Doi: 10.33158/ASB.2016v2i1p11

Productivity potential and coconut waste quality for biorefining

Renan Becker[1], Taiane Nunes de Queiroz[1,*], Fernando Santos[1], Marlon Cristian Toledo Pereira[2], Robson Bohrer[1], Jeane Dullius[3], Matheus Vilares[1] and Grazielle Machado[1]

[1]Universidade Estadual do Rio Grande do Sul, RS, Brazil. [2]Universidade Estadual de Montes Claros, Janaúba, MG, Brazil. [3]Pontifícia Universidade Católica do Rio Grande do Sul, RS, Brazil. *Corresponding author, E-mail: taiane.qz@hotmail.com

ABSTRACT

The use of biomass as an energy source has increased as far as it aims at providing sustainable energy alternatives and considerable reduction in agro-industrial and urban solid waste. Techniques employed for different types of biomass by biorefineries intend not only to add value to a bioproduct, but also to reduce environmental impact caused by industrial and agricultural residues. The coconut fruit shell residue, largely consumed in coastal regions, rich in fiber, lignin, cellulose and hemicelluloses, may be transformed through chemical, biochemical and thermochemical processes, into several bioproducts with proper energetic yield such as activated carbon, ethanol and biodiesel. This work was done through literature review, magazines and articles in order to analyse the energetic potential use of green dwarf coconut biomass (*Cocos nucifera*) by biorefineries as well as alternatives for reducing tons of fruit fibrous drupe waste commonly dumped in the environment.

Key words: Coconut, bioenergy biomass, lignocellulosic biomass, solid waste.

INTRODUCTION

Access to sustainable and reliable energy is a daily challenge for one out of four people on the planet. Currently, 1.2 billion people lack access to electricity, and other 800 million people are deprived of a reliable power grid that meets their basic energy needs. Despite current and planned investments for improvements, 1 billion people in developing countries will not have access to basic electricity services in 2030 (Walters et al., 2015; Desjardins et al.,2014; IEA 2014).

Electric power generation in Brazilian public services and self-producers in 2014 was 3.4% higher than in 2013. Public service power plants, with 84.1% of the total generation, remain as major contributors. The main source of electricity generation is hydropower, although it has presented a reduction of 4.5% compared to the previous year. Self-production generated 5.9% of total production in 2014, considering the sum of all sources used amounting to 94.0 TWH. From the total, 52.2 KWH are produced and consumed at the generating station. The non-injected self-production aggregates several industrial facilities that produce energy for their own consumption, such as pulp and paper industries, steel, sugar and ethanol, chemistry, among others (EPE 2015).

According to Braga et al. (2005), the industrial revolution and the search for new technologies and energy sources triggered a frantic production generating residues, and consequently, causing a global concern. Due to major environmental impacts of fossil fuels, society is giving high priority to sustainable energy sources through attitudes and financial investments in public health concerning environmental areas restoration. Climatic variations, high levels of CO_2 emissions, pollution and interference with terrestrial and marine environments are just some of the issues directly related to the dependence and high consumption of non-renewable energy sources such as oil, oil products and coal (UNEP 2014).

Currently, economy is mainly governed by the use and trade of different oil products. According to Petrobras (2015), even in face of the financial crisis affecting the country in August, this year the record of 2.88 million barrels/day of oil and natural gas were produced, with an increase of 4.5% compared to December 2014. However, another energy sector maintaining a significant increase in production is the sugarcane industry, which produces both commercial sugar and biofuel ethanol from sugarcane biomass conversion. This made sugarcane occupy 8.5 million hectares of planted area in the 2008/2009 harvest (Neves et al., 2008).

Brazil has a large continental extension, being the fifth largest country in the world with over 850 million hectares. It holds about 12% of the world´s fresh water and is located in an inter-tropical zone, providing pluviometric index and a climate favorable for plant cultivation and energy potential in almost all the national territory during all seasons of the year (Eichler et al., 2015). Numerous advantages qualify Brazil to lead the energy, agriculture and biofuels market on a global scale, with the possibility of increasing the area for these activities without extending deforested areas and without reducing the area used for food production, keeping environmental impacts limited to socially accepted. Economic conditions are favorable for Brazilian agribusiness to incorporate biodiesel as one of its most important components, together with ethanol and other forms of bioenergy. Social (employment, income, migration) and environmental (climate change, pollution) pressures strengthen and consolidate this position (Oliveira and Ramalho 2006; Neves et al., 2008).

To improve the use of agro-energy, biorefineries are attractive options since they are industrial facilities that transform biomass into marketable products. Several agribusinesses operate in accordance with biorefinery rationale, with sugar and ethanol as the most striking examples in Brazil (Favaro 2013; Santos et al., 2013).

