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Biomass Potential and Kinetics of Drying Model of Piptocoma discolor (pigüe) as a Source of Renewable Energy Source in Ecuador

(Potencial de la biomasa y la cinética del modelo de secado de Piptocoma discolor (pigüe) como fuente de energía renovable en el Ecuador)

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Abstract

The importance of *Piptocoma discolor* is a predominantly fast-growing native species of secondary forest ideal for a sustainable forest due to its predominance in the Amazon of Ecuador and Latin America. Currently it is wood and its waste does not have an alternative to produce electricity. Scarce information on its biomass potential and energy value. The objective was to obtain fresh biomass and drying kinetics, we worked in the four cantons of the Pastaza province with 20 plots of 400 m^2 and 600 m^2 that had an average of 15 to 20 trees, whose chest height diameters ranged from 10 and 33 cm., Establishing the following values: a) Average number of trees per hectare (1274 NA2/ha); b) Biomass in 100 987 hectares with an average of 41 097 686.87 tons, which means that it contributes with 49.72 % of water and 50.28 % of solid matter; c) A kinetic model of R2 = 0.9855, the estimate of a = 1.1318, k = 0.0637765, n = 0.560617 and b = -0.193993, based on a standard error of 0.0301682 and residual autocorrection of 0.182239 on drying kinetics; and d) Total energy means more than 13.5 GW of thermal energy using 100 % biomass.

Keywords

Biomass, renewable energy source, biofuel, *Piptocoma discolor*.

Resumen

El Piptocoma discolor es una especie nativa de bosques secundarios y de crecimiento rápido ideal para un bosque sustentable por su predominancia en la Amazonía del Ecuador y de América Latina. Actualmente, esta madera y su desperdicio no se consideran como una alternativa para producir energía eléctrica. La información sobre su potencial de biomasa y valor energético es escasa. El objetivo fue obtener biomasa fresca y conocer la cinética del secado. Se trabajó en los cuatro cantones de la provincia de Pastaza con 20 parcelas de 400 m^2 *y 600* m^2 *que tenían un promedio de 15 a 20 árboles, cuyos diámetros de altura del pecho oscilaban entre 10 y 33 cm, y se establecieron los siguientes valores: a) Número de árboles por hectárea promedio (1274 NA2/ha); b) Biomasa en 100 987 hectáreas con un promedio de 41 097 686.87 toneladas, lo que significa que contribuye con 49.72 % de agua y 50.28 % de materia sólida; c) Un modelo cinético de R2 = 0.9855, la estimación de a = 1.1318, k = 0.0637765, n = 0.560617 y b = -0.193993, basado en un error estándar de 0.0301682 y autocorrección residual de 0.182239 de la cinética de secado, y d) Energía total significa más de 13.5 GW de energía térmica utilizando 100 % de biomasa.*

Palabras clave

Biomasa, fuente de energía renovable, biocombustible, Piptocoma discolor.

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1. Introduction

For Ecuador, the potential of biomass facilitates its contribution to the energy matrix and represents an important challenge for the scientific community (Gaibor-Chávez et al., 2016). The potential of forestry biomass requires the establishment of suitable techniques for its use, as described in Article 21 of the country's Forestry Law (Ley Forestal y de Conservación de Áreas Naturales y Vida Silvestre, 2004). Mexico has pledged to reduce greenhouse gas (GHG) emissions by 22 % by 2030 and they have managed to mitigate emissions with clean energy production through international agreements (Colegios de Ingenieros Ambientales de México, 2017). In order to evaluate biomass, we created an inventory by employing logistic regression methods, Landsat TM images, topographic information and variables derived from the Forest Map (García-Martín et al., 2006). We quantified the dendrometric variables with technological advances and for the drying process, we used proven models such as Midili and Page, which were also adopted for estimating citrus biomass (Velázquez-Martí et al., 2016). Other investigators judge that the drying rate must be adjusted in relation to time and temperature, and that one must determine the reduced moisture content (RMC), which contributes to models particular to each species. (Umaña-Calderón et al., 2019). Another exhaustive quantification and characterization of the products is by means of analyzing physical, chemical and energetic properties with a direct or indirect link to the drying process (Montero Puertas, 2005). The kinetics of drying is a process that encompasses four stages of humidity removal by convection (Gómez de la Cruz, 2015).

The fresh shrub biomass analysis techniques allow for the calculation of apparent volume for mathematical, cylindrical and parabolic models (dm^3 or m^3), and allow for the determination of amount of biomass (Velázquez-Martí et al., 2010). With these models, the potential of citrus biomass is also assessed (Velázquez-Martí et al., 2012). Humidity was evaluated using the gravimetric method with respect to the dry weight (free of humidity) of the wood's dry biomass (Córdoba, 2005). In Ecuador, there is little information on the subject in available forest inventories. In October 2010, fieldwork was performed in Andean and Amazonian dry forests and in 2012, the forest inventory survey was carried out with random sampling of all types of forest in the nation's territory (MAE, 2015). The inventory of *Piptocoma discolor* and the determination of its fresh biomass potential in forests according to the diameter at breast height (DBH) in the secondary forest of Mera canton, Pastaza province (Merino, 2010). Currently, the forestry species are dried by the forest's atmosphere (Salinas et al., 2019). It is necessary to utilize this plant, because it is a pioneer species of the early and late secondary forest of the Amazon Region. (Merino, 2010). It is used as an energy crop, due to its rapid and natural growth (González et al., 2018). A Softwood tree that reaches a maximum height of 30 m, its trunk diameter is approximately 60 cm, is cylindrical and has ramifications above the lower third. This herbaceous plant has well-formed straight branch stubs and flaky, grayish cracked bark. It boasts natural regeneration, which allows it to repopulate the secondary forests of the Amazon Region. (Vallejo, 1982). It grows at different altitude levels (500 to 1500 masl) at an average temperature of 20 °C and covers a radius of 25 to 30 km from Pastaza province. (Merino, 2010). As a species native to the Amazon Region (Erazo et al., 2014), it is associated with forestry calculations and its biomass potential predominates over the Ecuadorian Amazon Region's other natural resources (Forest Carbon, 2014). It is produced in an associative way with other species of greater relevance in the area (Hurtado & Guayara, 2013). and the annual production volume is 8754 m^3 (MAE, 2009). This study deals with the potential of fresh and dry forestry biomass as a Renewable Energy (RE), due to its natural replacement (Unión General de Trabajadores, 2016). Biomass models in recent years have increased and the most commonly used are models of regression and combination of variables, because they correlate most adequately for forest inventories (Fonseca et al., 2009).

