CHEMICAL ENGINEERING TRANSACTIONS

VOL. 58, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216

DOI: 10.3303/CET1758091

Lignocellulosic Biomass from Fast-Growing Species in Colombia and their Use as Bioresources for Biofuel Production

Mario A. Hernández*[a], July Romero[b], Cristian Jaime[b], Jeffrey León-Pulido[a], Iván O. Cabeza[b]

[a]Universidad EAN, Calle 79 11 45, Bogotá, Colombia
[b]Universidad Santo Tomás, Carrera 9 51 11, Bogotá, Colombia
mahernandez@universidadean.edu.co

Biomass is a promising source to produce energy or biofuels, chemicals and biobased products in order to reduce dependency on fossil fuels. Fast growing crops are an ideal source of lignocellulosic biomass due to their high cellulose, hemicellulose and lignin content. In this sense, eleven (11) families were selected and compiled in twenty one (21) species according to soil type and crop requirement. Cultivation areas were selected through analyses of the Geographic Information System (SIG by its Spanish acronym) highlighting soil characteristics (mainly as arid and semiarid areas) and crop requirements. Two main groups were defined during this analysis: species established in Colombia and species not yet reported in Colombia. Species established in Colombia were related to family *Asteraceae, Euphorbiaceae, Fabaceae, Lamiáceas, Myrtaceae* and *Pinaceae*. The estimated area for this crop group was around 1.7 million hectares with an energy potential of 94,677 TJ/year. Meanwhile, species not yet reported in Colombia were related to family *Leguminosae, Myrtaceae, Paulowniaceae, Pinaceae* and *Poaceae*. The estimated area for this crop group was around 2.4 million of hectares with an energy potential of 65,525 TJ/year. The energy value achieved for each specie was in the range of 2,000 TJ/year to 10,000 TJ/year, the other species that were out of this range, were not take into account. The main region available to develop these types of crops in Colombia was located in the departments of Cundinamarca, Antioquia, Santander, Quindío, Risaralda, Caldas, Tolima, Valle del Cauca and Nariño. Technologies such as gasification and pyrolysis were identified to be applied to some families as *Asteraceae, Euphorbiaceae, Paulowniaceae* and *Pinaceae*, which have around 25% of lignin; obtaining liquid and gaseous fuels. Meanwhile, a high cellulose and hemicellulose content (48% and 64% respectively) in families as *Fabaceae, Lamiáceas* and *Myrtaceae* make them viable to be used as a sugar source in biofuel production.

1. Introduction

On a global level, there is a collective commitment for biofuel production as a renewable energy source for current energy demand in different economic sectors (e.g. transportation and industry). World biofuel production increased exponentially in the last decade. The drive to develop this new bioenergy economy is supported by energetic independence, environmental benefits and feedstock supply on an industrial level (Koçar & Civaş, 2013). On the other hand, governments are obliged to review politics driving large scale biofuel production systems in order to prevent the risk of introducing invasive species that are problematic in countries' normal dynamics (Smith et al., 2013).
In present day, Colombia produces first generation biofuels particularly from sugar cane and oil palm cultivations. These are mainly found in the Cauca river Valley and the Cauca, Valle, Risaralda and Caldas departments which contain 47 municipalities (Montaño, 2014). Development of these cultivations in the national territory reached an annually rate of 10%, due to biodiesel industry broadening the palm oil domestic market, obtaining up to 326,033 hectares of cultivated land (Castro, 2009). However, it's important to highlight that the research made has been centered on the leguminous plants oil palm and gramineae, setting aside

Please cite this article as: Hernandez M.A., Romero J., Jaime C., Leon-Pulido J.,Cabeza I.O., 2017, Lignocellulosic biomass from fast-growing species in colombia and their use as bioresources for biofuels production, Chemical Engineering Transactions, 58, 541-546
DOI: 10.3303/CET1758091

research on second generation lignocellulose cultivations. The main focus of second generation crops is based on three main aspects; Adaptation to degraded soils, resistance to adverse weather conditions and higher biomass production per time and area unit. This is vital for the estimation of lignocellulosic biomass production level in cultivation areas, and for the possibility of development around second generation biofuels (Chiaramonti et al., 2014; Nagy & Hegedüs, 2015). Additionally, “energy-cultivation” fields can be established to complement local energy projects (Niño, 2013).
The purpose of this work is to establish native lignocellulose species or non-native climate adapted species as well as species that aren’t reported in Colombia but can be climate adapted and have high biomass production yields. With this in mind, it is important to evaluate lignocellulose biomass generation and energy potential of different rapid growing crops viable for development in Colombia, with the purpose of using them as feedstock in a biorefinery.

