be pre-processed as much which results

in less time and energy in pre-processing (Obernberger and Thek, 2004). Briquetting waste by-products and reusing them on site for energy rather than transporting them to another location or to a landfill can save on disposal costs (Wright et al., 2010). Briquetting generally uses less power. The initial investment, maintenance costs and returns on invested capital (ROIC) to make briquettes are less than for pellets (Wright et al., 2010). Pellets have been considered more of a residential fuel even though they are used in some larger commercial applications. If transportation is one of the main criteria, pellets are more advantageous because there are more kilograms per meter than briquettes. This is particularly the case if the briquettes are larger because it allows for more air between them when they are stacked (Austin, 2010).

o **Drying**

During storage the moisture content of some material can be reduced below 15%, which is suitable for compressing. On the other hand, some feedstock fed into the briquetting press, often wet, may still be dried as the process continues (Nussbaumer, 2003). Drying can be done in the sun, with a heater, hot air, or rotating drum. This step can swap position with the size reduction process (Martínez-Lozano, 2009).

o **Size reduction**

Firstly to be suitable for briquetting the material must be reduced to smaller parts; this process can be done by chopping, breaking, grinding, milling, cutting, and others, until reaches a suitable size and homogeneity (Cosgrove-davies, 1985). This size reduction should be as short as possible in order not to increase energy consumption; as stated above, some materials do not need this step.

o **Mixing**

The prepared feedstock can include a mixing method which consists, as the name implies, of the mix the raw material with any binder substance that can vary widely in types in order to improve compaction and reduce the abrasion (Cosgrove-davies, 1985). It is recommended to determine the correct ratio between raw material and binder substance before start full-scale production by a trial and error method making several briquettes with different binder concentrations, then testing for mechanical and burning properties. This process, simmilar to drying, can affect the economic

balance of the production if the smallest amount of binder needed is not adequately set.

- o **Compression**

As was stated before, there are two types of technology for briquetting: the piston press and the screw press.

- o **Piston press**

High-pressure mechanical hydraulic piston press systems take the electric energy from the motor/engine and transmitt it to the piston, pressing the biomass. The output of a hydraulic piston press is lower compared to mechanical processes. The briquettes have a bulk density lower than 1,000 kg/m^3 because the pressure is limited to 40-135 kg/h. However, these machines can tolerate higher moisture contents than the usually accepted 15% (Wright et al., 2010).

3 Aims of the thesis

3.1 Problem formulation research

Is the biomass from guava (*Psidium guajava L.*) wood pruning suitable for solid biofuel; fulfilling the minimum quality requirements (quality control) according to the international standards?

3.2 Overall objective

The main objective of the thesis have been to determine the suitability of biomass from guava (*Psidium guajava L.*) wood pruning, used as an energy resource; under international standards of quality.

3.3 Specific objectives

The main aim is supported by the specific objects which are set in order to help to fulfil the main goal and conclude if the biomass is suitable or not under the standard EN 17225-3:2014.

The specific aims are following:

- To determinate the physical and mechanical properties of guava wasted biomass
- To determinate the chemical properties of guava wasted biomass
- To determinate the mechanical properties of briquettes produced from guava (*Psidium guajava L.*) wood.

4 Methodology

4.1 State of the art and literature review methodology

For elaboration of the theoretical part of the thesis, it was divided in two parts, firstly was important the literacy specifically about guava (*Psidium guajava L.*) such a morphology, cropping and harvesting, then the context where the topic is located, means all concerned to biomass, briquettes, pellets, compaction; including physical, chemical and mechanical properties, standardization for briquette; secondly related to the use of guava wood for biofuel purposes, searching in available sources and literature in Spanish, Portuguese and English in scientific databases mainly from Scopus, Science Direct, Agris, Agricola, Worldwide science among other web of Science.

4.2 Practical research methodology

4.2.1 Material

Owing to brotherhood between Northern Technical College, Ecuador and Department of Suitable Technologies, FTA-CULS; it was possible get sample (15 kg) of *Psidium guajava L.*, on October 2015, recollection was made in field of "Lita" with an area of 5 ha closed to small community located in the province of Imbabura 100 km from the city of Ibarra, Ecuador on 1st of May 2015.

Ministry of agriculture of Ecuador (2009) reported that the time between flowering and fruit maturation is 3 months; there are 2 crops per year; it may differ depending on raining seasons, Figure 4. It is also reported that the second harvest season has higher production potential related to the rainy season. The precipitation and average temperature are shown in the Chart 4.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