The study was carried out *in situ,* because there are two methods: direct and indirect. The former is destructive and consists of cutting the tree to weigh the components and the latter consists of measuring tree volume (Fonseca et al., 2009), in order to determine the fresh and dry biomass potential of *Piptocoma discolor.* A model was created to estimate the secondary forest's biomass production using individual volumes, with averages of height and weight in relation to the volumetric equation for truncated cones (Aristizábal, 2011). The kinetics of drying was examined by eliminating moisture from the wood, which varies between 25 and 50 % with respect to its initial weight and does not undergo appreciable changes for treatments and industrial uses (Fogila, 2005). For the production of steam, a humidity of 10 (% H) is required as an optimal value for renewable energy generation (Arroyo-Vinueza et al., 2016).

2. Materials and Methods

2.1. Study Area

The study was carried out in four cantons in the province of Pastaza, namely Arajuno, Mera, Santa Clara and Pastaza. Altitude ranged from 550 to 960 m above sea level, with relative humidity rates between 80 and 90 %, and an average temperature of 22 °C (Quezada, 2013). This information is based on the meteorological data of the area. We selected areas of interest in the secondary forest in relation to species, (Murillo & Camacho, 1998), and then proceeded to gather information (Ministerio de Ambiente, Proyecto Manejo Forestal Sostenible ante el Cambio Climático, & Organización de las Naciones Unidas para la Alimentación y la Agricultura [MAE et al.], 2014).

SAMPLING METHOD

The sampling method applied was by means of stratification. We randomly selected extensions of 1 to 2 ha, with 12 plots of 400 m^2 and 8 plots of 600 m^2, in vegetation areas of *Piptocoma discolor* (MAE et al., 2014), and another extension with 5 plots with densities of 15 to 20 trees (Murillo & Camacho, 2013). This was carried out in the four cantons of Pastaza province (Figure 1).

The experimental study was carried out using criteria of diameters and categorization of the raw material using the following classification and including 3 trees per category: first (10-15 cm); second (16-21 cm); third (22-27 cm); and fourth (28-33 cm). 12 trees per canton were chosen, giving a subtotal of 48 trees of the 600 trees studied, with similar morphological characteristics (Escoto García et al., 2017).

Figure 1. Location of the Plots of Piptocoma discolor

a. Location of the plots

b. Tree species

An average of 25 geographical points (latitude, longitude and altitude) were selected in each canton, with GPS. Diameter was measured with forestry caliper lengths and widths of the plots with tape measure. We proceeded *a priori* to apply two methods of direct and indirect weighing, which allowed us to determine weight of logs. Lastly, tree samples were obtained in relation to amount of biomass, which was on average 3 kg per log and had a total of 36 kg per canton. Subsequently, the biomass was dried (Romahn & Ramírez, 2010). for optimization and representativeness, according to the method proposed by Hapla and Saborowski (1984), and for the determination of the sample size, we utilized equation 1 (Fernández-Puratich & Oliver-Villanueva, 2014).

$$IM = \frac{n}{N}*100 \tag{1}$$

where:

IM = Intensity of trees for estimating forestry biomass
n = Number of trees per plot
N = Tree population per hectare

To define the existing biomass potential in the four cantons in the province of Pastaza, the following formula was utilized:

$$Wt = \frac{Wp}{Á}*\frac{NA_2}{Ha} \tag{2}$$

where:

W_t = total biomass weight (kg/ha).
W_p/Á = average weight (kg/tree).
NA_2/ha = number of trees per hectare

METHOD FOR THE FOREST INVENTORY

The method used was low-intensity destructive allometry, which allowed is to estimate the biomass by regression analysis with the use of mathematical equations in relation to the biomass and the measurements of the woody vegetation at the feet of the trees for quantitative variables (DBH, commercial height, total height, basal area, mass and volume (Cancino, 2002). This was mainly intended for the calculation of plant biomass (Riofrío et al., 2006). and volumetric analysis (MAE & Ecuador, 2015).

THE ASSESSMENT FOR QUANTIFYING BIOMASS POTENTIAL

Mathematical models by Huber, Smalian and Newton (Cancino, 2010). were used for the volumetric quantification of fresh and dry biomass of shrubby plant species.

Tree volume was measured in relation to the volumetric equation for truncated cones:

$$V = \frac{\pi(R^2+r^2Rr)*h}{3} \tag{3}$$

where:

V = volume of branch stub (m³).
R^2 = major square of the radius (m²)
r^2 = lesser square of the radius (m²)
Rr = major square multiplied by lesser square (m²)
h = height of branch stub up to the apparent superior diameter (m)

For tree simulation and biomass potential simulation, the Autodesk Inventor Professional 2017 software was used. Based on the indicated data of the inventory and what equation 2 validates, the program simulated the tree and calculated the fresh biomass potential.

BIOMASS DENSITY

The quantification and estimation of the biomass potential, according to the diameters of the base and of the final branch stub, was considered for measuring the allometric method and branch diameters etc., which allowed us to establish biomass potential (Álvarez et al., 2013).

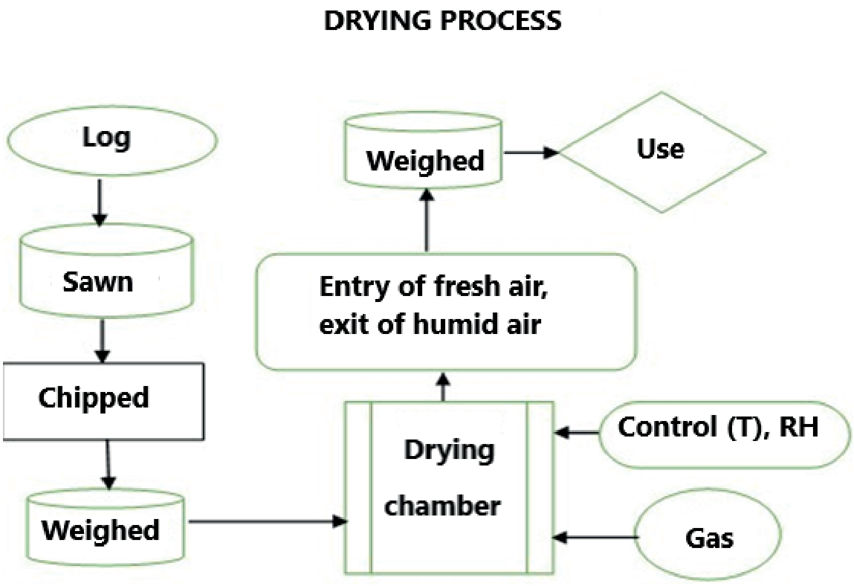
$$\boldsymbol{\rho = \frac{m}{v} = \frac{kg}{m^3}} \tag{4}$$

2.6. Drying the Biomass

3 kg of samples without bark were extracted from three sections of the tree log, from the base to the final branch stub of the tree (lower, intermediate and upper) in order to perform a homogeneous mixture and obtain complete information about the tree. Drying was achieved at room temperature (25°C) in the Pastaza canton. The time taken to air-dry the samples was 15 days and oven drying occurred at 120°C to achieve wood shavings that were 2 to 3 cm thick (Calderón & Solis, 2012).