2. Material and Methods

Identification: Species identification was carried out from consultation of Colombia’s Biodiversity Information System database (SIB by its Spanish acronym) (SIB, 2017). Through this, a first group of native Colombian species was established. Then a second group of species not reported for Colombia was established from a review of the current literature on the matter.
Physicochemical characterization and regrouping: The physicochemical information such as the percentage of hemicelullose, dry matter, ashes, and apparent humidity was identified. The purpose of this baseline information is to establish the most suitable treatment for biomass in an energy transformation process. After separating the species in the two groups described; each one was evaluated according to its main obtainable biomass fraction, stem, leaves and branches. This characterization was carried out through specialized data bases and previous works.
Requirements for development: The optimal growth conditions of each species associated with the agro-energetic requirements was determined. Based on this, the information about each crop characteristic such as annual median rainfall and temperature, soil pH, elevation above sea level, moisture content and soil requirements was compiled.
Growth rate: Growth rate determination for each species consisted of identifying the metabolism type, yearly growth cycle, crop yield, biomass production per area and current usage. With this information, production yields where established for each fraction of biomass per species cultivated.
Identification of suitable cultivation areas: With the Geographic Information System (SIG by its Spanish acronym), suitable growth areas where established on a national level. This was achieved cross comparing the agro-energy requirements of the species with information of national geographic conditions from the Colombian Hydrology, Meteorology and Environmental Studies Institute (IDEAM by its Spanish acronym). Data used was: ecosystem shape, annual median rainfall and temperatures and a digital elevation model given by the Colombian Geological Institute (IGAC by its Spanish acronym).
Determination of energy potential: Energy potential for each species was evaluated once suitable cultivation areas and growth rates where determined. Additionally, the inferior heat of combustion and crop biomass yield was taken into account.

3. Results and discussion

3.1 Species selection

Identification determined seventy-five (75) lignocellulosic species classified into two groups; The first compiles forty-two (42) species distributed in Colombia (native and adapted to climatic conditions). The second group comprises thirty-three (33) species that are not reported in the country. The fraction in percentage corresponding to stem, leaves and branches of total biomass was determined for each species. Based on this criterion, four (4) species belonging to the group of species not reported in Colombia were discarded.
Regarding cultivation requirements, twenty five (25) species were discarded twelve (12) of which are not reported in Colombia and thirteen (13) are established in the country. After cross comparing the information of the species requirements and the national geographic characteristics, the areas suitable to establish the second generation energy crops were found. In order to facilitate the information analysis, the species were reclassified by families. This analysis allowed the construction of 11 maps where the different selected families were evaluated.

3.2 Characteristics analysis of the species for Colombia

Species established for Colombia

The families identified at national level belong to the *Asterácea*, *Lamiaceas*, *Euphorbiaceae*, *Fabaceae*, *Myrtaceae* and *Pinaceae* families. Within these, 6 species are found to have a C4 metabolism which indicates a higher production of biomass and poses them as possible competitors to first generation crops (Koçar & Civaş, 2013). The pH ranges required by these species fluctuate between 5.25 and 6.75 indicating development possibilities in acid soils. However, the species with the greatest capacity for synthesis of carbon dioxide (C4) are in values above 6.25.

The species are located in regions with average temperatures between 14 and 25 ºC, rainfall levels between 450 and 1,750 mm and elevation between 800 and 2,730 m.a.s.l. Obviously, these ranges cover a large proportion of the territory although the characteristics for each species vary around 40%. The main fraction of usage is the stem of the plant which represents more than 50% of the biomass synthesized by the plant.

