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Research article

Aprovechamiento de leña en una comunidad de la Sierra Sur de Oaxaca, México

Use of firewood in a community in the Southern *Sierra* of *Oaxaca*, Mexico

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Abstract

In several rural communities in Mexico, wood plays an important role as an energy source. Depending on the geographic area, different tree species are used as fuel, and each locality has its knowledge of collecting and using firewood. This work aims to taxonomically locate the main forest species used as fuelwood and to analyze their appropriation, use, management, and energy quality in *San Sebastián Coatlán*, *Miahuatlán* municipality, state of *Oaxaca*. Forty-five families were selected and interviewed through a semi-structured survey, using the snowball sampling. The basic density and calorific value of wood of the identified species were determined according to ASTM (American Society for Testing and Materials) standards. The results indicate that 40 % of the interviewees use firewood exclusively, and 60 % use firewood and Liquefied Petroleum Gas (LPG). Twelve species were recorded as being used as firewood, the most used species are: *Quercus laurina* 22 %, *Q. glaucoides* 18 % and *Q. resinosa* 17 %. The species basic density varied from 0.50 to 0.81 g cm^{-3} for *Lippia myriocephala* and *Dodonaea viscosa*, respectively. Their calorific value was from 19.53 to 21.06 MJ Kg^{-1} for *Acacia pennatula* and *Dodonaea viscosa*, respectively. In conclusion, due to their basic density, calorific value, and distribution in the study area, the species most used as fuel belong to the genus *Quercus*.

Key words: Wood energy, basic density, oaks, renewable energy, firewood, high heating value.

Resumen

En diversas comunidades rurales de México, la leña cumple un papel importante como fuente de energía. En función de la zona geográfica, se emplean diferentes especies arbóreas; además, cada localidad ejerce sus propios conocimientos para la recolecta y uso. Este trabajo tuvo como objetivos ubicar taxonómicamente las principales especies forestales utilizadas como leña y analizar su forma de apropiación, uso, manejo y calidad energética en el municipio San Sebastián Coatlán, distrito de Miahuatlán, Oaxaca. Se seleccionaron 45 familias mediante el muestreo de bola de nieve, las que fueron entrevistadas mediante una encuesta semiestructurada. A la madera de las especies identificadas se le determinó la densidad básica y el poder calorífico según las normas de *American Society for Testing and Materials* (ASTM). Los resultados indican que 40 % de los entrevistados utiliza exclusivamente leña, y 60 % usa leña y gas licuado de petróleo (LP). Se registraron doce taxa, las más utilizadas fueron: *Quercus laurina* 22 %, *Q. glaucoides* 18 % y *Q. resinosa* 17 %. La densidad básica de su madera varió de 0.50 a 0.81 g cm^{-3} para *Lippia myriocephala* y *Dodonaea viscosa*, respectivamente. Su poder calorífico fue de 19.53 a 21.06 MJ kg^{-1} para *Acacia pennatula* y *Dodonaea viscosa*, respectivamente. En conclusión, por su densidad básica, poder calorífico y distribución en la zona de estudio, las especies más utilizadas como leña pertenecen al género *Quercus.*

Palabras clave: Dendroenergía, densidad básica, encinos, energía renovable, leña, poder calorífico superior.

Introduction

Fuels derived from forest biomass have been part of man's daily life since he discovered fire. Currently, firewood and charcoal continue to be an energy input to meet human and productive needs, both in developing and industrialized countries. Firewood is essential in rural communities because it meets energy needs and, even when new technologies emerge, it continues to be the main input (Guyat *et al*., 2004; Vázquez *et al*., 2016).

The growing demand for energy implies the persistent use of fossil fuels, such as oil and its derivatives; however, its nature as a non-renewable resource and its high levels of greenhouse gas emissions emphasize renewable energy. Wood energy or energy from wood fuels is a renewable resource and its use as fuel does not increase the concentration of carbon dioxide (CO_2) in the atmosphere, at the same level as fossil fuels (Pinilla and Hernández, 2010).