■ pre-harvest pruning
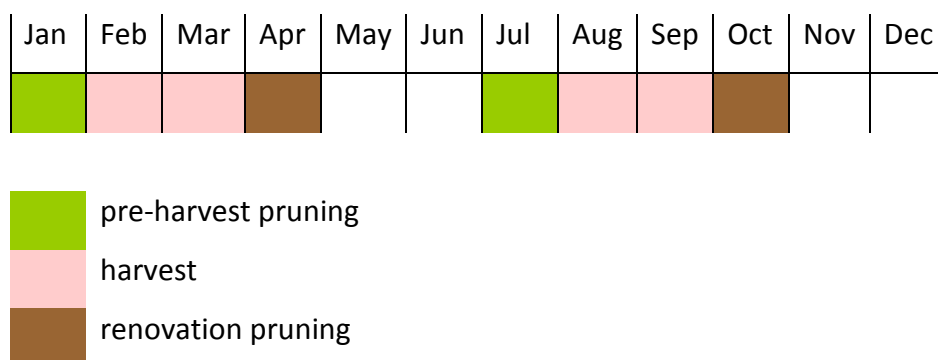
■ harvest

■ renovation pruning

Figure 4 Crop calendar of guava in Ecuador
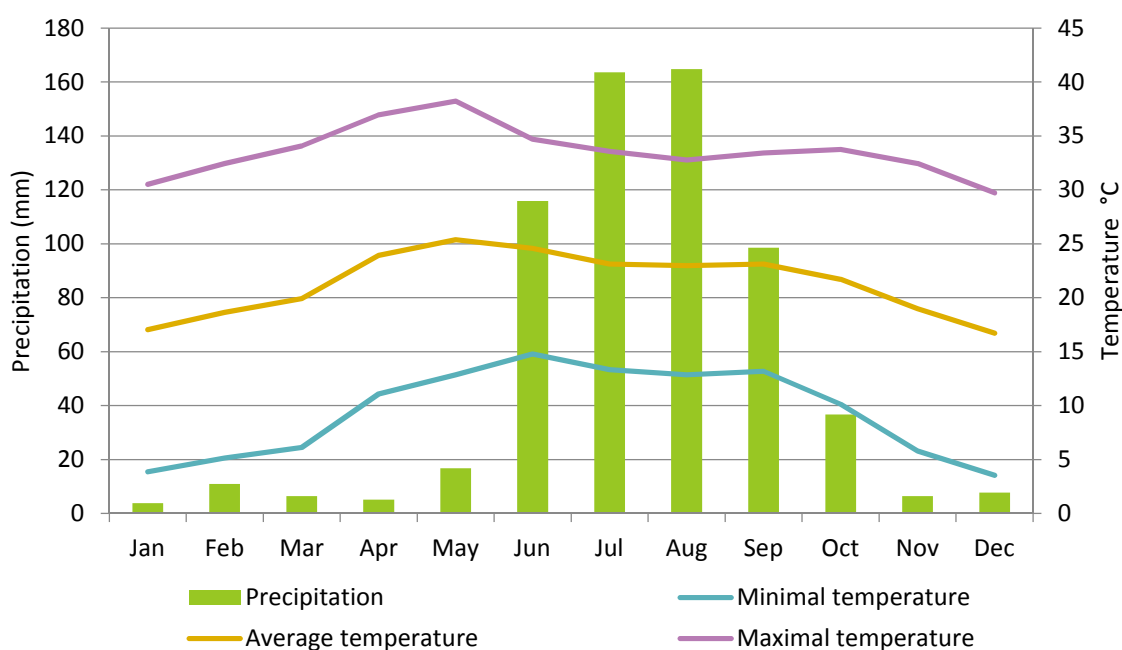Source: (Ministery of agriculture of Ecuador, 2009)

Chart 4 A climate chart for Ibarra, Ecuador for 2012
Source: (Ministry of Agriculture of Ecuador, 2012)

The figures below show the tree before and after the pruning. The biomass waste material produced was measured as 12.5 kg per tree (Author, 2016).
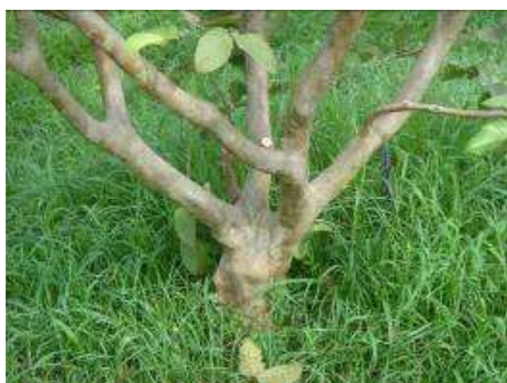
Figure 5 Guava tree before renovation pruning
Source: (Barrantes, 2014)
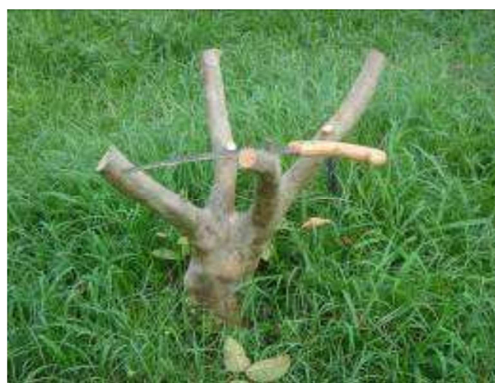
Figure 6 Guava tree after renovation pruning
Source: (Barrantes, 2014)

Sample preparation

15 kg of *Psidium guajava L.* were received from this sample and was divided into two sub-samples one with 200 g weight and second one with the rest, which means 14.8 kg; subsample one was firstly crushed into pieces of 20 mm and then ground by hammer mill; IKA® MF 10.1, afterwards it was homogenized in a knife mill; Grindomix GM 100, meanwhile, the other samples were used for briquetting.

4.2.2 Briquetting and grinding

Briquetting

Material grinding consisted of two operations. Firstly, guava wood biomass was cut by shredder AL-KO New Tec 2400R into the pieces of 20 to 30 mm. Secondly, hammer mill 9FQ-40C with sieve holes' diameter of 6 mm was used.

The grinded material was briquetted by hydraulic piston briquetting press BrikStar CS 50 (Briklis) with the diameter of pressing chamber of 50 mm, under the working pressure of 18 MPa.

Furthermore it is necessary to declare if any binding agents were added. Also, the sample was not mixed with any other type of biomass; ambient temperature was 10 °C with a humidity of 58%.