To dry the samples, they were taken to an American Range industrial oven automated with a temperature regulation of ± 5 °C. The oven was set at a relative humidity of 90 % (% RH) and at a temperature of 120 °C. In order to examine the aforementioned samples according to their length and control the humidity at different times (0, 20, 50, 110, 170 and 200 min), the weight of each sample was checked using Pioneer digital analytical scales with an accuracy of 0.001 g until the samples reached a constant weight.

Figure 2. Diagram of Relative Humidity Removal



The experimentation considered 6 time periods and with 3 replicas, giving a total of 18 experimental runs, with samples weighing 2 kg. They were placed in trays inside the industrial oven for drying, which was carried out with the COPANT-wood standard 458 and its methodology (Garay y Henriquez, 2012). as shown in Figure 2 of the drying system.

2.7. Moisture Determination

The fresh sample was immediately weighed and the relative humidity of 90 % was determined, according to Chilean standard NCh176/1 (1984). The following formula for the initial moisture of the fresh wood was applied.

$$CH = CHC_{Fresco}\text{-}W_{H2O}/W_{Wfresco} \tag{4}$$

The pre-dried samples were placed on plastic tarpaulins to be later taken to the stove based on ASTM D 346-04 International Standards.

2.8. Modeling of Kinetics of Drying

The model was created, as visualized in Figure 2, with an industrial furnace that has a ventilation system that allows one to control temperature and time with tests of temperature ranges of ±5°, and has a permanent gas supply generating uniform heat according to the temperature, time and particle size. Water evaporated towards the surface and it was possible to identify the presence of two zones with hygroscopic domain, where the migration of humidity was governed by the diffusion of steam and liquid water. In the inner area, free water migrated by capillarity and the decreasing drying rate implied the start of an evaporation front below the surface, which moved to the center of the wood and was removed out of it (Ananías y Venegas, 2005).

The kinetics of drying are characterized by a curve based on the dimensionless parameters f(CHR) and CHR. Thus, the speed of drying represents the water removal ratio (Wan Noor et al., 2014), and the methods of solar drying in open and closed systems, such as industrial furnaces (Sunil y Ajaygiri, 2015).

$$\Phi = f(CHR).\Phi_{Max} \tag{5}$$

Con f(CHR) =1 if CH>CHC or f(CHR)=CHR if CH<CHC.

The content of reduced humidity CHR is defined as follows:

$$CH = CHC_{Fresh}\text{-}W_{H2O}/W_{WFresh} \tag{6}$$

$$CHR = \frac{CH\text{-}CHE}{CHC\text{-}CHE} \tag{7}$$

where:

CH = moisture content at any time (g water / g dry solid)
CHC = moisture content (g water / g dry solid)
CHE = the equilibrium moisture content of the sample (g water / g dry solid).

The drying curves obtained for *Piptocoma discolor* are based on the proposed new model, as shown in Table 1, where the maximum speed ΦMAX is calculated.

The equilibrium moisture determination (%) was determined using the Hailwood-Horrobin equation and the Simpson constants (Siau, 1984). depending on the temperature (T) of the dry bulb, and the relative humidity (RH) using a hygrometer (Molina Aiz) taking into account the conditions of the Ecuadorian Amazon Region.

$$CHE = \frac{1800}{K3}\times\left[\frac{K1\times K2\times HR}{1+K1\times K2\times HR}+\frac{K2\times HR}{1-K2\times HR}\right] \tag{8}$$

where:

CHE: Moisture Content in Balance with the Environment.
HR: Relative Humidity of 87 %. Obtained using a hygrometer.
K1, K2, K3: Constants determined by Simpson (Siau, 1984), depending on the temperature.

K1 = 4.737 + 0.0477 * T-0.0005 * T2 = 5.681
K2 = 0.7095 + 0.0017 * T-5.5534 * 10-6 * T2 = 0.753
K3 = 223.385 + 0.694 * T + -0.0185 * T2 = 257.327.

The equilibrium moisture content according to Broche et al. (2002) y Bruce (1985). for this purpose is intended to test the following mathematical models and we adjusted it to the reality of the experimentation of the kinetics of drying, which is related to the reduced moisture content (RMC), temperature, time and weight of the mass, according to Table 1, for drying *Piptocoma discolor* in Ecuadorian Amazon conditions of Ecuador.

Table 1. *The most commonly used mathematical models in kinetics of drying for forestry biomass*

Name	Model	Reference
Henderson & Pabis, modified	$MR = ae^{-k_1t} + be^{-k_2t} + ce^{-k_3t}$	(Midilli, et al., 2002)
Midilli-Kucuk	$MR = a\exp(-kt^n) + bt$	(Ananías & Venegas, 2005).
Wang-Singh	$MR = at^2 + bt + 1$	(Sebastián et al., 2010)
Newton	$MR = \exp(-kt)$	(Chen et al., 2012)
Aidawati	$MR = a\exp(-kt^n) + b$	(Henderson, 1974)

The parameters a, b, c, k1, and n are coefficients of the models.

We decided to utilize Aidawati's mathematical model of the kinetics of drying with data about the species that has allowed the experiment to be validified. The authors of this work consider that the models based on individual elements are still marginalized. It should be noted that the drying mechanisms must have regulators of the basic parameters to obtain a drying mechanism that must be applied during the elimination of moisture and obtain a biomass that guarantees combustion and a constant calorific value.

2.9. Statistical Analysis of Fresh and Dry Biomass Potential

Descriptive statistics were applied for fresh biomass based on information from GPS points and tree count based on DBH, experimental plots and the MAE (Ministerio de Ambiente) database, total landowners and number of hectares of the province in use of the secondary forest according to the information *in situ*. And for mathematical modeling, in the kinetics of drying, we worked with the data of dry biomass weight and inferential statistics were applied by comparing and adjusting the models by regression of exponential and polynomial equations. The data of the indicated variables were processed in the statistical program STATGRAPHICS Centurión, version 16.0.0.C (Gutiérrez Pulido y Salazar, 2008). In this way, the validity of the adjustment and development of the mathematical model has been demonstrated.