Globally, the countries with the highest production of firewood in 2020 were: India (301 million m^3), China (157 million m^3), Brazil (123 million m^3) and Ethiopia (114 million m^3) (FAO, 2020). In Mexico, firewood represents 5.4 % (449 409 m^3r) of timber forest production. The main producing states in 2018 were: *Chihuahua* with 35.6 %, *Puebla* (13.5 %), *Oaxaca* (9.8 %) and *Durango* (9.3 %) (Semarnat, 2021).

However, in Mexico the registered numbers for firewood are low in relation to what is recorded in other nations, considering that firewood is one of the most difficult timber products to quantify, from the regular use made by communities to satisfy their needs.

The use of firewood must be done in a sustainable way; therefore, it is necessary to propose actions such as implementing programs for saving fuels and stoves that translate into ecological, social, and health benefits. The use of improved stoves reduces the consumption of firewood by 44 % compared to the use of traditional stoves (May, 2013; Ruiz-Mercado and Masera, 2015).

The selection of tree species with energy potential is necessary to determine the quality of the fuel, in which both the calorific value and the basic density of the wood are two of its most important indicators (Escobar-Ocampo *et al.*, 2009).

The objectives of this study were to identify the main forest taxa that are used as firewood in the *San Sebastián Coatlán* municipality, *Miahuatlán* district, *Oaxaca*; analyze the form of appropriation, its use and management, as well as evaluate its energy quality.

Materials and Methods

Study area

The study was carried out in *San Sebastián Coatlán*, *Miahuatlán* district*, Oaxaca*, Mexico. The municipality has a total area of 19 030 ha, is located in an altitudinal interval of 100 to 2 300 m, and the predominant vegetation corresponds to pine-oak forest (Monjaraz, 2013).

The predominant types of climate in the region are warm sub-humid with rains in summer (58.92 %); semi-warm humid with abundant rains in summer (17.82 %); sub-humid temperate with summer rains, more humid (14.58 %); semi-warm sub-humid with summer rains (6.01 %); and temperate sub-humid with rains in summer, of average humidity (2.67 %) (INEGI, 2008). The municipaltown is inhabited by a total population of 1 226 inhabitants, of which 585 are men and 641 women (Inegi, 2020).

Survey application

The collection of field data involved the design and application of a semi-structured survey to a population sample of 45 families in the study area, through a non-probabilistic random sampling, known as the snowball method, which from a nucleus basic sample, of few cases, that gathers a series of characteristics of interest for the study, the sample is built progressively. That is, of a member or group that suggests linking with other individuals, and so on (Atkinson and Flint, 2001; Bisquerra, 2009; Hernández *et al*., 2014; López-Roldán and Fachelli, 2015; Rivas, 2017). The application of this type of sampling is justified given the impossibility of recognizing or locating the population of interest, because it is a marginal and geographically dispersed community (INEGI, 2011; Baltar and Gorjup, 2012). It is also a method that has been used, in an important way, in qualitative and exploratory research works.

Based on the above, the sampling consisted of locating a potential individual who uses firewood for various activities at home, who recommended it to other people, and so on until a representative sample of the population was obtained. In the surveys, information was collected on the main tree species that are used as fuel, the form of use and its management.

In order to corroborate if the number of surveys applied to the participating population was adequate, the accumulation curve of species indicated by the families surveyed in the community of *San Sebastián Coatlán* was generated.

Collection of specimens and identification

The botanical collection of the main forest species recorded in the surveys was made from the location of each representative and healthy specimen, from which samples of flowers, branches with leaves, fruits and catkins were obtained (BCMF, 1996).