Coconut cultivation has increased in several countries to meet the growing demand for coconut products. In Brazil, production aims primarily to yield natural dried coconut and / or in the form of processed product (grated coconut and coconut milk) especially coconut water production (Martins 2014). Advances in cultivation technology, along with appropriate new rules of society, are makingit possible, especially in fragile agro-ecosystems such as the Atlantic Forest regions and coastal areas, with the inclusion of small producers in search of better conditions of life (Siqueira et al., 2002).The objective of this paper was to conduct a literature review on the potential and difficulties of coconut biomass - based biorefinery (*Cocos nucifera*) in Brazil.

BIOMASS AND BIOREFINERIES

The rise of technology and industry sparked off an increase in the demand for raw materials and natural resources. As the world's human population grows exponentially, the demand for greater food production and better technologies has encouraged scientific research on the utilization of agro-industrial residues, reduction of environmental impact and production of high value added products.

Biorefinery is a developing area, since it encompasses chemical refining processes with biological processes for the conversion of different types of biomass. According to Santos et al., (2013), using biorefining production techniques, it is possible to reuse by-products, for instance, bagasse from sugarcane to optimize yield without increasing the amount of planted area, and at the same time decreasing the amount of agroindustrial waste.

Biorefinery refers to the production facility integrating processes and technologies capable of producing biofuel, food, animal feed, biofertilizers, chemicals of high value added and energy (heat and electricity) from biomass. The fact that a biorefinery can generate renewable energy encourages further studies on different types of biomass and their physicochemical characterization (Martins, 2014; Santos et al., 2013).

Biomass is amaterial of biological origin excluding those incorporated in geological formations and transformed into fossils (Santos et al., 2013). According to Cortez et al. (2008), the concept of biomass is more restrictive in its use, since it refers to all renewable resources that come from organic matter of vegetable or animal origin having primarily engaged in energy production. Santos et al. (2013) and Evert and Eichhorn (2014) state that lignocellulosic biomass chemical composition is based on three major components: cellulose, hemicelluloses and lignin, along with minor components, which are extractives - low molecular weight organic compounds - and ashes - inorganic material.

Therefore, "biomass for energy" is characterized by its origin, and it may be woody plants, non-timber and organic waste (Fernandes et al., 2011). Woody plants are those from the forest (such as Eucalyptus, biomass that has been widely used to obtain cellulose and paper). However, non-woody or agricultural biomass (such as rice, sugarcane and grape) are divided into energy storage groups that may be saccharides (sugarcane), cellulosic (forest residues, rice husk), amylaceous (corn), oilseeds (oil palm, peanuts) or aquatics (algae).

Both urban and agroindustrial organic solid waste can be used as energy sources. The use of biodigesters containing aerobic or anaerobic bacteria to add value to animal manure and other organic materials in the generation of biogas, energy and biofertilizers, is an example of how biorefinery may be used to enhance sustainability, and still benefiting the farms (Barbosa and Langer 2011).

Considering that currently, Brazil is the 4th largest pork producer, standing only behind China, the United States of America and the European Union, with an estimated herd of 42 million heads (ABCS 2011). They are more likely to use it in energy production through biogas. The high production of liquid effluents with higher pollution potential deserves special attention, given the need for appropriate treatment and disposal systems (Aita et al., 2014; Doneda 2014). Its irrational use may result in various environmental impacts (Dahan et al., 2014). Peralta-Zamora et al. (1999) shows that effluent generation values range from 8.5 to 4.9% in relation to live animal weight (15 to 100 kg), with an approximate daily production of7.5 litres of manure / day, causing at the end (100-120 days) 0.9 m^3 (Perdomo and Lima 2001).

Woody biomass comprises about 50% cellulose, a polysaccharide that presents, along unbranched chain of β-glucose, units linked by β-1,4 glycosidic bonds (Evert and Eichhorn 2014). Hemicelluloses, also present in woody biomass, are heterogeneous and hydrophilic macromolecules primarily made up of the carbohydrates D-xylose, L-arabinose, D-mannose and D-glucose. Bonds between these monomers are also β-1,4 glycosidic, and once molecular interactions between cellulose-hemicelluloses are set, they formares istant structure linked to lignin, defining the energy yield through biomass burning (Santos et al., 2013).

Lignin consists of phenolic polymers present in plants vascular walls. It is responsible for the stiffness and transport of nutrients and water, with molecular variations in species of angiosperms and gymnosperms (Santos et al., 2013. Evert and Eichhorn 2014; Taiz and Zeiger 2013). According to Saliba et al. (2001), the core unit of lignin is phenylpropanoid, formed by an aromatic ring and an aliphatic chain of three carbon atoms (*x,x* and *x*); these structures are linked by C-C and C-O-C bonds. It features hydrophobic potential and it is branched, consisting of three phenylpraponoid monomers, guaiacyl (G), syringyl (S) and p-hydroxyphenyl (H) derived from the phenylpropanoid alcohols: coniferyl, coumaryl and sinapyl.