Results

3.1. Potencial of Available Biomass

Table 2 shows the dendometric parameters of *Piptocoma discolor* in the plots of the four cantons. It can be observed that in the DBH categories of 4 to 9.9 cm and 22 to 27.9 cm, similarity was apparent in number of trees.

Table 2. Average diameters of trees in secondary forest plots, province of Pastaza

Details		**Diameter (cm)**			**Height (m)**		
DCH (cm)	**N.º of Trees**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
4 a 9.9	252	7.2	4.2	9.7	11.6	8.0	14
10 a 15.9	698	12.8	10.0	15.6	17.4	14.0	19.4
16 a 21.9	156	17.3	16.4	18.5	19.7	19.5	20
22 a 27.9	228	22.9	21.8	24.5	22.8	20	28.5
28 a 33.9	108	30.5	28.0	33.0	28.5	28.5	28.5
Total	1442	18.17	16.08	20.26	20.03	18.00	22.08

We recorded results in Table 3 regarding average diameters and weight of trees that were extracted to analyze biomass potential with commercial characteristics and non-commercial characteristics with industrial uses.

Table 3. Design of experiments to obtain samples of the biomass inventory in the province of Pastaza

DBH (cm)	**N.º of trees**	**Diameter of tree**		**Length of tree (m)**		**Total length**	**Weight (kg)**		
		Lower base (cm)	**Final upper (cm)**	**Commercial**	**Not useful**	**(m)**	**Commercial**	**Not useful**	**Total Weight**
10 a 15	12	13.25	9.01	10.76	5.22	15.98	54.63	15.43	70.08
16 a 21	12	18.33	13.52	8.83	6.93	15.75	116.89	46.82	163.73
22 a 27	12	23.82	15.77	12.05	7.58	19.79	210.47	54.42	264.92
28 a ≥ 33	12	30.14	24.55	11.88	12.04	23.93	577.42	207.09	784.53
Average	48	21.39	15.71	10.88	7.94	18.86	239.85	80.94	320.81

Table 4 presents results concerning information about the investigation of the forest resource *Piptocoma discolor* and a difference in the estimation of biomass potential.

Table 4. Analysis of biomass potential in the plots of Piptocoma discolor, province of Pastaza

Canton	**Weight kg/tree**	**N.º of plots /ha**	**Area (m^2) plot/ha**	**N.º of trees per plot**	**N.º of trees per ha**	**Total Weight kg/ha**
Pastaza	287.33	4	2400	46	767	220 286.3
Arajuno	384.67	4	2400	60	1000	384 670.0
Mera	261.98	4	2400	58	967	253 247.3
Santa Clara	346.60	6	3200	126	2363	818 842.5
Total/Average	320.15	18	10400	73	1274	419 261.5

By incorporating the number of populated hectares of *Piptocoma discolor* in the 4 Cantons studied, it was possible to obtain a biomass production potential for each canton (Table 5).

Table 5. Total biomass potential for Piptocoma discolor in the province of Pastaza

N.º	**Canton**	**Total Weight (kg/ha)**	**N.º (ha of Piptocoma discolor)**	**Subtotal (kg of Piptocoma discolor)**	**Total Weight (ton of Piptocoma discolor)**
1	Pastaza	220 286.30	44 879.00	9 886 230 353.67	9 886 230.35
2	Arajuno	384 670.00	13 461.00	5 178 042 870.00	5 178 042.87
3	Mera	253 247.30	15 714.00	3 979 528 596.00	3 979 528.60
4	Santa Clara	136 560.40	26 933.00	22 053 885 052.50	22 053 885.05
	Total	1 677 046.20	100 987.00	41 097 686 872.17	41 097 686.87

Figures indicate that more than 13.7 million tons of fresh *Piptocoma discolor* matter has the potential for industrial use. Non-usable wood for energy purposes came to 3.7 million tons. These are properties of the species' biomass potential (Table 6).

Table 6. Usable and non-usable biomass potential of *Piptocoma discolor*

Canton	**Total of Fresh Matter (ton)**	**Trees**	**Branches**	**Trees**	**Branches**
		Usable Wood (ton)	**Non-usable wood (ton)**	**Usable (%)**	**Non-usable (%)**
Pastaza	2 475 857.74	1 899 725.64	576 132.10	76.73	23.27
Arajuno	1 294 510.72	933 471.68	361 039.04	72.11	27.89
Mera	9 996 255.03	7 985 008.52	2 011 246.51	79.88	20.12
Santa Clara	3 677 981.25	2 882 066.12	795 915.13	78.36	21.64
Total	17 444 604.74	13 700 271.96	3 744 332.78	78.54	21.46

Unlike Spain, other species in forests for wood and daily consumption are imported from abroad (Martínez, 2009). Production is differentiated in the secondary forest, as this is a pioneer species in the province of Pastaza and the Amazon Region of Ecuador.

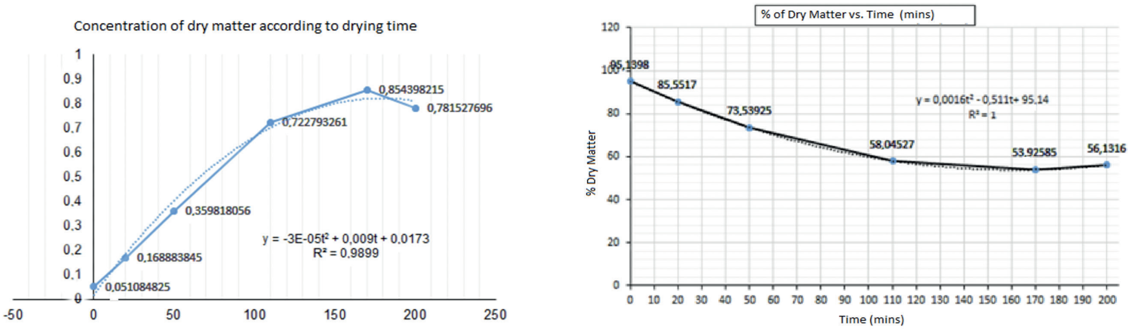
3.2. Dry Matter as a Source of Energy

The total raw material of *Piptocoma discolor* is 41 097 686.87 metric tons. 50.28 % of dry matter is equivalent to 20 124 108.68 metric tons and 49.72 % of water, with 20 973 578.20 metric tons remaining, which is added to the secondary forest which contributes to the Ecuadorian Amazon Region. An amount of 17 444 604.74 metric tons of *Piptocoma discolor* per year can be extracted from the forest, leading to a potential of 129 992.71 metric tons per month. This figure represents a considerable amount in terms of energy potential; it is around 13.54 GW of thermal and about 3380 MW of electric energy.