Determination of length and diameter

The diameter and length were determined for produced cylindrical briquettes according to the EN 17225-1:2014 and EN 17225-3.2014. From the pile of briquettes obtained, 10 of them were picked out to be measured by using Digital caliper (Figure 7), both length, and diameter. The average was used for interpretation of results.

Apparatus: Digital caliper

Figure 7 Digital caliper
Source: (Author, 2016)

Calculation:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$ **(1)**

Where:

$\bar{x}$ - is the mean;

n - is the number of values;

x_i - is the last value.

Formula was used for calculation of diameter and length.

Determination of mechanical durability

Mechanical durability was determined to meet the standard EN 15210-2:2009, and done with rotating durability drum. The process was repeated four times; with approximately 2 kg of weight each sample (m_E). Once the briquettes were placed into the drum (Figure 8) and rotated 105 times during 5 minutes, all of the material was transferred to a sieve, through which, the small particles were separated, with the briquettes remaining on the sieve (m_A).

Apparatus: Drum briquette tester, with 598 mm of internal diameter and baffle of 200 mm; sieve; balance, PCE-BS.

Figure 8 Drum briquette tester
Source: (Author, 2016)

Calculation:

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

(2)

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.

4.2.3 Determination of guava biomass and briquettes properties

Measurements of physical, chemical and mechanical properties of guava biomass and briquettes were realized during the period between October 2015 and January 2016. Above mentioned measurement were conducted in the following institutions and laboratories:

- Czech University of Life Sciences Prague: Laboratory of biofuels, Faculty of Tropical AgriSciences; Laboratory of the Faculty of Engineering; Laboratory of environmental chemistry, Interfaculty Centre of Environmental Sciences;

- Research Institute of Agricultural Engineering: Bioenergy centre;

- University of Chemistry and Technology Prague: Laboratory of organic chemistry, Laboratory of environmental chemistry.

Physical and mechanical properties

Determination of moisture content

Following the standard EN 14774-3:2009, determination of total moisture content (W) was measured by the oven dry method, in accordance with this method the material already treated (grained), was placed in the baker which was weighed prior, sample and baker were weighed together (m_w) (Figure 9) and introduced into the drying oven (Figure 10) with controlled temperature at 105 °C for 3 hours. After this drying process (Figure 11) the sample was measured (m_d); subsequently the process was repeated n times until the difference between procedure n and n-1 stood equal or less than 0.2%.

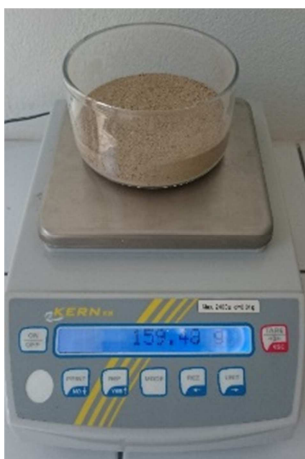**Apparatus:** Drying oven, Memmert series 800-100; balance, PCE-BS; beakers.

Figure 9 Measuring sample
Source: (Author, 2016)

Figure 10 Drying oven
Source: (Author, 2016)
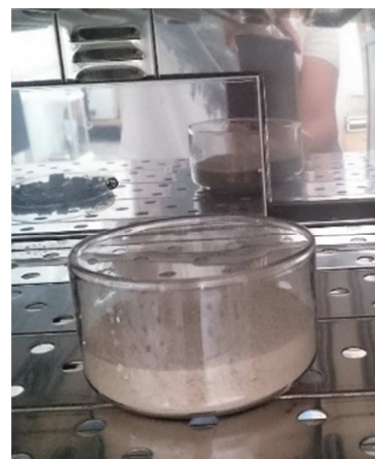
Figure 11 Sample in the dryer
Source: (Author, 2016)

Calculation: moisture content in the analytic sample expressed as a percentage was calculated using the following equation.

$$W = \frac{m_w - m_d}{m_w} \times 100 \ (\%)$$

(3)

Where:

W - is the moisture content (%);

m_w - is the mass in g of the baker and sample before drying;

m_d - is the mass in g of the baker and sample after drying.

Determination of ash content

In concordance with the standard EN 14775:2009.; ash content (A_d) was determined by analysing about 1 g of the sample, spread in the bottom surface of the crucible. It should be remembered that the sample was dried at 105 °C prior; then the dish was placed in a cold furnace (Figure 12) and heated from ambient temperature to 250 °C over a period of 30 mins and then retained at this temperature for 60 mins more. This was done in order to allow the volatile matter content to leave before ignition; then from that time (90th minute of the whole procedure) the temperature was raise once again to 550 °C over a period of 30 mins and lastly this temperature was maintained for a period of 120 mins (from 120th minute to 240th minute of the whole procedure) when the 240th minute was reached, the sample was removed from the furnace and left in ambient temperature to cool down. Finally the ash remaining in the crucible was weighed. To ensure the results, the determination was measured twice. The difference between measurements did not exceed 0.2%.

Apparatus: Muffle furnace, LAC LH 06/13; balance, RADWAG AS/220/C/2; crucible.

Figure 12 Muffle furnace
Source: (Author, 2016)

Calculation: Ash content on dry basis expressed as a percentage was calculated using the following equation.

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

Where:

A_d - is the ash content in anhydrous condition (%);

m_1 - is the mass, in g, of the empty crucible;

m_2 - is the mass, in g, of the crucible plus the test sample;

m_3 - is the mass, in g, of the crucible plus ash;

M_{ad} - is the moisture content of the test sample used for determination (%).