According to Coral (2009), to perform fragmentation and conversion of biomass in biorefineries, there is a wide range of techniques and technologies available, considering the characteristics of the initial biomass and the desired product. The routes used in biomass process are chemical, biochemical and thermochemical. Chemical processes aim at degrading or forming some specific substance in the organic material, while biochemical pathway provides biological processes, in which microorganisms such as yeasts and bacteria are used for synthesis or fermentation of some material (Santos et al., 2013). Among thermochemical processes, techniques including gasification and biomass pyrolysis are widely used in the process of burning coal, biomass or residues, with the objective of obtaining synthesis gas, a fuel that can be used to generate electricity (Santos et al., 2013).

The fruit of *Cocos nucifera* may belong to the variety Typica or Giant (large) and Nana (dwarf), although the biggest difference between them is that the variety of the large fruit is more used to obtain fibers and pulp, while the dwarf is used to obtain water (Fontes et al., 2002). The solid waste of dwarf coconut is composed of epicarp / epidermis (outer part), mesocarp (fibrous part) and endocarp, and coconut water is present in liquid or solid endosperm (pulp) (Evert and Eichhorn 2014).

Table 1 presents the variation of cellular chemical composition among different types of lignocellulosic biomass, improving the viability of byproducts production from different raw materials in a biorefinery. According to the table below, coconut fiber has good production potential use in biorefineries, since it is composed of more than 40% lignin and 35% of cellulose. It may be used to generate lignocellulosic ethanol through fermentation (Corradini et al., 2009).

Table 1. Chemical composition between different biomass.

Lignocellulosic Biomass	% Cellulose	% Hemicelluloses	% Lignin
Sugarcane Straw	40-44	30-32	22-25
Sugarcane Bagasse	32-48	19-24	23-32
Hardwood	43-47	25-35	16-24
Softwood	40-44	25-29	25-31
CornStalk	35	25	35
CornCob	45	35	15
Cotton	95	2	0,3
WheatStraw	30	50	15
Sisal	73,1	14,2	11
Rice Straw	43,3	26,4	16,3
CornStover	38-40	28	7-21
CoconutFiber	36-43	0,15-0,25	41-45
Banana TreeFiber	60-65	6-8	5-10
BarleyStraw	31-45	27-38	14-19

Source: Santos (2013).

PRODUCTION AND ECONOMIC POTENTIAL OF COCONUT

Coconut palm (*Cocos nucifera*) is considered a plant of multiple functionalities, given the range of products that may be exploited, receiving a worldwide recognitionas a vital vegetable resource for all humanity (Foale and Harries 2009). The impact of coconut in human history of dispersal in the tropics does not have parallels in the plant kingdom. As a portable source of food and water, coconut palm has played a critical role in the ability of humans to travel, to establish trade routes and to colonize lands in the Pacific Rim and tropical regions in theoldworld (Harries 1978). Currently, coconut palm species still have hundreds of uses, such as sources of food, drink, fiber, building materials, coal and oil (used for food preparation, pharmaceuticals and biofuels), with over 12 million hectares planted in the world, with a production of 60 million tons (Gunn et al., 2011; Martins 2014).

Coconut palm develops better at altitudes lower than 1000 m and near coastal regions, where the average temperature is between 23-34°C, with the absence of temperatures lower than 15°C and relative humidity between 60 and 90%. Annual precipitation must exceed 1500mm, preferably distributed throughout the year. Coconut trees maybe cultivated in a wide variety of soils, as long as the soil has a good drainage (Carr 2011).

The majority of the coconut tree planted area in the world is located in Asia, mainly in India, the Philippines, Indonesia, Sri Lanka and Thailand, representing approximately 70% of the world's total, while the rest is distributed along the continents of Africa, Latin America, Oceania and the Caribbean. Indonesia stands out as the biggest coconut producer, followed by the Philippines and India. In harvested area, however, the Philippines stands out with a greater acreage, with more than 500,000 hectares of coconut ahead of Indonesia. In terms of productivity, Brazil leads the ranking of countries with the highest yield with a productivity of about 11 million tons per hectare (Martins 2014).

Nationwide in Brazil, coconut is cultivated with the objective of producing fruits for agribusiness, mainly for the production of grated coconut and coconut milk, besides coconut water. The coconut water segment has increased in the last years, presenting also great future prospects, in view of its increase consumption by the domestic and foreign markets, which has normally been associated with quality of life and health.In Brazil, approximately 70% of coconut tree exploration in properties occurs in up to 10 hectares.

The national coconut cultivation traditionally occurs in the northeastern region, although in the last thirty years, the areas forthis crop are having a special attention in other regions of Brazil, mainly in the southeast, midwest and north of the country (Aragão and Melo 2009; Martins 2014). Currently, the country is the fourth biggest producer, with a production of about 2.8 million tons, in a harvested area of 257.000 hectare of coconut (Martins 2014).