3.3. Kinetics of Drying by Convection

The result of the fresh biomass of *Piptocoma discolor* is represented by a solid phase (hemicellulose, cellulose and lignin), a liquid phase (water) and a gas phase (air and water vapor) of the porous structure of the wood. By analyzing the proportions and understanding the isothermal mechanism of drying, experimental calculations and biomass ratios of *Piptocoma discolor* trees were established in the drying process (Figure 3).

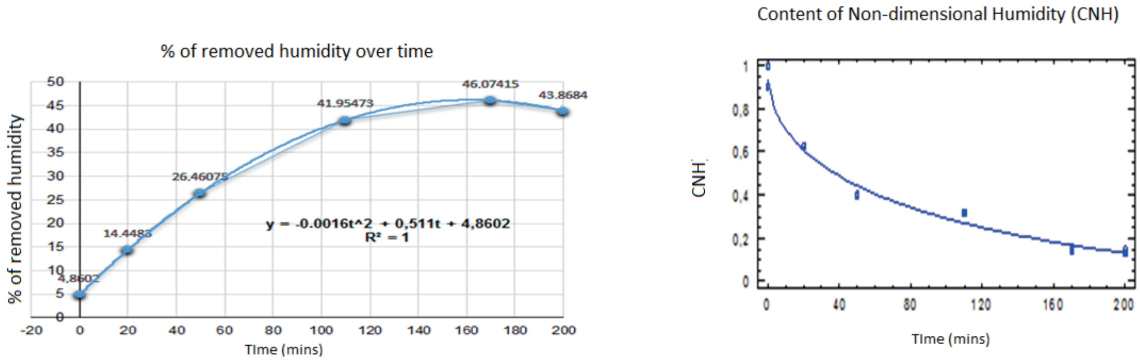
Figure 3. Behavior of the Drying Stages of *Piptocoma discolor* Wood: a and b



The gravity or density was 0.759 g/cm³ in fresh matter and 0.560 g/cm³ in dry matter, the fraction of the porosity of the moisture of the initial sample was 0.12 and humidity removed was 0.43. According to the proposal for centimeter cubed of *Piptocoma discolor*, the humidity content was 7.28 %. In the drying isotherms, the air entering the empty spaces tended to remove the water towards the surface, as outlined by (Wan Noor et al., 2014).

The four stages of removal of total humidity are shown in Figure 4.

Figure 4. Stages of Humidity Removal and Reduced Moisture Content (RMC)

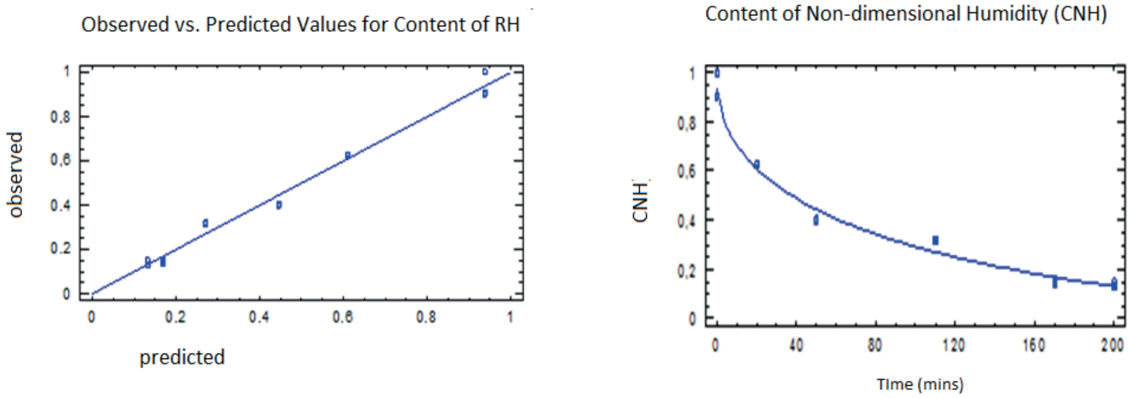


This kinetics of drying fulfils the four stages, as shown in Figure 4. Changes or behavior occur where the drying period is completed. The portion is decreasingly separated in the period AB and lower portion in the period BD. The portion goes down and gets further away for the first period (BC), and the second portion goes down in the period CD, as mentioned in the literature (Treybal,1988). It is necessary to remove some temperatures and the water molecule present in the wood is confidential in these free water molecules (Dengyu, et al., 2012). Drying takes advantage of the zero portion when the resistances of water molecules conduct strongly (Treybal,1988).

Table 7. Characteristics of the evaluation of drying curves

Model Parameters						
Model	**Temperature**	**A**	**B**	**K**	**n**	**R2**
Wan-Singh	30	0.0000315	-0.01199			0.8965
Henderson-Pabis	30	1.016		0.03065		0.9984
Midilli-Kucuk	30	0.9931	1.466E-05	0.02055	1.104	0.9988
Wan Noor	30	0.9898	0.00291	0.02038	1.107	0.9988
	45	1.015	0.003993	0.036	1.072	0.9999
Proposed Model	120	1.13E+00	-1.94E-01	0.0637765	0.56062	0.9855

Figure 5. Observed vs. Predicted Relative Humidity (RH) and Non-dimensional Humidity; a and b

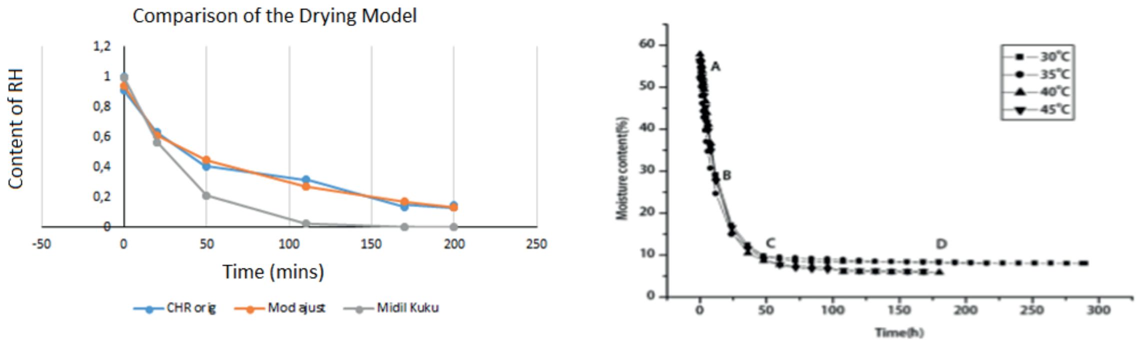


The biomass of *Piptocoma discolor* reaches 79 % of the total water removed at 120 °C during the time period of 170-200 mins with an average 170.53 mins. Portion prediction models were in accordance with experimentation and point information.