Determination of calorific value

Calorific value was determined under the standard EN 14918:2009; before the process, the sample was prepared from the material already ground to approximately 1 g, having been compressed in an unbreakable test piece. With the piece already in the crucible, the fuse was attached to the cotton thread (Figure 13) and then in contact with the sample, water was added to the bomb (lower part). Having readied all components, the bomb was assembled and placed into the calorimeter. At this point the calorimeter (Figure 14) was configured (Figure 15) with the information on requiring such at sample weight, amount of water, initial temperature.

Apparatus: Automatic calorimeter, IKA C6000; digital balance, RADWAG AS 220/C/2; crucible; pellet press.

Figure 13 Attaching the cotton thread
Source: (Author, 2016)
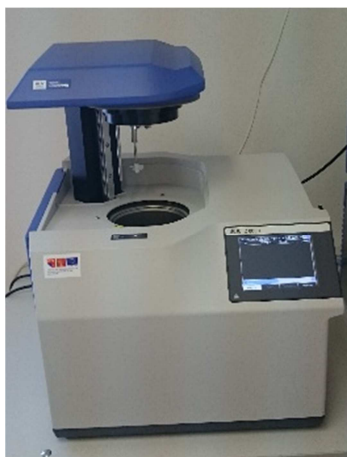
Figure 14 Calorimeter
Source: (Author, 2016)
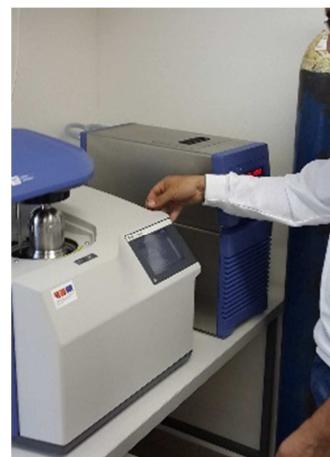
Figure 15 Setting the calorimeter
Source: (Author, 2016)

Calculation:

Net calorific value:

$$Q_{net} = Q_{gr} - 24.42 \times w + 8.94 * H^a \qquad \textbf{(5)}$$

Where:

Q_{net} - is the net calorific value in J/g;

Q_{gr} - is the gross calorific value in J/g;

24.42 - is the coefficient corresponding to 1% of the moisture from the sample at 25 °C;

w - is the water content in the sample (%);

8.94 - is the coefficient for conversion of hydrogen to the water;

H^a - is the hydrogen content in the sample (%).

Determination of the volatile matter content

The crucible and lid (m_1) were placed into the furnace at 900 °C for 7 minutes. Once the time had passed it was removed from the furnace and allowed to cool down and weighed. The test sample was poured into the cold crucible (m_2), then transferred to the furnace for 7 minutes more. After this time the sample was removed and let cool down till 50 °C above room, once the sample reached the temperature (50 °C + 18 °C), it was weighed once again(m_3). The method was performed based on the EN 15148:2009.

Apparatus: Muffle furnace, LAC LH 06/13; Crucible; crucible stand; thermocouples.

Calculation:

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

Where:

V_d - is the volatile matter (%);

m_1 - is the mass, in g, of the empty crucible and lid;

m_2 - is the mass, in g, of the crucible, lid and the test portion before heating;

m_3 - is the mass, in g, of the crucible, lid and the test portion after heating;

M_{ad} - is the moisture, as a percentage by mass, in the general analysis sample.

Chemical properties

Determination of content of carbon, hydrogen and nitrogen

Before starting the procedure for determining C, H and N for guava biomass, two pre-processing steps were performed: calibration of the analyser (Figure 16) and the preparation of the sample according to the standard EN 15104:2011, three samples of about 0.1 g of phenylalanine (substance calibration) which contained known levels of carbon, hydrogen and oxygen, were prepared; and three samples of material of about 0.1 g (all samples were into 502-186 tin cones squares foil).

A prepared instrument for operation as outlined in the operator's instruction manual. Calibration sample is called as a "blank", selecting 3 replicates; all samples were placed

in the carousel (3 for calibration) (Figure 17), once obtained the results, the C, H and N analyser was calibrated.

Next step was to place the 3 samples into the carousel selecting 3 replicates; from the CHN628 gave the results C_{ad}, H_{ad}, N_{ad}; it is recalled that determinator works with 100% oxygen at 948 °C.

Apparatus: digital balance, RADWAG AS 220/C/2; analyser of carbon / hydrogen / nitrogen, Leco 628 series; Tweezers; pincers and 502-186 tin cones squares foil.

Figure 16 C, H and N analyser
Source: (Author, 2016)

Figure 17 Carousel of the C, H and N analyser
Source: (Author, 2016)

Determination of total content of S, Cl, Ca, Fe, P, K, Si, Cr, Mo, Sb, Rh, and Zr by X-ray fluorescence method

To determine chemical components by X-ray fluoresce method (XRF) based on the standard EN 15290:2011 a dry sample of 30 grams was used; ground and homogenised. It was placed in standard 32 mm XRF sample cup, following the user guides the analysis area was set up on the screen, which took less than 30 s; XRF (Figure 18) was calibrated. Afterwards, the sample was analyzed for a total of 90 s (30 s main, 30 s low, 30 s high), results were shown on the screen in %.