Species not reported for Colombia

Families with potential at a national level belong to the *Leguminosae*, *Myrtaceae*, *Paulowniaceae*, *Pinaceae* and *Poaceae* families. Within these families most species have a C4 metabolism and are adapted to low pH ranges of soil (between 3.5 and 7.75). Unlike species established in Colombia, these species move in a strip of acidic and slightly basic soils. The species are located in regions with a greater temperature range between 14 and 35 ºC, rainfall levels between 325 and 2,050 mm and elevation between 90 and 3,200 m.a.s.l. The broadening in the ranges favors the implementation of these crops in a greater number of regions compared to the existing species in Colombia. The main fraction of usage is the plant stem although its proportion compared to the total biomass generated represents from 17.7 to 60.3%. This leads to less energy recovery for some of the species identified. It is important to emphasize that some these species found in both cases have evidence of being invasive species, so an evaluation of the impact on the national ecosystem is necessary in case of implementing these in Colombia (Smith et al., 2013).

3.3 Analysis of suitable areas and energy potential

Species established for Colombia

According to the requirement information for each species and the geographic conditions, the *Myrtaceae* and *Pinaceae* families present the greatest potential of implementation in terms of viable areas with a total of 544,123 ha and 493,407 ha respectively (Figure1). A second group of families was found with high potential cultivable areas (from 10,000 to 400,000 ha). In this group 4 families are found: the first family is *Asteraceae* with the species *Cynara cardunculus* which can be cultivated in 86.766 ha. This area is distributed in the departments of Norte de Santander, Santander, Boyacá, Cundinamarca, Tolima, Valle del Cauca, Huila and Nariño (Figure 1). It is important to point out that this latter specie is already established in Colombia in the departments of Cundinamarca and Antioquia mainly for medicinal purposes (Vera & Sanchez, 2015).

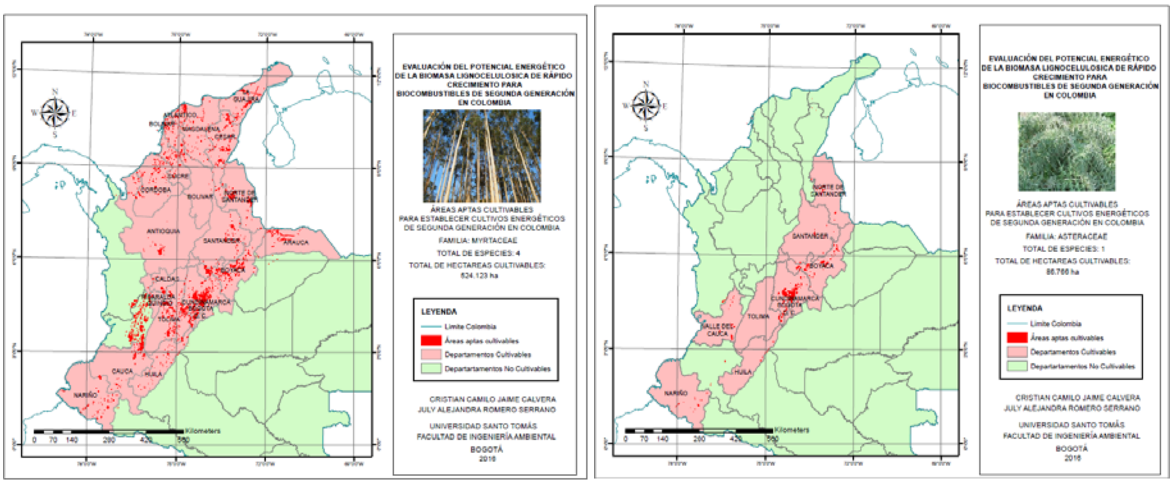

Figure 1: Example of maps generated for suitable areas: a) Myrtace family; b) Asterácea family.