3.3. Comparison Kinetics of Drying

The results of the statistical analysis model in Table 7 and Figure 5 are considered to be the experimental drying at a temperature of 120 °C. This is, as an example, appropriate for comparing a model in order to demonstrate Midilli-Kucuk's model, as opposed to the other closed models indicated in the above table and according to the drying curves detailed below.

Figure 6. Comparison of kinetics of drying model with Midilli-Kucuk; a and b



The new model of kinetics of drying has a similarity to what Wan Noor found, based on the statistical analysis and parameters (a, b, k, and n value). When studying the different times and constant temperature, the proposed model and result of the variance R2 of the residual model, whose value was 0.9855, we found the following: estimated a = 1.131, k = 0.0637765, n = 0.560617 and b = -0.193993, based on a standard error = 0.0301682 and residual autocorrection = 0.182239 respectively. This was produced properly and compared to other models that describe the characteristics of *Piptocoma discolor* in its hydrating behavior of 2.16 % and its humidity, which is due to the conditions of the Amazonia Region.

$$\text{Proposed Model} \qquad CHR = a\exp(-ktn)+b.$$

Discussion

The biomass potential of *Piptocoma discolor,* due to its abundance and climatic characteristics and dominance over other species, makes its predation difficult compared to others. Tables 4 and 5 present the results that were obtained by direct methodology *in situ*, unlike similar studies conducted by indirect methods that reached an average of 0.47 t ms / ha per year (Dengyu, et al., 2012). In this case, the high forestry dominance of *Piptocoma discolor* provides better alternatives for management and its use, as well as for energy purposes, because the extraction rate must be adequate. One cannot use all the wood for this purpose, since one must also try to maintain the species' vigor and secondary forest sustainability (Spitler,1995). Other investigations carried out in the Ecuadorian Amazon Region determined that the revegetation was qualified as excellent at 96.8 % and acceptable at 86.3 % (Domínguez, 2011). This is due to the quality of biodiversity and to *Piptocoma discolor* itself (Murillo & Camacho, 1997). One of the reasons why people are so eager to boost the production of *Piptocoma discolor* is its rapid and natural growth in comparison to other species, so the interest of industrial exploitation is justified. In Argentina, the *Cabrelea canjerana* species grows naturally due to the light that reaches the undergrowth and has a high ecological and timber value (Moretti et al., 2019). The comparative advantage of our country with respect to others, such as Spain, is the climatic and edaphic conditions for production (Martínez, 2009). According to these analyses of *Piptocoma discolor*, there is still no other species that predominates over the Amazon Region and it is our interest to carry out an industrial process for energy purposes.

The behavior of the drying stages and the drying isotherms, as seen in Figures 3 and 4, defined and predicted the biomass portions (Martínez, 2009). and this agrees with studies regarding type of humidity (Dengyu, et al., 2012). obtaining a dry biomass with a density of 0.560 g / cm^3 and achieving a 43 % removal of humidity that was removed to the surface (Wan Noor et al., 2014). Wood is a heterogeneous, anisotropic, porous and unsaturated material, as discussed by Turner and Mujumdar (1997). From the point of view of drying, humidity is altered in relation to the equilibrium of the environment, in which numerical and statistical methods intervene, as proposed by mathematical models (Salinas et al., 2004).

The kinetics of drying systems with open and closed models were compared. The characteristics of *Piptocoma discolor* in Amazonian conditions resulted in a relative humidity of 80 and 90 %, and average temperature of 22°C (Quezada, 2013; Murillo & Camacho, 1998). based on the standard COPANT-woods 458 (Garay y Henriquez, 2012). This allowed us to obtain our own mathematical model for the species through the use of some models and their comparison with a kinetics of drying model similar to that of Midilli-Kucuk a and b 458 (Garay y Henriquez, 2012).

Due to the humidity of the Amazon Region, constant measurements of kinetic parameters must be carried out for its industrial use and to guarantee the production of renewable energy with a reliable potential of Gw in electrical terms.

Conclusion

The secondary forest where *Piptocoma discolor* is the most abundant. It delivers a biomass potential of 41 097 686.87 tons per year over 100 987 hectares. This reflects its contribution in fresh and dry biomass.

The Autodesk Inventor Professional 2017 software and equation 2 of the mathematical model of truncated cones allowed us to determine the biomass potential, as demonstrated in Table 3 and 4, due to the species' dominance against other Amazonian species.

The analysis of the kinetics of drying of the *Piptocoma discolor* biomass obtained its own mathematical model in Amazonian conditions that presented different characteristics to the Midilli-Kucuk in terms of values and its humidity stages, which are similar to what Wan Noor found in other species.

In energy terms, this represents a potential of 13.54 GW electric thermal, which could help meet the electrical demands of difficult-to-access areas in the Amazon Region.

References

Álvarez, E., Benitez [sic], D., Velásquez, C., & Cogollo, A. (2013). Densidad básica del fuste de árboles del bosque seco en la costa Caribe de Colombia, *Intrópica*, *8*(1), 17-28. https://doi.org/10.21676/23897864.729

Ananías, R. A., & Venegas, R. (2005). Secado industrial del pino radiata: Tiempo de esterilización con calor y evolución temporal de la temperatura. *Maderas. Ciencia y Tecnología*, *7*(3), 179-188. https://www.redalyc.org/pdf/485/Resumenes/Abstract_48507303_2.pdf

Aristizábal, J. D. (2011). Desarrollo de modelos de biomasa aérea en sombríos de cafeto (*Coffea arabica L.*) Shade Trees Via Simulated Data. *Rev. U.D.C.A Act. & Div. Cient.*, *14*(1), 49-56, http://www.scielo.org.co/pdf/rudca/v14n1/v14n1a07.pdf

Arroyo-Vinueza, J., & Reina-Guzmán, W. S. (2016). Aprovechamiento del recurso biomasa a partir de los desechos de madera para una caldera de vapor. *Ciencia y Tecnología*, 16, 1-10. doi: 10.17163/ings.n16.2016.03

Broche, W., Ananías, R., Salinas, C., & Ruiz, P. (2002). Modelación del secado convencional del coigüe: Parte 2. Resultados experimentales. *Maderas. Ciencia y Tecnología*, *4*(2), 69-76. http://dx.doi.org/10.4067/S0718-221X2002000100006

Bruce, D. M. (1985). Exposed-layer Barley Drying: Three Models Fitted to New Data up to 150C. *Journal of Agricultural Engineering Research*, *32*(4), 337-348. doi: 10.1016 / 0021-8634 (85) 90098-8