Apparatus: x-ray fluorescence analyzer; Niton XL3t GOLDD+, 32 mm XRF sample cup

Figure 18 X-ray fluorescence analyzer
Source: www.thermoscientific.com

Determination of total content of Cd, Co, Cu, As, Hg, Ni, Pb and Zn by ICP-MS method

The freeze-dried and homogenized sample was decomposed based on the standard EN 15289:2011 in a microwave-assisted wet digestion system with focused microwave heating. A solution (~0.3 g of dry matter, in 3 replicates), the sample, was weighed in a vessel (volume 35 ml) and 6 ml of concentrated nitric acid was added; the mixture was heated at maximum power 300 W, temperature 180 °C, and maximum pressure 21 bars for 12 minutes. After cooling, the solution was quantitatively transferred to polyethylene containers, filled with 30 ml of purifying water. Element contents in the digests were measured by inductively coupled plasma mass spectrometry using non-gas mode or a collision cell mode to reduce potential interferences.

The experimental conditions were as follows:

RF power of 1,550 V, sample depth of 8 mm, plasma flow of 15 l/min, the auxiliary flow of 0.9 l/min, helium collision cell flow of 7.2 l/min, Ge and Lu used as internal standards. The auto-sampler ASX-500, a three channel peristaltic pump, and a MicroMist nebulizer equipped the ICP-MS (Figure 19) (Šindelářová et al., 2015). Results were shown in %.

Apparatus: ICP-MS, Agilent 7700x, Agilent Technologies Inc.; microwave, Discover SPD-Plus; quartz-glass digestion vessel and Integral Water Purification System, Milli-Q.

Figure 19 ICP-MS, Agilent 7700x device
Source: www.agilent.com

5 Results and discussion

This chapter describes the data findings followed by a discussion of the research results. The outcomes correlated to the specific objectives, guided to answer the research question. These data were analysed to identify, describe, determine and finally evaluate the parameters of guava (*Psidium guajava L.*) biomass. These data were obtained from experiments performed by the author in the laboratories mentioned in chapter 4.2.3.

At the first part of this chapter, results related to the raw material are shown; classification of biomass according to standard EN 14961-1:2010, moisture content, bulk density , ash content, calorific value, and volatile matter. These properties are related to the combustion performance of biomass (Van Loo and Koppejan, 2007).

Elemental composition, in this section N, C, H, S, and Cl are presented as a percentage and other elements are shown as a concentration (mg/kg).

Two parameters from briquettes made from guava biomass, diameter, and length, and mechanical durability were measured; finally, a comparative table with the minimum requires of standard EN 17225-3:2014; in order to evaluate the fulfilment of standard.

5.1 Origin and source classification

Following the specifications given in the standard EN 14961-1:2010, biomass from guava (*Psidium guajava L.*) is classified as a woody biomass into the subgroup, "forest, plantation and other virgin wood" 1.1.3.; Briquettes from guava were assorted as graded wood briquettes. Therefore, properties of the material were compared under the standard EN 17225-3:2014 Solid biofuels - Fuel specifications and classes Part 3: Graded wood briquettes.

5.2 Physical and mechanical properties

Moisture content

Moisture content (MC) was measured according to the standard EN 14774-2:2009, by simple method. The results are shown in the table Table 5.

The importance of MC is known, particularly if weight is the measure for assessing the solid volume and the energy content, for example in guava biomass. (Lucas et al., 2006) reported green MC of 84%, also (Camarena-Tello et al., 2015) described a green moisture content of 68%, comparing this results with the moisture content MC_{db} determined in this thesis, it is possible to affirm a reduction seven/eight times between green moisture and MC_{db}, which means if the wood is first allowed to dry, then the moisture content may be around 9.8% depending on the relative humidity of the atmosphere.

Table 5 Moisture content of guava biomass

Material	Moisture content (%)
Guava (*Psidium guajava L.*)	9.8

Source: (Author, 2016)

Following the specifications of solid biofuel given by the standard EN 17225-3:2014, MC of biofuel should not exceed 15%. However, other authors differ from this percentage. Based on (McKendry, 2002) MC can be up to 20%.

In comparison with other material for energy proposes, for example *Miscanthus giganteus L.*, MC 7.8%, reported by (Ivanova, 2012) and Pine sawdust, MC 10.35% (Chaloupkova, 2015), guava biomass MC fulfils the requirements for standard and also is within the range recommended by other authors.

Table 6 Moisture content of guava biomass after briquetting process

Material	Moisture content (%)
Guava (*Psidium guajava L.*) briquettes	8.25

Source: (Author, 2016)

The table Table 6 shows the MC after compaction, with a reduction of 1.55%. The measurement was made under the same parameters and method declared in chapter 4.2.3.

Ash content

The content of ash of *Psidium guajava L.* was determined according to standard EN 14775:2009.

Ash content can affect behaviours during combustion and play a major role in optimizing combustor/boiler design for enhanced combustion efficiency and fewer operation problems (Shao et al., 2012).

As shown in table Table 7, measured ash content was determined to be 3.74% which is far above the maximum allowed for the standard EN 17225-3:2014, in accordance with this standard, the ash content of woody biomass category A1 is 1%, A2 is 1.5%, and for class B is 3%. Regardless, biomass classed as category B is not recommended for baking ovens.