Although the northeastern region maintains the highest participation in coconut production, crop yield in terms of productivity is lower than in other regions (Rio de Janeiro and Espirito Santo). That situation arises mainly from the level of technology used, the coconut varieties exploited and their use. In the northeastern region, a semi-extractive system prevails, with varieties of giant coconut palm for dry coconut production, while in other regions, crops of hybrid dwarf coconut palm(coconut water) are dominant, which is naturally more productive than the giant coconut (Wanderley and Lopes 2009).

PROBLEMS CAUSED BY COCONUT WASTE

The concept of solid waste has several definitions, probably due to the heterogeneity of waste collection produced in urban areas, and to the fact that its nature varies from region to region (UNEP 2015a, 2015b). It can be classified as household, shopping, industrial and institutional waste in an urban area (Barros 2012). However, the most frequently used is that according to the Brazilian Standard ABNT (NBR) 10.004/2004, which classifies waste as: community, industrial, domestic, commercial, agricultural, sweeping services, in solid state and semi-solid, including residues from water and effluent, as well as control and pollution treatment systems. Characteristics and quantities of solid waste produced in a region do not only depend on living standards and lifestyle of its inhabitants, but also on the abundance and types of natural resources in this region (UNEP 2015a, 2015b). Municipal Solid Waste (MSW), when poorly managed, has a high negative potential on the environment and public health (Ustohalova 2011) through air, water and soil contaminations (EPA 1994). MSW can be divided into two groups: organic and inorganic. The main difference between the wastes generated in developing countries from that generated in industrialized countries isthe high concentration of organic material (UNEP 2015a, 2015b).

In 2010 Brazil launched the Solid Waste Policy (SWP), which legally establishes rules for the management of all solid waste produced in the country. The SWP determines, among its objectives, two important aspects for the management of solid waste, highlighting the environmentally adequate final destination and disposal. Concepts are different, and the final disposal includes recycling reuse, composting and attention to energy recovery and proper disposal in sanitary landfills. It must comply with the provision of materials considered only as waste. As for materials with no possibility of recovery and treatment processes available not meeting these requirements, for technological and economic reasons (Brasil 2010), the final disposal should be used as the last resort (Becker et al., 2012).

The possibility of energy recovery is included in the Brazilian law, supported by the Federal Law 12,305 / 2010, in which energy recovery processes will be accepted as long as proven environmental technical viability and gas emission monitoring are offered (Brasil 2010).

The chain logistics of green coconut starts with agricultural production and ends with the consumer market, which can be a product of the processing industry for pulp extraction or coconut water bottling industry. It can also reach consumer´s markets through bars, restaurants and kiosks, where water marketing is rather primitive, being distributed in bottles or in other containers (Faé et al., 2006).

In 2014, Brazil generated a total of 78.6 million tons of Municipal Solid Waste (MSW) (Abrelpe 2014), and from the total generated MSW, 51.4% was organic material (Abrelpe 2015). Considering that coconut water mostly consumed, its waste volume corresponds to 85% of the fruit's weight. This green coconut waste is responsible for a large volume of MSW, mainly in the Brazilian coast where consumption is high. In the year of 2010, data estimated the disposal of 7 million tons of coconuts (Silva 2014).

Since this is an organic product, it deteriorates easily attracting disease vectors especially flies, mosquitoes, cockroaches and rats, which can cause several problems to human health (Faé et al., 2006). Improper management of waste may also favor the emergence of diseases such as cholera and dengue, due to their potential of blocking public drainage pathways (UNEP 2015a, 2015b). The disposal of such waste in landfills is an additional cost for management entities, given waste weight and volume. In this sense, data from Embrapa Tabuleiros Costeiros claim that 125 units of coconuts occupy 1m^3 volume (Silva 2014), representing a costly final disposal. Another alarming factor towards waste generated by coconut chain production is that its biggest production is concentrated in coastal regions located in the Northeast, where the final waste disposal, in 64.4% of cases, is performed incorrectly or in inappropriate places (33.1% in inappropriate landfills and 31.3% in dumps) (Abrelpe 2015), generating a series of impacts on the environment. The main consumers´ locations and the consequent coconut waste generators are kiosks on beaches of coastal municipalities, supermarkets, street markets, street carts and bottling industries. However, a significant amount of waste comes from household consumption, which are numerous generating points within the transportation logistics network. The disposal of such waste in landfills is an additional cost for management entities.

POTENTIAL OF COCONUT RESIDUE UTILIZATION IN BIOREFINERIES

The Brazilian vegetation biodiversity offers a wide range of species with potential use in the context of biorefinery. However, logistics issues and the development of technologies, in order to achieve their maximum, are restricted at the time to species that have in fact this profile (Favaro 2013). Within this scenario, we can see coconut waste as potentially exploitable by biorefineries.