Calderón, D., & Solis, D. (2012). Cuantificación del carbono almacenado en tres fincas en tres estados de desarrollo del bosque de pino *(Pinus oocarpa, L.)* Dipilto, Nueva Segovia, Nicaragua [Tesis de grado, Universidad Nacional Agraria]. Repositorio institucional. https://repositorio.una.edu.ni/1158/1/tnk10c146.pdf

Cancino, J. (2002). Crecimiento. En *Dendometría básica*. https://bit.ly/3gdyV9e

Cancino, J. (2010). *Dendometría básica (Determinación de volumenes de árboles).* https://www.academia.edu/28227698/Dendrometria_Basica

Colegio de Ingenieros Ambientales de México. (2017). *Evaluación del potencial de la biomasa como parte de la matriz energética de México*. https://bit.ly/3mNIE8M

Córdoba, R. (2005). Conceptos básicos del secado de la madera. *Forestal Kurú (Costa Rica)*, *2*(5), 88-92. https://revistas.tec.ac.cr/index.php/kuru/article/view/546

Dengyu, C., Li, M., & Zhu, X. (2012). TG-DSC Method Applied to Drying Characteristics and Heat Requirement of Cotton Stalk During Drying. *Heat and Mass Transfer*, *48*(12), 2087-2094. doi:10.1007 / s00231-012-1050-6

Domínguez. (2011). *Evaluación del área reforestada y revegetada en el campo petrolero secoya, cantón Lago Agrio, provincia de Sucumbíos* [Tesis de grado, Escuela Superior Politécnica de Chimborazo]. DSpace ESPOCH. https://bit.ly/3ggqOJ1

Erazo, G., Izurieta, J., Cronkleton, P., Larson, A., & Putzel, L. (2014). Manejo sostenible de una especie pionera de madera para los medios de vida locales. *CIFOR Brief*, 24, 2 https://www.cifor.org/publications/pdf_files/infobrief/4424-infobrief.pdf

Escoto García, T., Beas, N., Contreras, H., Rodríguez, A., Diaz-Ramos, S. G., Anzaldo, J., & Vega R. (2017). Caracterización dasométrica y químico-micrográfica de tres especies de pino y su viabilidad de aprovechamiento integral. *Revista Mexicana de Ciencias Forestales*, *8*(41), 1-30. doi: 10.29298/rmcf.v8i41.28

Fernández-Puratich, H., & Oliver-Villanueva, J. V. (2014). Cuantificación de biomasa y valor energético de renovales de Quercus ilex en condiciones mediterráneas. *Bosque*, *35*(1), 65-74. doi:10.4067/S0717-92002014000100007

Fogila, R. C. (2005). Conceptos básicos sobre el secado de la madera. *Kurú. Revista Forestal*, *2*(5),1-5. https://revistas.tec.ac.cr/index.php/kuru/article/view/546/472

Fonseca, G. W., Alice, F., & Rey, J. (2009). Modelos para estimar la biomasa de especies nativas en plantaciones y bosques secundarios en la zona Caribe de Costa Rica. *Bosque*, *30*(1), 36-47. https://scielo.conicyt.cl/pdf/bosque/v30n1/art06.pdf

Instituto del Bien Común. (2014). Densidad de carbono, área protegidas y territorio indígenas, *Instituto del Bien Común*. https://ibcperu.org/en/publicacion/mapa-amazonia-densidad-de-carbono-areas-protegidas-y-territorios-indigenas-2/

Gaibor-Chávez, J., Pérez-Pacheco, S., Velázquez-Martí, B., Niño-Ruiz, Z., & Domínguez-Narváez, V. (2016). Dendrometric Characterization of Corn Cane Residues and Drying Models in Natural Conditions in Bolivar Province (Ecuador). *Renewable Energy*, *86*, 745-750. https://doi.org/10.1016/j.renene.2015.09.009

Garay, M., & Henriquez [sic], M. R. (2012). Tratamiento químico de acetilación en madera de Pinus radiata. *Maderas. Ciencia y Tecnología*, *14*(1), 103-113. doi: 10.4067/S0718-221X2012000100009

García-Martín, A., Pérez-Cabello, F., & De la Riva, J. (2006). Evaluación de los recursos de biomasa residual forestal mediante imágenes de satélite Landsat y SIG. *GeoFocus. Revista Internacional de Ciencia y Tecnología de la Información Geográfica*, 6, 205-230.

Gómez de la Cruz, F. (2015). Estudio y análisis de la cinética de secado de subproductos de almazara para su aplicación a secaderos rotativos [Tesis doctoral, Universidad de Jaén Escuela Politécnica Superior de Jaén]. Repositorio Institucional de Producción Científica. http://ruja.ujaen.es/bitstream/10953/675/1/9788484399391.pdf

González, J., Papue, A., González, V., Borja A., & Oliva, D. (2018). Crecimiento y conservación de *Piptocoma discolor* (Pigüe) en la provincia de Pastaza. *Cfores. Revista Cubana de Ciencias Forestales*, *6*(3), 366-379. http://scielo.sld.cu/pdf/cfp/v6n3/2310-3469-cfp-6-03-366.pdf

Gutiérrez Pulido, H., & Salazar, R. (2008). *Análisis y diseño de experimentos* (2.ª ed.). McGraw-Hill.

Henderson, S. M. (1974). Progress in Developing the Thin Layer Drying Equation. *Transactions of the ASAE*, *17*(6), 1167-1172. http://dx.doi.org/10.13031/2013.37052

Hurtado, E., & Guayara, A. (2013). Potencial de uso de *Piptocoma discolor* (Kunth) pruski en sistemas silvopastoriles. *Ingenierías & Amazonía*, *6*(1), 8. https://bit.ly/2JBhm7e

Ley Forestal y de Conservación de Áreas Naturales y Vida Silvestre. (2004). Capítulo VI: De producción y aprovechamiento forestal. 10 de septiembre. Registro Oficial 418. https://bit.ly/33KLJPE

MAE (2015). *Proceso metodológico para el desarrollo de modelos alométricos para especies, grupo de especies y estratos en el Ecuador.* Informe Guía.