The identification of the species was carried out in the herbarium of the *Universidad de la Sierra Juárez*. The manual Flora Phanerogamic of the Valley of Mexico (Calderón de Rzedowski and Rzedowski, 2005), the revision of the genus *Leucaena* in Mexico (Zárate, 1994) and the Flora of the *Bajío* (Rzedowski and Calderón de Rzedowski, 2002; Andrade *et al.*, 2007). The oak specimens were identified using different manuals (González, 1986; Romero *et al.*, 2002; Zavaleta, 2003).

Basic density of wood

To determine the basic density of wood, the methodology of ASTM D143-94 (ASTM, 2007) was followed, under the following equation:

$$Db = \frac{P_o}{V_v} \qquad (1)$$

Where:

Db = Basic density (g cm^{-3})

P_o = Anhydrous weight of wood (g)

V_v = Green volume of wood (cm^{-3})

Higher calorific power

The calorific value was determined using the ASTM E711-87 standard (ASTM, 2004). The test was carried out in a Parr® (1341) flat jacket calorimeter.

Statistic analysis

In the data analysis, 12 treatments (forest species) were used. The basic density and the calorific power were evaluated with five replications. The significant differences in each treatment were evaluated with a Completely Random Design (DCA), using a Tukey mean comparison test at a significance level of α=0.05, in the statistical package SAS® version 9.0 (Montgomery, 1997; SAS Institute Inc., 2014).

The adjusted model was the following:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij} \qquad (2)$$

Where:

Y_{ij} = Response of treatment *i* in its replication *j*

μ = General average effect

τ_i = Effect of the i^{th} treatment

ε_{ij} = Random error term, where the ε_{ij} have a normal and independent distribution with mean 0 and constant variance

Results and Discussion

Intervention of the population in the use of firewood

According to the agrarian authority of *San Sebastián Coatlán*, the property regime in its territory is communal and private. People who own land in the community with abundant tree vegetation can select trees that they consider to be better quality firewood; on the contrary, those people who lack land, resort to buy firewood or use species with less aptitude for their energy use. Antonio *et al.* (2006) point out that not all communities administer and manage vegetation to produce firewood, because this possibility is closely related to land tenure.

Based upon the Forest Management Program (PMF, for its acronym in Spanish), forest use in the community is carried out using the Mexican Method for the Management of Irregular Forests (MMOBI, for its acronym in Spanish), through the selection method that consists of the removal of trees that present the criteria of maturity, singly or by small groups at constant intervals. This indicates that, within the intermediate forestry treatments and the harvest, a large volume of woody residues is not generated (Cofosa, 2013). The branches and tips that come from timber harvesting are not used as fuel because most of them belong to coniferous species.

Preference for the use of firewood

The species accumulation curve shows that as the survey was carried out and the taxa were recorded, it increased in the first homes and then stabilized, until reaching an asymptotic point (Figure 1). This agrees with what was proposed by Álvarez *et al.* (2006), who cite that when an accumulation curve is asymptotic, even if the number of sampling units or individuals registered is increased, that is to say, the effort is increased, the number of species will not be greater.