Table 1 shows the species information according to the departments where they can be cultivated, the total areas and the total energy potential of the plant. The energy potential of *Myrtaceae* family made up of three species was: *Eucalyptus benthamii* with 8,819 TJ/year; *Eucalyptus globulus* with 5,991 TJ/year and

Eucalyptus grandis with 5,971 TJ/year. In the case of the *Pinaceae* family, which consists of two species, *Pinus patula* and *Pinus radiate*, energy potentials of 3,829 TJ/year and 2,155 TJ/year, respectively, were found. These species are in a medium high range according to the classification of the atlas of residual biomass of Colombia being in the range from 2,000 TJ/year to 10,000 TJ/year (UPME, 2014). It is important to highlight the energy potential of the species *Cynara cardunculus*, which is 10,450 TJ/year for the whole plant. The potential of the species in relation to its leaves and branches fraction was 7,634 TJ/year, which indicates that the use of the leaves and branches represents more than 60% of the energy that can be recovered. Unlike *Eucalyptus grandis* which is below 25%. However, it is important to take into account the current uses of this species and the impact that the shift in crop functions would have on the regional economy (Vera & Sanchez, 2015).

Table 1: Evaluation of energy potential of species in Colombia

Family	Specie	Departments	Areas (ha)	Potential (TJ/year)
Asteraceae	Cynara cardunculus	Antioquia - Rio Negro, Cundinamarca	86,766	10,458
Euphorbiaceae	Hura crepitans	Santa Marta, Antioquia, Cartagena, Sucre, Córdoba, Santander, Meta Y Valle del Cauca.	61,749	2,918
	Pedilanthus tithymaloides	Choco y Antioquia		2,182
Fabaceae	Gliricidia sepium	Santa Marta, Choco, Valle del Cauca, Meta, Antioquia, Córdoba, Cesar, Bolívar, Santander, Tolima, Cauca, Caquetá y Sucre	382,682	2,343
	Leucaena leucocephala	Córdoba, Santander, Antioquia, Tolima, Choco, Cundinamarca, Meta, Quindío, Valle del Cauca, Vaupés, Cauca, Caquetá y Amazonas.		3,139
	Pueraria phaseoloides	Antioquia, Guaviare, Meta y Caquetá.		19,899
Lamiáceas	Tectona grandis	Antioquia, Choco, Santander, Valle del Cauca y Nariño.	148,368	23,030
Myrtaceae	Eucalyptus benthamii	Antioquia	524,123	8,819
	Eucalyptus globulus	Antioquia, Caldas, Boyacá, Cundinamarca y Nariño.		5,991
	Eucalyptus grandis	Valle del Cauca, Antioquia, Cauca Y Nariño.		5,971
	Eucalyptus spp	Antioquia, Caldas, Manizales, Valle del Cauca		3,943
Pinaceae	Pinus patula	Santander, Antioquia, Risaralda, Cundinamarca, Nariño.	493,407	3,829
	Pinus radiata	Risaralda		2,155

Species not reported in Colombia

From the analysis of the information obtained it was found that the families *Paulowniaceae* and *Poaceae*, would exceed 660,000 cultivable hectares within the national territory thanks to their agro-energy requirements (Figure 2). However, the *Paulowniaceae* would only energetically use its stem which represents a low energetic potential in comparison to other species. Therefore, the energy potential is amongst the smaller ranges from 300 to 2,000 TJ/year (UPME, 2014). On the other hand, the *Poaceae* family, although they are pastures, have a reasonable yield per cultivated area and their use is integral. Therefore, it presents an energy potential between 2,000 and 10,000 TJ/year. Furthermore, some species like *Panicum Virgatum*, *Pennisetum Sp, Switchgrass* and *Tripsacum dactyloides* can be considered suitable for biomass production to obtain energy (Table 2).