The growing demand for edible oils and fats, biofuels and oleo chemicals (FAO 2011) requires raw materials with high productivity from these macromolecules. Oleaginous with annual cycle traditionally used do not meet this requirement. Palm trees are plant sources with higher energy density and therefore recognized as plants that will gain more space in the lipid production scenario (Favaro 2013). In 2010, about 2 billion MT of coconut oil was produced in Asia. From this data, it is estimated that 178,000 tons of oil is derived from waste coconut. More than 173,000 tons of biodiesel can be produced per year from waste coconut in addition to biodiesel.Residues reduce dependence on other vegetable oils and reduce fuel production costs (Sulaimanet al., 2014).

The coconut fruit is a drupe consisting of a smooth skin or epicarp, which involves a thick fibrous flesh inside a hard layer (stony) (Ferreira et al., 1998). The fruit is wrapped by a greenish or yellowish external shell, which becomes dry and brown with time. Under the shell, there is a layer of fibers 3 to 5 cm thick. Coconut fibers are characterized by hardness and durability attributed to the high content of lignin, compared with other natural fibers (Santos 2002). The endocarp can be used in the production of activated charcoal (Ferreira et al., 1998). Statistical equalization of fixed carbon yields of coals from mature coconut cored and eucalyptus wood was observed, distilled under three maximum temperatures, sometimes analyzed and the whole coconut distilled at 450 and 550°C (Andrade et al., 2004).

Due to main characteristics of coconut fiber such as: low density, high percentage of elongation and low values for tensile strength and elastic modulus, its use in composites tends to decrease the density of the material with a good elongation potential and average reinforcement capacity, but to potentially improve the performance of fiber-matrix interaction due to agglutinative action of lignin. Studies designed for light building materials containing cement, sand and young coconut fiber waste have been developed, in which a reduction in the thermal conductivity and a decrease indensity of the composite were observed, without compromising the necessary characteristics for its use, recommending its use in walls and roofs. This provided a cement consumption reduction in the mixture up to 5% by weight, as well as reductions in the final product cost and environmental impacts linked, since every 1 kg of cement, produce an average of 0.8 kg CO_2 (Bonato et al., 2014).

Fuel ethanol production from lignocellulosic materials is complicated due to the recalcitrant nature of molecules present in these materials. In order to make cellulose and hemicelluloses more accessible to attack by cellulase and hemicellulases, a pretreatment process is necessary. After the enzymatic pretreatment by hydrolysis, it is likely to obtain high concentrations of ethanol from coconut shell, mature coconut fiber and mature coconut shell, subjected to semi-simultaneous saccharification and fermentation (SSF) (Gonçalves et al., 2014).

Coconut fruit is suitable for charcoal production with good productivity and good quality as well as for the generation of byproducts of carbonization. Aiming at charcoal productivity without considering, for instance, the calorific value, whole coconut should be used distilled at a maximum temperature of 350°C, the average gravimetric yield being 34.31%. By targeting the quality of charcoal without, however, paying attention to the coal productivity, cored mature coconut should be chosen for use, distilled at a maximum temperature of 450°C. Aiming at both charcoal productivity and quality, cored mature coconut, distilled at a maximum temperature of 350°C or the whole coconut should be chosen, distilled at 450°C. Charcoal derived from whole coconut may likely be used as energy source in furnaces of Ceramic Industries, bakeries and pizzerias among other similar applications. This coal, however, does not seem suitable for steel mills due to the good gravimetric income presented (from 30.55 to 34.31%), although specific studies for improvementare needed (Andrade et al., 2004).

Activated carbon canbe producedfrom coconut buttons, grilling them and performing the activation treatment by using sulfuric acid and steam. This low cost activated carbon proved to be able to absorb heavy metal ions (lead, mercury and copper) from industrial effluents (Anirudhan and Sreekumari 2011).

Mature coconut shell residues have been used as agricultural substrates, due to their advantageous physical structure that provides high potential to retain moisture, high porosity and biodegradability. It is recommended for seeds germination, flowers and vegetables cultivation as well as for nursery gardens. For coconut powder commercialization, the product final moisture should range 15-25% when sold in bags; when pressed, itis recommended that moisture does not exceed 30% before pressing. When compared with other agricultural substrates, compounds which have coconut powder proved to be promising for the production of melon seedlings, and may be associated with a greater retention of moisture and a higher content of nutrients (Embrapa 2002).

Coconut shell powder is an effective adsorbent and has a great potential for adsorption treatments in effluents containing cadmium, chromium (III) and chromium (VI). The removal efficiency of the process to 20ppm concentration was 90%, 86% and 99% for chromium (III), chromium (VI) and cadmium, respectively, producing solutions with final concentrations of 2.2, 2.3 and 0.2 mg/L for each metal species. Preliminary results show the possibility of using coconut shells as biosorbent materials (Pino et al., 2006).

When coconut milk is subjected to centrifugation, three phases are obtained: fat phase (coconut cream), aqueous phase (skim coconut milk) and solid phase (insoluble protein). Coconut skim milk and insoluble protein were mixed, homogenized and submitted to spray drying so as to obtain a dried protein powder. Analysis of this powder revealed a high protein content (33% weight / weight), and a low fat content (3% weight / weight). Powdered coconut protein possesses good emulsifying properties, as well as a potential use in emulsified foods (Naik et al., 2012).