Table 7 Ash content of guava biomass

Material	Ash content (%)
Guava (*Psidium guajava L.*)	3.74

Source: (Author, 2016)

The ash value determined by (Martínez-Pérez et al., 2012) content in guava bark was 5.76%. In this thesis the total wood biomass (core and bark) was measured. The percentage of core and bark in unknown for guava biomass, but the bark share ranges from 5% to 8%, but the amount can vary according to other factors such age, location, species, among other elements (Fengel and Wegener, 1983). To infer if the ash content in the bark directly affects the ash content in the guava biomass more information and studies are necessary.

In comparison with other biomass materials for energy purposes, guava biomass is comparable with Flax Straw with 3.7% ash content (Clarke and Preto, 2011) which is a material classed as a herbaceous biomass.

Calorific value

The calorific value of *Psidium guajava L.* was determined according to standard EN 14918:2009. In table Table 8 the gross calorific value (GCV) and the net calorific value (NCV) for the material are reported.

NCV of *Psidium guajava L.* was calculated using the formula (5) on the basis of GCV, and moisture content found in the formula (3); as a result NCV of 17.114 MJ/kg, catalogues the material to the highest quality class A1 with its value 15.5 MJ/kg according to the standard EN 17225-3:2014.

Table 8 Calorific value of guava biomass

Material	GCV (MJ/kg) $_{ar}$	NCV (MJ/kg) $_{ar}$
Guava (*Psidium guajava L.*)	18.424	17.114

Source: (Author, 2016)

The net calorific value of guava (*Psidium guajava L.*) is slightly below for the average of hardwood 19 MJ/kg (Clarke and Preto, 2011). It is comparable with straw residual biomass such a barley straw 17 MJ/kg, reported by (Adapa et al., 2009), NCV of guava (*Psidium guajava L.*) covers 74% of the coal NCV performance, reported in 25 MJ/kg (Nussbaumer, 2003).

Volatile matter content

Volatile matter content was determined under the parameters given for the standard EN 15148:2009. As is visible in table Table 9, it corresponds to three quarters of the original weight.

The volatile matter content is not established in the standards. However it is included in this study because fractional heat contribution by volatile substances in biomass is approximately 70% (Wright et al., 2011). So as the higher the volatile matter content, the more heat is produced by the biomass.

Table 9 Volatile matter content of guava biomass

Material	Volatile matter (%)
Guava (*Psidium guajava L.*)	77.43

Source: (Author, 2016)

The result obtained is higher than other biomass materials (see graphic Chart 5), the highest content of volatile matter in biomass is approximately 80% (Van Loo and Koppejan, 2007). Guava (*Psidium guajava L.*) biomass volatile matter almost reaches this level. Besides, the high content of volatile matter produces a rapid combustion of the material (Sirignano, 1986). On the other hand, lower volatile matter causes more smoke and releases toxic gases (Van Loo and Koppejan, 2007).
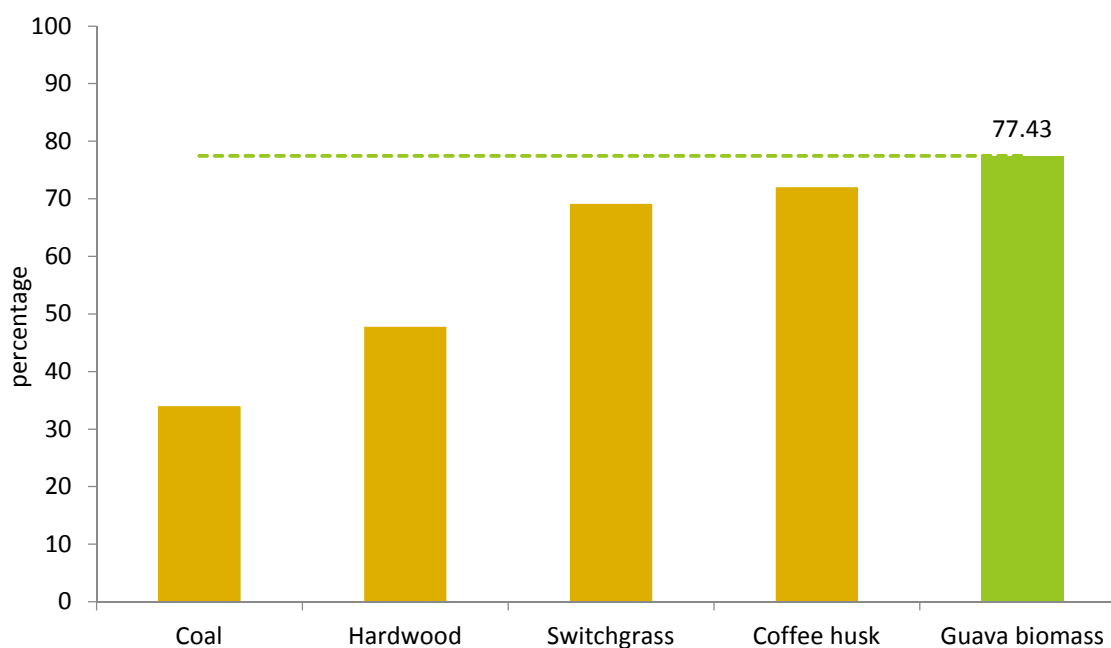
Chart 5 Volatile matter content of selected biomass resources
Source: Coal (Wright et al., 2011), Hardwood (Sirignano, 1986), Switchgrass (Clarke and Preto, 2011), Coffee husk (Saenger, 2001), Guava biomass (Author, 2016).

Diameter and length of guava biomass briquettes

Table Table 10 shows the average diameter and length of briquettes.

Diameter is given by pressing cylinder diameter. In this case, the pressing cylinder diameter was 50 mm; the extra diameter was added by the absorption of the ambient humidity after the process.