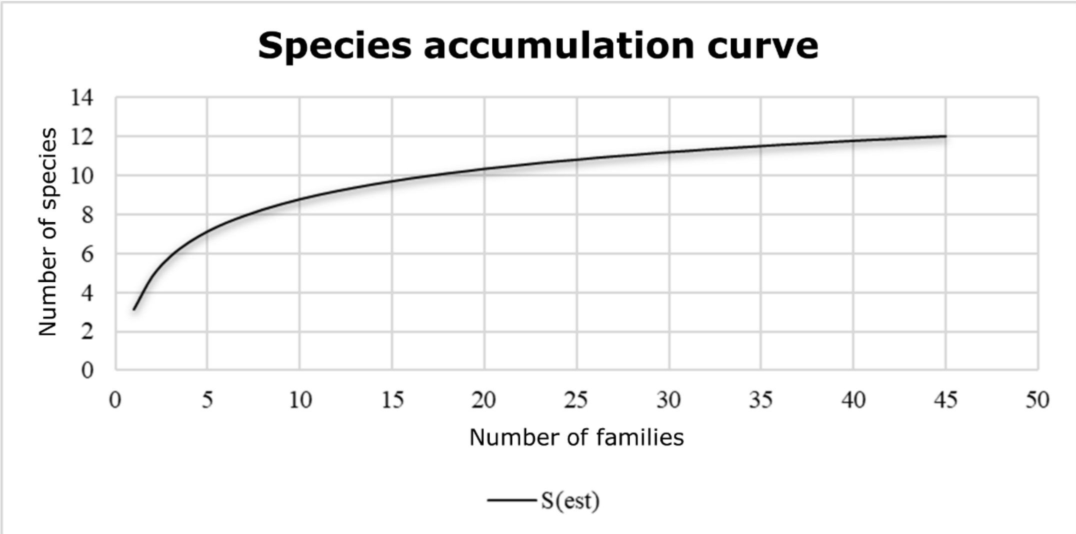

Figure 1. Species accumulation curve registered in the surveys applied in the *San Sebastián Coatlán* municipality, *Miahuatlán*, *Oaxaca*.

The curve was obtained using the wealth projection method proposed by Mao *et al.* (2005). This allowed obtaining a list of 12 plant species used as fuel in the *San Sebastián Coatlán* community.

The majority of the female population is dedicated to domestic chores, their main activity is cooking and they use firewood as essential fuel. 45 families were surveyed, of which 40 % exclusively use firewood, while 60 % use it in combination with LP gas. The same happens in the *Los Sauces ejido*, *Tepalcingo* municipality, state of *Morelos*, where 40 % of households use only firewood and 60 % combine it with LP gas (Yescas *et al.*, 2016). In this sense, in a study carried out in *Yanhuitlán*, *Oaxaca*, it is documented that 18 % uses exclusively firewood and 82 % combines it with another fuel, particularly LP gas, due to its ease of handling and its quickness to ignite (Contreras-Hinojosa *et al.*, 2003).

Results indicate that the percentage of people who only use firewood is lower than the one who uses a combination of firewood and LP gas, due to the practicality of combining both products to produce heat, especially in rainy seasons, when its transfer is difficult and the moisture content of the wood is high, which hinders its ignition.

The 45 families surveyed that continue to use firewood mainly commented that they do so because when cooking, the flavor of the food is more pleasant to the palate, also for some other activities this product is irreplaceable, for example, in the elaboration of tortillas, bread and some families that are dedicated to the butcher shop. LP gas is only used to prepare some foods or cook others that do not require a large amount of heat. Something similar happens in *Usme*, *Bogotá*, where firewood is used for the quality it adds to food, for tradition and for fuel economy (Sierra-Vargas *et al.*, 2014).

Selection of firewood in the field

Men are the ones in charge of collecting firewood, especially when they are large volumes. To carry out this activity, people select those trees with the largest diameters and heights on their property, and then cut them down. The smaller specimens remain standing for their growth and development, so that they can be used at later dates. Also they use as firewood the individuals that are felled in the process of slashing and burning. On some occasions, the head of the family collects firewood in combination with other agricultural activities, that is, they take advantage of their trip to the fields so that during their return to their homes they carry the firewood on pack animals. In various studies, there are records that firewood is obtained from the cutting of whole green trees, dead trees, collection of branches and woody material from the soil. In addition, firewood is extracted from the forest, from the maize field, from the plot or backyard, even from parks or public gardens (Quiroz and Cantú, 2012; Salgado-Terrones *et al.*, 2017; Jung and Huxham, 2019).

Women and children collect firewood in the vicinity of the community, as they are in charge of collecting firewood of short dimensions and in small diameters; this fuel is usually in a dry state and the type of tree to which it belonged is unknown. Cavalcanti *et al.* (2019) and Jung and Huxham (2019) point out that the person who collects firewood is mainly the head of the family (man or woman), with occasional help from small children and close relatives.