CHALLENGES AND OPPORTUNITIES OF COCONUT BIOREFINERY

In general, logistics is seen as materials flow management from acquisition to consumption. However, there is also a reverse logistics flow from consumption to origin, which needs to be managed (Abrelpe 2015). After arrivingat the final consumer, the product may move to three different destinations: going to a safe disposal location such as sanitary landfill and specific deposits, an unsafe destination, being discarded in nature(polluting the environment) or finally, returning to a reverse distribution chain (Faé et al., 2006). It means that the main obstacle for coconut biorefinery is the logistics required to manage and allocate coconut waste to the location of its reuse in an economically viableway.

However, Brazilian federal law 12,305 of 2010 foresees the restructuring of management systems and municipal solid waste management, by implementing technologies for waste recovery and treatment. In this case, to support the restructuring of the waste management, in particular, the coconut solid waste, the need and possibility of selective collection implementation are necessary so that the solid waste collection can occur correctly and separately (at least in two fractions: wet and dry) according to its characteristics (Brasil 2010). It is an instrument of major importance for the reduction and treatment of both dry and wet waste, supporting the implementation of recovery systems and waste treatment, provided by the law 12,305 (Brasil. 2010).

The use of coconut residues by biorefineries in Brazil is an important condition for the advancement of the coconut agro-industrial chain, generating jobs and income opportunities, and at the same time mitigating the generation of environmental impacts.

REFERENCES

ABCS - Associação Brasileira de Criadores de Suínos (2011) ABCS e representantes de agroindústrias se reúnem para discutir Projeto de Lei sobre produção integrada. http://www.abcs.org.br/informativo-abcs/909-abcs-e-representantes-de-agroindustrias-se-reunem-para-discutir-projeto-de-lei-sobre-producao-integrada. Accessed 28 November 2015.

Abrelpe – Associação Brasileira de empresas de limpeza pública e resíduos especiais (2014) Panorama dos Resíduos Sólidos no Brasil. http://www.abrelpe.org.br/Panorama/panorama2014.pdf. Accessed 3 December 2015.

Abrelpe – Associação Brasileira de empresas de limpeza pública e resíduos especiais (2015) Estimativas dos Custos para viabilizar a Universalização da Destinação adequada de Resíduos Sólidos no Brasil. http://www.abrelpe.org.br/arquivos/pub_estudofinal_2015.pdf. Accessed 7 December 2015.

Aita C, Gonzatto R, Miola EC, Santos D, Rochette P, Angers DA, Chantigny MH, Pujol SB, Giacomini DA and Giacomini SJ (2014) Injection of DCD-Treated Pig Slurry Reduced NH3 Volatilization without Enhancing 2 Soil N2O Emissions from No-till Corn in Southern Brazil. Journal of Environmental Quality 43: 789-800.

Andrade A, Passos P, Marques L, Oliveira L, Vidaurre and Rocha J (2004) Pirólise de resíduos do coco-da-baía (Cocos nuciferalinn) e análise do carvão vegetal. Árvore 28: 707-714.

Anirudhan T and Sreekumari S (2011) Adsorptive removal of heavy metal ions from industrial effluents using activatedcarbon derived from waste coconut buttons. Journal of Environmental Sciences. http://www.jesc.ac.cn/jesc_en/ch/reader/create_pdf.aspx?file_no=2011231209. Accessed 16 December 2015.

Aragão W and Melo M (2009) Cultivares de coqueiro para a produção de coco seco: coqueiro Gigante vs híbridos. In: Cintra F, Fontes H, Passos E and Ferreira J (Eds.) Fundamentos tecnológicos para a revitalização das áreas cultivadas com coqueiro gigante no nordeste do Brasil. Embrapa Tabuleiros Costeiros, Aracaju, p. 37-60.

Barbosa G and Langer M (2011) Uso de biodigestores em propriedades rurais: uma alternativa à sustentabilidade ambiental. Unoesc & Ciência – ACSA 2(1): 87-96.
Barros R (2012) Elementos de Gestão de Resíduos Sólidos. Tessitura Editora, Belo Horizonte, 424 p.

Becker R, Corrêa E and Corrêa L (2012) Política Nacional de Resíduos Sólidos. In: Corrêa E and Corrêa L. Gestão de Resíduos Sólidos. UFPel-Evangraf, Pelotas.

Bonato M, Bragança M, Portella K, Vieira M, Bronholo J, Santos J and Cerqueira D (2014) Photocatalytic mortars and concretes with addition of coconut and sisal fibers to reduce environmental impacts of pollutant gases. Cerâmica 60(356): 537-545.

Braga B, Hespanhol I, Conejo, J, Barros M, Spencer M, Porto M, Nucci N, Juliano N and Eiger S (2005) Introdução à engenharia ambiental. Prentice Hall, São Paulo, 336p.