Table 10 Diameter and length of Guava biomass briquettes

Material	Diameter (mm)	Length (mm)
Guava briquettes	52.025	50.806

Source: (Author, 2016)

Mechanical durability of guava biomass briquettes

Mechanical durability was determined by the parameters described by the standard EN 15210-1:2009 and calculated by the formula (2). Results are shown in the table below.

Table 11 Mechanical durability of guava biomass briquettes

Material	DU (%)
Guava briquettes	88.25

Source: (Author, 2016)

For briquette made from wood, guava biomass has a poor performance as average DU for briquettes of wood is between 90% and 95%, (Brožek et al., 2012)**.** Contrasting with miscanthus biomass briquettes (97.7%), (Ivanova et al., 2014).

5.3 Chemical properties

Determination of nitrogen, carbon, hydrogen, sulphur, and chloride

Determination of nitrogen, carbon and hydrogen (N, C and H) content was performance according to EN 15104:2011, and determination of sulphur and chloride according to EN 15289:2011. Outputs are shown in table Table 12 and table Table 13 respectively. The results were contrasted with the minimum requirement described in the standard EN 17225-3:2014.

Nitrogen (N) percentage content exceeded by 0.18 the maximum allowed to be classified for A2 and by 0.38 for A1 classification, can be classed as B level, in this level nitrogen percentage is up to 1%, carbon (C) content and hydrogen (H) content are not set into the standard. Regardless, they were included in this thesis because the combustion of biomass is essentially a chemical reaction that involves carbon and hydrogen. Also the content of hydrogen is used for NCV calculation.

Table 12 Content of nitrogen, carbon, and hydrogen in guava biomass

Element	%
N	0.68
C	49.64
H	5.99

Source: (Author, 2016)

The nitrogen content in wood biofuels is relatively low, typically less than 1% (Millar, 2009) while it is much higher in cereals, especially beans (FAO, 2008) and in Jatropha seed cakes percentage is around 4% (Gübitz, 2009). Nitrogen has a direct impact on the formation of nitrogen oxides (NOx) which, during combustion, become gases.

Guava biomass has a similar percentage of carbon as a *Salix dasyclado* (Stolarski, 2008) and coniferous trees (Millar, 2009), both around 50%; and is slightly below other tropical trees, the average percentage of which is around 52% (Institute el salto, 2010).

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Hydrogen is now considered as "energy vector" of enormous potential. Its combustion produces water and a high amount of energy (27 kcal/g). The content of hydrogen in some shrub willow species is on average 7% (Stolarski, 2008), in comparison with guava content of 6%. On average woody biomass has a hydrogen content of 6%.

Table 13 Content of sulphur and chloride in guava biomass

Element	(%)
S	0.063
Cl	0.020

Source: (Author, 2016)

The sulphur (S) percentage content exceeded by 0.02 the maximum percentage allowed to be classified as A2 or A1 level, and can be classed as B level; in this level the sulphur percentage is up to 0.06%. Sulphur content in guava biomass is considerably low in comparison with sulphur content in coal which ranges between 0.4% and 0.7% (Calkins, 1993).

Chloride (Cl) content fulfilled the maximum level allowed by the standard can be classed A1, A2 and B. Content range from 0.08 up to 0.71 are reported in some Mexican crops (Camarena-Tello et al., 2015).

Other chemical compounds

Chemical analysis of major elements was determined according to EN 15290:2011 and minor elements according to EN 15297:2011. Results from the determination of chemical compound are shown in table Table 14. Guava biomass has low concentration of heavy metals, and other harmful elements fulfilled the standard EN 17225-3:2014.

Table 14 Content of chemical elements in guava biomass

Element	(mg/kg)
Co	0.020
Ni	0.212
Cu	2.652
Zn	4.570
As	0.012
Cd	0.001
Hg	0.005
Pb	0.035
Fe	0.000
Si	0.213
Ca	1.155
P	0.036
K	2.137
Mo	0.002
Cr	0.000
Zr	1.002
Rh	0.000
Cd	0.003
Sb	0.003

Source: (Author, 2016)

Concentration of some elements differs from (Camarena-Tello et al., 2015) reported Phosphorus (P) range from 4.90 mg/kg to 8.88 mg/kg, potassium (K) from 43.11 mg/kg to 52.10 mg/kg, calcium (Ca) from 26.17 mg/kg to 33.44 mg/kg; Silicon (Si) concentration is comparable with a range from 0.15 mg/kg to 0.40 mg/kg.

5.4 Evaluation of guava biomass properties comparing to the standards

The following properties of guava biomass according to EN 17225-3:2014, by all classes of quality A1: high quality, A2: medium quality, B: low quality, are presented.

Table 15 Standard EN 17225-3:2014 classed A1.