In Mexico, the main collectors of firewood are women and children (Masera *et al.*, 2006). The collection is the social space of coexistence where the members of the family and the families interact with each other; this activity helps to strengthen the social fabric and also serves to plan different activities for the development of the community.

Firewood transfer

The transfer of firewood in large volumes is carried out in trucks with a 1 and 3 t capacity. The frequency of collection depends on the amount consumed at home, which is a function of the number of members that make up the family unit. Of the households interviewed, 31 % collect firewood every 6 months, 22 % once a year, 18 % every 8 days and 29 % do it more frequently. Semenya and Machete (2019) document that among the factors that influence the consumption of firewood is the size of the family, the affordability of fuel and its availability.

The distance, in terms of travel time of the places where family heads collect firewood varies from 10 minutes to 2 hours from the community; in this regard, Contreras-Hinojosa *et al.* (2003) record that collectors invest from 30 minutes to 2.5 hours to supply firewood, depending on the location of their plots.

Once the fuel arrives at the home of each family, the man is responsible for cutting those logs that have large diameters into smaller pieces to later accommodate them in "tasks", which constitute a stack of firewood about 1.5 m high by 2 m long. In the rainy season, families store and protect firewood at home to have a good quality of fire when using the fuel. Quiroz and Cantú (2012) indicate that when firewood is stacked in the house, its inhabitants take care of it and protect it because their well-being depends on it; in the rainy season they protect it to prevent it from getting wet, since in that condition it becomes difficult to light it on. In the dry season, green or semi-green firewood is left to dry in the open air.

Types of stoves used in the community

Based on the Census of the Rural Medical Unit (CUMR, 2020), in the population of *San Sebastián Coatlán* 99.7 % of its inhabitants have a separate kitchen from the rest of the house and 0.23 % lack a separate room for cooking. With data from the surveys, 64 % cook on "U" type stoves, 16 % have "*Lorena*" stoves, 11 % cook on "three stone" stoves, and 8 % use a combination of the aforementioned stoves. On the contrary, in *La Montaña de Guerrero* it was observed that 45 % of the respondents use a “three stone” stove, 43.3 % a “*Lorena*” type stove and 11.7 % an open stove with and without a chimney (Salgado-Terrones *et al.,* 2017). In *Chiapas*, 96 % use traditional open hearths of three or more stones, type "U" or double "U" and 4 % firewood-saving stoves (Escobar-Ocampo *et al.*, 2009). Open hearths (traditional) are the predominant ones; however, these do not take advantage of all the calorific power of firewood.

The open hearth generates high levels of contamination inside the home, presents low efficiency in the cooking or heating processes and, consequently, requires a large amount of firewood (Masera *et al.*, 2006; Escobar-Ocampo *et al.*, 2009). In addition, the smoke generated by this traditional system can cause respiratory diseases, allergic sensitization, acute and chronic alterations in lung function, as well as eye problems and decreases the air quality inside the home (García-Sancho *et al.*, 2013; Flores, 2016).

Species used as fuel in the community

Based on the surveys carried out, within the community there is a record of 12 species used as firewood (Table 1).

Table 1. Species used as firewood in the of *San Sebastián Coatlán* municipality, *Miahuatlán*, *Oaxaca*.