Brasil (2010) Política Nacional de Resíduos Sólidos. Lei nº 12.305, de 2 de agosto de 2010. http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm. Accessed 29 November 2015.

Carr M (2011) The water relations and irrigation requirements of coconut (Cocos nucifera): a review. Experimental Agriculture 47(1): 27–51.

Coral D (2009) Indicadores técnicos-econômicos das rotas termoquímicas e bioquímica para a obtenção de biocombustíveis utilizando bagaço de cana para as condições brasileiras. Dissertação, Universidade Federal de Itajubá.

Corradini E, Rosa MF, Macedo BP, Paladin PD and Mattoso LHC (2009) Composição química, propriedades mecânicas e térmicas da fibra de frutos de cultivares de coco verde. Revista Brasileira de Fruticultura 31(3):837-846.

Cortez L, Lora E and Gómes E (2008) Biomassa para energia. Unicamp, Campinas, 29p.

Dahan O, Babad A, Lazarovitch N, Russak E and Kurtzman D (2014) Nitrate leaching from intensive organic farms to groundwater. Hydrology and Earth System Sciences 18: 333-341.

Desjardins S, Gomes R, Pursnani P and West C (2014) Accelerating Access to Energy: Lessons Learned from Efforts to Build Inclusive Energy Markets in Developing Countries. Shell Foundation. https://www.shellfoundation.org/ShellFoundation.org_new/media/Shell-Foundation-Reports/Access_to_Energy_Report_2014.pdf. Accessed 24 November 2015.

Doneda A (2014) A acidificação de dejetos líquidos de suínos afeta as emissões de amônia e gases de efeito estufa no processo de compostagem automatizada. Tese, Universidade Federal de Santa Maria.

Eichler P, Santos F, Toledo M, Zerbin P, Schmitz G, Alves C, Ries L and Gomes F (2015) Produção do biometanol via gaseificação de biomassa lignocelulósica. Química Nova 38(6): 828-835.

Embrapa - Empresa Brasileira de Pesquisa Agropecuária (2002) Utilização da casca de coco como substrato agrícolo. Documentos 52, Fortaleza, 22p.

EPA - Environmental Protection Agency (1994) Composting Yard Trimmings and Municipal Solid Waste. http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=10000S77.txt. Accessed 29 November 2015.

EPE - Empresa de Pesquisa Energética. 2015. Balanço Energético Nacional 2015: Ano base 2014. https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2015.pdf. Accessed 24 November 2015.
Evert R and Eichhorn S (2014) Biologia vegetal. Guanabara Koogan, Rio de Janeiro, 876p.

Faé MI, Ribeiro GM and Schwartz Filho AJ (2006) Industry location for coconut recycling. In: International Conference on Industrial Logistics. Proceedings ICIL'2006, Kaunas,1: 65-71.

FAO - Food and Agriculture Organization of the United Nations (2011) Oilseeds and oilseed products, in OECD-FAO Agricultural Outlook 2011, OECD Publishing. http://dx.doi.org/10.1787/agr_outlook-2011-12-en. Accessed 7 December 2015.

Favaro S (2013) Aproveitamento de espécies nativas e seus coprodutos no contexto de biorrefinaria. Embrapa Agroenergia, Brasília, 37p.

Fernandes D, Suzuki A, Vieira A, Araújo I, Costanzi R, Faria R and Edwiges T (2011) Biomassa como fonte de energia. Madeira 129:1-5. http://www.remade.com.br/br/revistadamadeira_materia.php?num=1570& subject =Biomassa&title=Biomassa%20como%20fonte%20alternativa%20de%20energia. Accessed 27 November 2015.

Ferreira J, Warwick D and Siqueira, L (1998) A cultura do coqueiro no Brasil. SPI, Brasília, 292p.

Foale M and Harries H. (2009) Farm and forestry production and marketing profile for coconut (Cocosnucifera). In: Elevitch CR (ed.) Specialty crops for pacific island agroforestry, Permanent Agriculture Resources (PAR), Holualoa, 24p.

Fontes H, Ferreira J and Siqueira L (2002) Sistema de Produção para a Cultura do Coqueiro. Embrapa Tabuleiros Costeiros. http://www.cpatc.embrapa.br/download/SP1.pdf. Accessed 28 November 2015.

Gonçalves F, Ruiz H, Nogueira C, Santos E, Teixeira J and Macedo G (2014) Comparison of delignified coconuts waste and cactus for fuel-ethanolproduction by the simultaneous and semi-simultaneous saccharificationand fermentation strategies. Fuel 131: 66–76.

Gunn B, Baudouin L and Olsen K (2011) Independent origins of cultivated coconut (Cocos nucifera L.) in the Old World Tropics. PLoS one 6(6): e21143. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0021143. Accessed 3 December 2015.