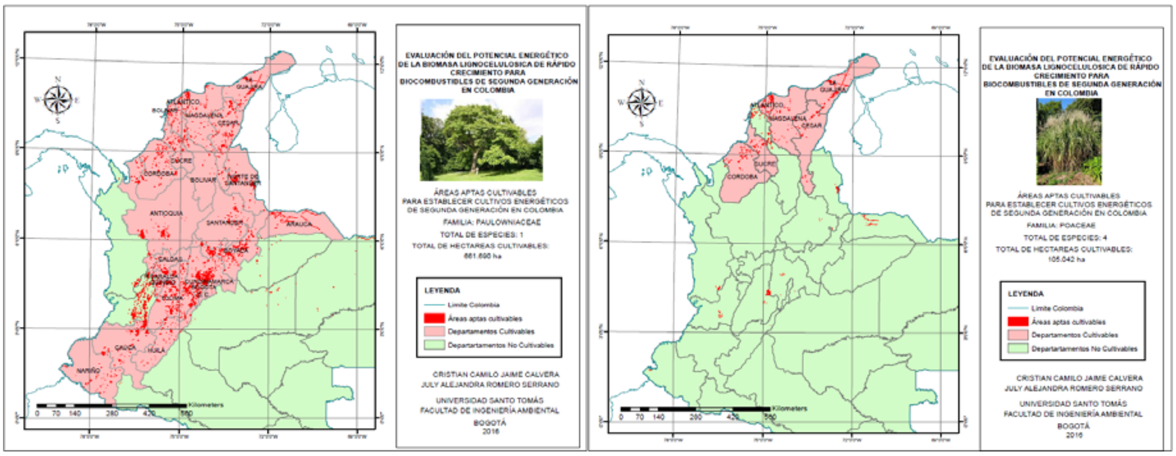

Figure 2: Examples of maps generated for suitable areas: a) Paulowniaceae Family; b) Poace Family.

Table 2: Evaluation of energy potential of species not reported in Colombia

Family	Specie	Departments	Areas (ha)	Potential (TJ/year)
Leguminosae	Acacia dealbata	Valle del Cauca, Tolima, Cundinamarca, Bolívar, Córdoba, Sucre, Cesar, Magdalena, Atlántico y La Guajira.	91,521	3,608
	Medicago sativa L.			167
Myrtaceae	Eucalyptus urophylla	Nariño, Huila, Arauca, Norte de Santander, Córdoba y Sucre.	524,123	9,347
Paulowniaceae	Paulownia	Arauca, Cundinamarca, Boyacá, Santander, Cauca, Norte de Santander, Tolima Quindío, Bolívar, Risaralda, La Guajira y Valle del Cauca.	661,690	583
Pinaceae	Pinus pinaster	Nariño, Cauca, Huila, Tolima, Cundinamarca, Risaralda, Quindío, Valle del Cauca, Choco, Casanare, Cesar, Norte de Santander, Bolívar, Atlántico, Magdalena y Sucre.	493,407	13
	Pinus silvestris L.			17
Poaceae	Miscanthus giganteus	Vaupés, Caquetá, Guaviare, Guainía, Vichada, Meta, Putumayo, Nariño, Cauca, Huila, Tolima, Arauca, Choco, Bolívar, Magdalena y Atlántico.	663,490	12,924
	Panicum Virgatum			3,877
	Pennisetum Sp			10,206
	Switchgrass			18,597
	Tripsacum dactyloides			6,186

3.4 Methods used for biofuel production

The characterization of lignocellulosic biomass of the fast growing energy crops evaluated in this study, found its composition in terms of percentage of cellulose, hemicellulose and lignin. These compounds are more difficult to use for biofuel production. However, theses systems' potential can be improved with biomass pretreatment methods and using them as products with added value as raw materials (Nagy & Hegedüs, 2015). In fact, most of the biomass with a high cellulose and hemicellulose content can be subjected to hydrolysis processes to release sugars (Hernández et al., 2014). Whereas, materials with high lignin content can be used in high-energy yield thermochemical processes, such as gasification and pyrolysis (Koçar & Civaş, 2013; Pérez et al., 2011). Regarding energy recovery by biological processes, different fractions can be evaluated through anaerobic co-digestion of waste in order to adjust optimum C/N ratio and maximize biogas production (Ivan et al., 2016). For the fraction discarded in several types of energy crops mentioned above, one of the alternatives is to give value to these materials with low energetic potential in aerobic activities like composting. These help structure to the work bed and inhibit the occurrence of anaerobic zones inside heaps. A stable material in terms of organic matter produced through composting can be used as fertilizer, biofiltration systems for volatile organic compounds, etc. (López et al., 2011).