Common name	Species	Superior calorific value (MJ kg^{-1})	Basic density (g cm^{-3})
Chamizo	*Dodonaea viscosa* Jacq.	21.06 (0.12) A	0.81 (0.01) A
Madroño	*Arbutus xalapensis* Kunth	21.05 (0.36) A	0.60 (0.02) CD
Abidul	*Alnus jorullensis* Kunth	21.03 (0.24) A	0.52 (0.03) E
Encino de raja	*Quercus candicans* Née	20.88 (0.19) AB	0.70 (0.02) B
Guajal	*Leucaena diversifolia* (Schltdl.) Benth.	20.84 (0.13) AB	0.70 (0.02) B
Palo de gusano	*Lippia myriocephala* Schltdl. & Cham.	20.53 (0.21) ABC	0.50 (0.04) E
Encino yegareche	*Quercus resinosa* Liebm.	20.28 (0.17) BC	0.77 (0.00) A
Encino negro	*Quercus glaucoides* M. Martens & Galeotti	20.20 (0.15) C	0.78 (0.01) A
Igazeta	*Montanoa leucantha* subsp. *arborescens* (DC.) V. A. Funk	20.10 (0.52) CD	0.54 (0.02) DE
Encino blanco	*Quercus laurina* Bonpl.	19.92 (0.51) CD	0.72 (0.03) B
Encino cucharilla	*Quercus rugosa* Née	19.91 (0.10) CD	0.79 (0.02) A
Espinal	*Acacia pennatula* (Schltdl. & Cham.) Benth.	19.53 (0.30) D	0.60 (0.01) C

The values in parentheses represent the standard deviation. Equal capital letters in the direction of the columns indicate statistical equality (Tukey, $p \geq 0.05$).

In *San Sebastián Coatlán* municipality, coniferous and broad-leaved trees are distributed; coniferous wood is used for the sawmill industry, while broadleaf wood is used as firewood, mainly species of the *Quercus* genus. A similar situation occurs in the *Chiapas* Highlands, where the predominant species with the greatest fuel potential is oak (Soares, 2006).

Among the families surveyed, the most used fuels are: white oak (*Quercus laurina* Bonpl.) with 22 %, followed by black oak (*Quercus glaucoides* M. Martens & Galeotti) with 18 % and *yegareche* oak (*Quercus resinosa* Liebm.) with 17 % (Figure 2). In general, the genus *Quercus* has a frequency of use of 79 %, and 21 % corresponds to other broadleafs.

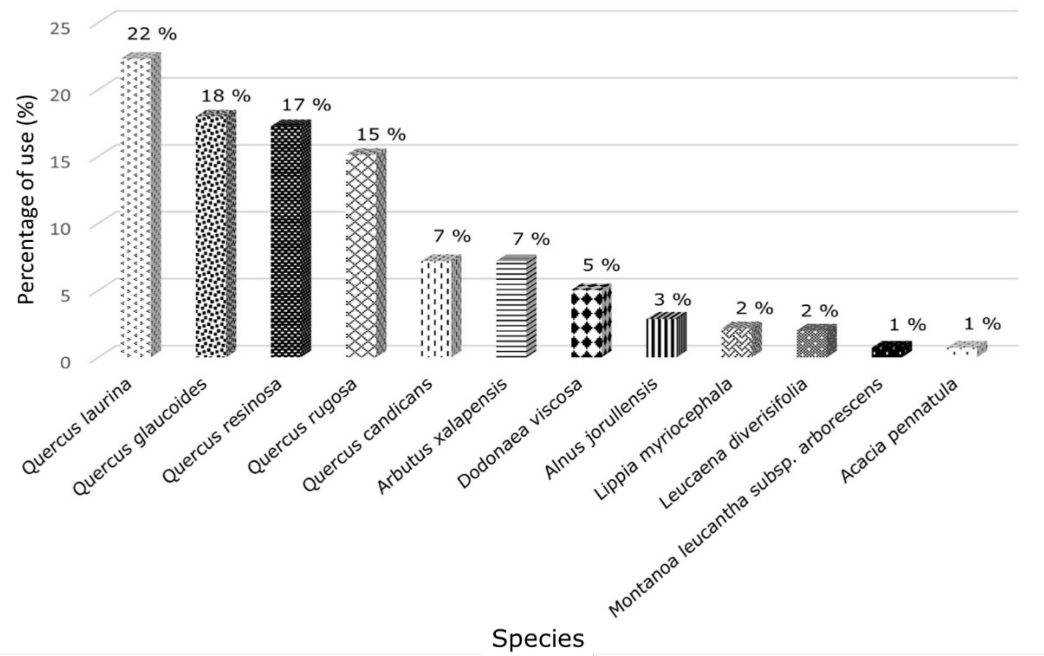

Figure 2. Percentage of use of the preferred species as firewood in *San Sebastián Coatlán*, *Miahuatlán*, *Oaxaca*.