Harries H (1978) The evolution, dissemination and classification of Cocos nucifera. L. The Botanical Review 44: 265-319.

IEA - International Energy Agency. (2014) Energy Access Projections, The World Energy Outlook 2014. http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessprojections/. Accessed 24 November 2015.

Martins C (2014) Produção e comercialização de coco no Brasil frente ao comércio internacional: panorama 2014. Embrapa Tabuleiros Costeiros, Aracaju, 53p.

Naik A, Raghavendra S and Raghavarao K (2012) Production of Coconut Protein Powder from CoconutWetProcessing Waste and its Characterization. Applied Biochemistry and Biotechnology 167: 1290-

1302.

Neves M, Trombin V and Consoli M (2008) Mapeamento e quantificação do setor sulcroenergético. Centro de Pesquisa e Projetos de Marketing e Estratégia, Ribeirão Preto. http://www.sindalcool.com.br/download/CD/Estudos_Etanol/Matriz_Mapeamento_QUANTIFICA%C3%87%C3%83O_SETOR_SUCROENERGETICO.pdf. Accessed 27 November 2015.

Oliveira A and Ramalho J (2006) Plano Nacional de Agroenergia 2006-2011. Ministério da Agricultura, Pecuária e Abastecimento. Embrapa Informação Tecnológica, Brasília, 114p.

Peralta-Zamora P, Kunz A, Moraes SG, Pelegrini R, Moleiro PC, Reyes J and Duran N (1999) Degradation of reactive dyes I: a comparative study of ozonation, enzymatic and photochemical processes. Chemosphere 38(4): 835-852.

Perdomo C and Lima G (2001) Suinocultura e Estratégias para redução de Gases e Poluentes. In: Lima M, Cabral O and Miguez J (eds.) Mudanças Climáticas Globais e a Agropecuária Brasileira. EMBRAPA Meio Ambiente, São Paulo, p. 325-346.

Petrobras (2015) Produção de petróleo e gás natural cresce e bate recorde em agosto. http://www.petrobras.com.br/fatos-e-dados/producao-de-petroleo-e-gas-natural-da-petrobras-cresce-e-bate-recorde-em-agosto.htm. Accessed 27 November 2015.

Pino G, Mesquita L, Torem M and Pinto G (2006) Biosorption of heavy metals by powder of green coconut shell. Separation Science and Technology, 41: 3141-3153.

Saliba E, Rodrigues N, Morais S, Veloso D (2001) Ligninas - Métodos de obtenção e caracterização química. Ciência Rural 31(5): 917-928 http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-84782001000500031. Accessed 28 November 2015.

Santos F, Colodete J and Queiroz J (2013) Bioenergia e Biorrefinaria: Cana-de-açúcar e espécies florestais. UFV, Viçosa, 551p.

Santos M (2002) Propriedades térmicas e mecânicas de materiais reciclados a base de PET pós-consumo e cargas de coco. Dissertação, Universidade Federal do Rio de Janeiro.

Silva A (2014) Reaproveitamento da casca de coco verde. Monografias Ambientais 13: 4077–4086.

Siqueira L, Aragão W and Tupinambá E (2002) A introdução do coqueiro no Brasil: importância histórica e agronômica. Embrapa Tabuleiros Costeiros, Aracaju, 24p.

Sulaiman S, Aziz A and Arqua M (2014) Biodiesel production from solid coconut waste. Advances in Environmental Biology 8: 781-786.

Taiz L and Zeiger E (2013) Fisiologia vegetal. Artmed, São Paulo, 954p.

UNEP - United Nations Environment Programme (2015b) Global Waste Management Outlook. United Nations Environment Programme, 346p.

UNEP – United Nations Environment Programme (2015a) Solid Waste Management. http://www.unep.org/ietc/Portals/136/SWM-Vol1-Part1-Chapters1to3.pdf. Accessed 29 November 2015.

UNEP - United Nations Environment Programme (2014). Year book: Air Pollution: World's Worst Environmental Health Risk. http://www.unep.org/yearbook/2014/PDF/chapt7.pdf. Accessed 24 November 2015.

Ustohalova V (2011) Management and Export of Wastes: Human Health Implications. In Encyclopedia of Environmental Health, p. 603–611.

Walters T, Rai N, Esterly S, Cox S and Reber T (2015) Policies to Spur Energy Access: volume 1. Clean Energy Solutions Center. http://www.nrel.gov/docs/fy15osti/64460-1.pdf. Accessed 24 November 2015.

Wanderlei M and Lopes G (2009) Importância socioeconômica da produção de coco seco no Brasil. In: Cintra F, Fontes H, Passos E and Ferreira J (eds.) Fundamentos tecnológicos para a revitalização das áreas cultivadas com coqueiro gigante no nordeste do Brasil. Embrapa Tabuleiros Costeiros, Aracaju, p37-60.

Received: June 30, 2015.
Accepted: April 20, 2016.
Published: June 30, 2016.