Standard	Property class	Units	A1	Guava briquettes	Evaluation
EN 17225	Origin and source			1.13	
	Diameter (D), Lenght (L1), width (L2) and height (L)	mm shape		D 52.025 L 50.806	
EN 18134	Moisture, M	w-% as received	≤12	9.8	✓
EN 18122	Ash, A	w-% dry	≤1.0	3.74	✗
EN 18125	Net calorific value, Q	MJ/kg as received	≥15.5	17.11	✓
EN 16948	Nitrogen, N	w-% dry	≤0.3	0.680	✗
EN 16994	Sulphur, S	w-% dry	≤0.04	0.063	✗
	Chlorine, Cl	w-% dry	≤0.02	0.020	✓
	Arsenic,As	mg/kg dry	≤1	0.012	✓
	Cadmium, Cd	mg/kg dry	≤0.5	0.001	✓
	Chlorimum, Cr	mg/kg dry	≤10	0	✓
EN 16968	Copper, Cu	mg/kg dry	≤10	2.652	✓
	Lead, Pb	mg/kg dry	≤10	0.035	✓
	Mercury, Hg	mg/kg dry	≤0.1	0.005	✓
	Nickel, Ni	mg/kg dry	≤10	0.212	✓
	Zinc, Zn	mg/kg dry	≤100	4.570	✓

Source: (Author, 2016)

Table 16 Standard EN 17225-3:2014 classed A2.

Standard	Property class	Units	A2	Guava briquettes	Evaluation
EN 17225	Origin and source			1.13	
	Diameter (D), Lenght (L1), width (L2) and height (L)	mm		D 52.025	
		shape		L 50.806	
EN 18134	Moisture, M	w-% as received	≤15	9.8	✓
EN 18122	Ash, A	w-% dry	≤1.5	3.74	✗
EN 18125	Net calorific value, Q	MJ/kg as received	≥15.3	17.11	✓
EN 16948	Nitrogen, N	w-% dry	≤0.5	0.680	✗
EN 16994	Sulphur, S	w-% dry	≤0.04	0.063	✗
	Chlorine, Cl	w-% dry	≤0.02	0.020	✓
	Arsenic,As	mg/kg dry	≤1	0.012	✓
	Cadmium, Cd	mg/kg dry	≤0.5	0.001	✓
	Chlorimum, Cr	mg/kg dry	≤10	0	✓
EN 16968	Copper, Cu	mg/kg dry	≤10	2.652	✓
	Lead, Pb	mg/kg dry	≤10	0.035	✓
	Mercury, Hg	mg/kg dry	≤0.1	0.005	✓
	Nickel, Ni	mg/kg dry	≤10	0.212	✓
	Zinc, Zn	mg/kg dry	≤100	4.570	✓

Source: (Author, 2016)

Table 17 Standard EN 17225-3:2014 classed B.

Standard	Property class	Units	B	Guava briquettes	Evaluation
EN 17225	Origin and source			1.13	
	Diameter (D), Lenght (L1), width (L2) and height (L)	mm		D 52.025	
		shape		L 50.806	
EN 18134	Moisture, M	w-% as received	≤15	9.8	✓
EN 18122	Ash, A	w-% dry	≤3.0	3.74	✗
EN 18125	Net calorific value, Q	MJ/kg as received	≥14.9	17.11	✓
EN 16948	Nitrogen, N	w-% dry	≤1.0	0.680	✓
EN 16994	Sulphur, S	w-% dry	≤0.05	0.063	✗
	Chlorine, Cl	w-% dry	≤0.03	0.020	✓
EN 16968	Arsenic,As	mg/kg dry	≤1	0.012	✓
	Cadmium, Cd	mg/kg dry	≤0.5	0.001	✓
	Chlorimum, Cr	mg/kg dry	≤10	0	✓
	Copper, Cu	mg/kg dry	≤10	2.652	✓
	Lead, Pb	mg/kg dry	≤10	0.035	✓
	Mercury, Hg	mg/kg dry	≤0.1	0.005	✓
	Nickel, Ni	mg/kg dry	≤10	0.212	✓
	Zinc, Zn	mg/kg dry	≤100	4.570	✓

Source: (Author, 2016)

6 Conclusions

Currently new generations are responsible for repairing one of the biggest human mistakes, in relation to the unmindful use of conventional energy resources for over a century, where natural resources have been overexploited, and pollution levels are almost unbearable for mankind.

Facing inescapable global warming, renewable energies take a leading role, essentially because the carbon footprint of alternative sources is significantly lower than non-renewable energies, making them more sustainable forms of energy in the short and long term.

Although the use of biomass is not considered a new technology, improving its performance as a sustainable resource of energy is still in development and is considered a contemporary issue.

The parameters that assure the quality control of biomass resources are described by International Standard Organization, ISO; and European Committee for Standardization.

In this research, the properties of the residual biomass from guava tree were determined and evaluated. Following the specific objectives; physical, chemical and mechanical properties were determined.

As a result, it is possible to conclude that residual biomass from guava tree reaches almost all parameters; low or nonexistent content of heavy metals, an energy capacity over 17 MJ/kg, and moisture content below 10%, however, it failed to meet three important requirements for use for energy purposes, listed below.

- Sulphur content, 0.063%, this parameter is not even suitable for class B, low quality.

- Nitrogen content, 0.68%, is more than double the percentage allowed, 0.30%, but it can be classified as class B.

- Another element, even if the value 0.02% fulfils the requirement for classes A1 and A2, matches exactly to the maximum content allowed for those classes.

These three elements (S, N and Cl), tend to generate corrosion and deterioration of combustion equipment (furnace), cause health problems, and produce greenhouse gasses (Calkins, 1993; Hiltunen et al., 2008; Obernberger and Thek, 2004).

Ash content, 3.74%, is almost 3 times higher than the maximum allowed for the highest quality class A1 and even though does not fulfil the lowest quality, class B.

Briquettes from guava (*Psidium guajava L.*) wood pruning are not suitable for solid biofuel under the standards EN 17225-3:2014. However, the concentration of heavy metals was almost zero, meaning guava biomass could be appropriate for energy purposes under mixing processes.

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