4. Conclusions

The main regions available to develop these types of crops in Colombia were located in the departments of Cundinamarca, Antioquia, Santander, Quindío, Risaralda, Caldas, Tolima, Valle del Cauca and Nariño. The species with the highest energy potential are those already found in Colombia, which would avoid any problems regarding invasive non-native species. Technologies like gasification and pyrolysis were found to be applicable to some families such as *Asteraceae*, *Euphorbiaceae*, *Paulowniaceae* and *Pinaceae*. These have around 25% of lignin; therefore liquid and gaseous fuels can be obtained. Meanwhile, a high cellulose and hemicellulose content (48% and 64% respectively) in families such as *Fabaceae*, *Lamiáceas* and *Myrtaceae* make suitable to use as source of sugar for biofuel production. It is important to evaluate the current use of the species in the country in order to analyse the impact of the energetic valorization in the economy of the regions.

Acknowledgments

This work was carried out within the project Energetic Crops, supported by Universidad Santo Tomás - EAN.

Reference

Castro, A., 2009, Cultivo De Palma De Aceite Modelo De Desarrollo Sostenible. Fedepalma, Bogotá, Colombia.

Chiaramonti, D., Martelli, F., Balan, V., Kumar, S., 2014, Industrial initiatives towards lignocellulosic biofuel deployment: An assessment in US and EU, Chemical Engineering Transactions, 37, 313-318, DOI: 10.3303/CET1437053

Hernández, M.A., Rodríguez Susa, M., Andres, Y., 2014. Use of coffee mucilage as a new substrate for hydrogen production in anaerobic co-digestion with swine manure, Bioresource Technology, 168, 112-118, DOI: 10.1016/j.biortech.2014.02.101

Ivan, C., María, T., Aura, V., Paola, A., Mario, H., 2016, Anaerobic co-digestion of organic residues from different productive sectors in Colombia: Biomethanation potential assessment, Chemical Engineering Transactions, 49, 385-390, DOI: 10.3303/CET1649065

Koçar, G., Civaş, N., 2013, An overview of biofuels from energy crops: Current status and future prospects, Renewable and Sustainable Energy Reviews, 28, 900-916, DOI: 10.1016/j.rser.2013.08.022

López, R., Cabeza, I.O., Giráldez, I., Díaz, M.J., 2011, Biofiltration of composting gases using different municipal solid waste-pruning residue composts: Monitoring by using an electronic nose, Bioresource Technology, 102(17), 7984-7993, DOI: 10.1016/j.biortech.2011.05.085

Montaño, H., 2014, Producción de Bioetanol a Partir de Material Lignocelulósico de Moringa Oleífera, MSc thesis, Universidad Nacional de Colombia, Bogotá, Colombia.

Nagy, E., Hegedüs, I., 2015, Second generation biofuels and biorefinery concepts focusing on Central Europe, Chemical Engineering Transactions, 45, 1765-1770, DOI: 10.3303/CET1545295

Niño, J., 2013, Potencial y Beneficio Socio-Ambiental Del Uso de Materiales Lignocelulósicos Generados en Proyectos Lineales, MSc thesis, Universidad Nacional de Colombia, Medellín, Colombia.

Pérez, S., Renedo, C.J., Ortiz, A., Mañana, M., Delgado, F., Tejedor, C. 2011. Energetic density of different forest species of energy crops in Cantabria (Spain). Biomass and Bioenergy, 35(11), 4657-4664, DOI: 10.1016/j.biombioe.2011.09.008

SIB, 2017, Sistema de Información sobre Biodiversidad de Colombia <www.sibcolombia.net.> accessed 20.04.2017

Smith, A.L., Klenk, N., Wood, S., Hewitt, N., Henriques, I., Yan, N., Bazely, D.R., 2013, Second generation biofuels and bioinvasions: An evaluation of invasive risks and policy responses in the United States and Canada, Renewable and Sustainable Energy Reviews, 27, 30-42, DOI: 10.1016/j.rser.2013.06.013

UPME, 2014, Atlas del Potencial Energético de la Biomasa Residual en Colombia. Gobierno de la República de Colombia, Bogotá, Colombia

Vera, B., Sánchez, M., 2015, Registro de algunas plantas medicinales cultivadas en San Cristóbal, municipio de Medellín (Antioquia - Colombia), Revista Facultad Nacional de Agronomía, 68