MAE (2009). *Estudio para determinar la abundancia de* Piptocoma discolor *y otras especies potenciales para la industria de pallets y cajonería en la provincia de Pastaza.*

Martínez, S. (2009). *Evaluación de la biomasa como recurso energético renovable en Cataluña* [Tesis doctoral, Universitat de Girona]. https://bit.ly/33Ng3J8

Merino, J. (2010). *Estudio económico de dos formas de aprovechamiento forestal del* pigüe *(Pollaslesta discolor) en el cantón Mera, provincia de Pastaza* [Tesis de grado, Escuela Superior Politécnica de Chimborazo]. DSpace ESPOCH. https://bit.ly/3qrSijD

Midilli, A., Kucuk, H., & Yapar, Z. (2002). New Model for Single-layer Drying. *Dry Technology*, *20*(7), 1503-1513. https://doi.org/10.1081/DRT-120005864

Ministerio de Ambiente, Proyecto Manejo Forestal Sostenible ante el Cambio Climático, & Organización de las Naciones Unidas para la Alimentación y la Agricultura. (2014). *Evaluación Nacional Forestal de Resultados*. https://bit.ly/2IelERn

Montero Puertas, I. (2005). *Modelado y construcción de un secadero solar híbrido para residuos biomásicos* [Tesis doctoral, Universidad de Extremadura]. Servicio de Publicaciones. https://biblioteca.unex.es/tesis/8477237115.pdf

Moretti, A. P., Olguin, F., Pinazo, M., Gortari, F., Vera, J., & Corina, G. (2019). Supervivencia y crecimiento de un árbol nativo maderable bajo diferentes coberturas de dosel en el Bosque Atlántico, Misiones, Argentina. *Ecología Austral*, *29*, 099-111. https://bit.ly/39QJLRg

Murillo, G. O., & Camacho, M. P. (1998, nov. 22-28). *Metodología para la evaluación de la calidad de plantaciones forestales*. Primer Congreso Latinoamericano IUFRO, Valdivia, Chile. https://bit.ly/37D6Nso

Murillo, O., & Camacho, P. (1997). Metodología para la evaluación de la calidad de plantaciones forestales recién establecidas. *Agronomía Costarrcense*, *21*(2), 189-206. https://www.mag.go.cr/rev_agr/v21n02_189.pdf

Pérez-Peña, N., Valenzuela, L., Diaz-vaz, J., & Ananías, R. (2011). Prediction of Equilibrium Moisture Content in Wood in Relation to the Specific Gravity of the Cell Wall and Environmental Variables. *Maderas. Ciencia y Tecnología*, *13*(3), 253-266. http://dx.doi.org/10.4067/S0718-221X2011000300002

Riofrío, J., Ramos, R., & Muñoz, J. (2006). Ajuste de modelos alométricos para biomasa de Acacia melanoxylum L bajo sistema agroforestal en la Sierra ecuatoriana. *X Congreso Ecuatoriano de la Ciencia del Suelo*. https://bit.ly/33MSCjn

Romahn, C., & Ramírez, H. (2010). *Dendrometría*. División de Ciencias Forestales, Universidad Autónoma de Chapingo. http://dicifo.chapingo.mx/pdf/publicaciones/dendrometria.pdf

Salinas, B., Carpio, C., Salazar E., Noboa, V., Espinoza, M., & Román, D. (2019). Caracterización anatómica de la madera de cinco especies comerciales del sector la colonia Simón Bolívar, cantón Santa Clara, provincia de Pastaza. *European Scientific Journal*, *15*(18), 255 https://pdfs.semanticscholar.org/cd54/f84b6750a37f260c366b276fdc6163ddec56.pdf

Salinas, C., Ananías, R., & Alvear, M. (2004). Simulación del secado convencional de la madera. *Maderas. Ciencia y Tecnología 6*(1), 3-18, http://dx.doi.org/10.4067/S0718-221X2004000100001

Sebastián, F., García, D., & Rezeau, A. (Coords.). (2010). *Energía de la biomasa* (Vol. 1). Publicaciones de la Universidad de Zaragoza. https://bit.ly/3gg3USi

Siau, J. F. (1984). *Transport Processes in Wood*. Springer. https://bit.ly/3lCLoo8

Sistema Nacional de Áreas de Conservación & Programa REDD/CCAD-GIZ. (2014). *Manual de campo inventario forestal nacional de Costa Rica: Diseño de parcela y medición de variables de sitio y dasométricas* (Vol. 2, pp. 25-40). Programa REDD/CCAD-GIZ. https://bit.ly/3mK4Yae

Sunil, J., & Ajaygiri, K. (2015). Application, Advancements and Research on Drying- A Review. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, *3*(VIII), 403-406. https://www.ijraset.com/fileserve.php?FID=3227

Treybal., R. E. (1988). Secado. En *Operaciones de transferencia de masa* (2.ª ed., pp. 723-791). McGraw-Hill. https://bit.ly/36G0uVy

Umaña-Calderón, M., Muñoz-Mena, J., Pacheco-Retana, Y., & Vargas-Elías, G.(2019). Cinética del secado de coco por radiación. *Revista Tecnología en Marcha*, *32*(Especial XIII CLIA). doi: https://doi.org/10.18845/tm.v32i7.4269

Unión General de Trabajadores. (2016). Introducción general. En *Estudio sobre el aprovechamiento energético de la biomasa, energías renovables y reducccción de emisiones de CO2 en los municipios de Castilla y León* (pp. 3-18). https://bit.ly/3lP9r3q

Velázquez-Martí, B., Fernández-González, E, Estornell, J., & Ruiz, L. A. (2010). Dendrometric and Dasometric Analysis of the Bushy Biomass In Mediterranean Forests. *Forest Ecology and Management*, *259*(5), 875-882. doi:10.1016 / j.foreco.2009.11.027

Velázquez-Martí, B., Gaibor-Chávez, J., & Pérez-Pacheco, S. (2016). Quantification Based on Dimensionless Dendrometry and Drying of Residual Biomass from the Pruning of Orange Trees In Bolivar Province (Ecuador). *Biofuels, Bioproducts and Biorefining*, *10*(2), 175-185. https://doi.org/10.1002/bbb.1635

Velázquez-Martí, B., Estornell, J., López-Cortés, I., & Martí-Gavilá, J. (2012). Calculation of Biomass Volumen of Citrus Trees from An Adapted Dendrometry. *Biosystems Engineering*, *112*(4), 285-292. https://doi.org/10.1016/j.biosystemseng.2012.04.011

Villalba, V. (2019). Determinación de la viabilidad técnica y económica de la combustión del pigüe (*Piptocoma discolor*) para su uso como combustible en la provincia de Pastaza [Tesis de grado, Universidad Estatal Amazónica]. Repositorio institucional. https://bit.ly/2L8BKNw

Wan Noor, A., Hashim, R., Danish, M., Sulaiman, O., & Hiziroglu, S. (2014). Model of Drying Kinetics of Acacia Mangium Wood at Different Temperatures. *Drying Tecnology An Internactional Journal*, *32*(3), 361-370. doi: 10.1080/07373937.2013.829855