The housewives argue that they prefer to use oak as firewood, because it burns better and the carbon left behind when burning is of good quality, that is, it preserves a long-lasting and powerful ember, in addition to the fact that these species generate little smoke. The amount of smoke they generate is related to the amount of volatile matter, it has been observed that some oak species have a lower amount of volatiles and a higher calorific value compared to other broadleafs (Ruiz-Aquino *et al.*, 2015). The same pattern of use is recorded in a community in the state of *Guerrero*, where the preferred species as firewood is *Quercus magnoliifolia* Née (Mozo and Silva, 2022).

In two municipalities of *Jolalpan*, state of *Puebla* it is cited that the attributes for wood energy species are: quality of burning (32 %), abundance of the species (30 %), obtaining embers (24 %), and the production of little smoke (14 %) (Vázquez *et al.*, 2016). This translates into a high basic density, higher calorific value and less amount of ash and volatiles. Most of the studies that include the quality of firewood have been carried out from a qualitative approach, which considers the preference for uses and knowledge of the women who use it (Contreras-Hinojosa *et al.*, 2003; Escobar-Ocampo *et al.*, 2009; Quiroz-Carranza and Orellana, 2010). However, in the present work quantitative data such as basic density and higher calorific value were included, which allowed determining that the preference in the use of firewood was related to the basic density of the wood, since 79 % of the people interviewed prefer oak firewood, classified as high density.

Basic density and higher calorific value

The species that presented the highest basic density was *Dodonaea viscosa* Jacq. (0.81 g cm^{-3}) and *Lippia myriocephala* Schltdl & Cham. (0.50 g cm^{-3}) registered the lowest basic density (Table 1).

According to Sotomayor's (2005) basic density classification, 25 % of the species studied are classified as medium density: *Lippia myriocephala*, *Alnus jorullensis* Kunth and *Montanoa leucantha* subsp. *arborescens* (DC.) V. A. Funk; 67 % as a high density category: *Arbutus xalapensis* Kunth, *Acacia pennatula* (Schltdl. & Cham.) Benth., *Quercus candicans* Née, *Leucaena diversifolia* (Schltdl.) Benth., *Quercus laurina*, *Q. resinosa*, *Q. glaucoides* and *Q. rugose* Née; and only 8 % are of very high density: *Dodonaea viscosa.* The basic density of wood is closely related to other properties such as mechanical resistance, rigidity, thermal conductivity and calorific value, the latter being the primary variable to determine the quality of wood as fuel (Gutiérrez *et al.*, 2010; Silva *et al.*, 2013).

In relation to the calorific value of the 12 species, it varied in an interval from 19.53 to 21.06 MJ kg^{-1}. Statistically they can be separated into three groups (Table 1), the means within each of them present statistical equality. The superior calorific value of wood is an elementary variable to determine its energy potential, and therefore, consider it as a source of raw material for firewood (Shanavas and Kumar, 2003; Apolinar *et al.*, 2017).

Within the species in *San Sebastián Coatlán*, the species of the genus *Quercus* were among the most used as fuel in the form of firewood and registered a calorific value higher than the interval documented by Ruiz-Aquino *et al.* (2015) and Herrera-Fernández *et al.* (2017), who reported values from 15.78 to 19.40 MJ kg^{-1} for four oak taxa. In the present study it was observed that the preference of the inhabitants of *San Sebastián Coatlán* for the use of biomass fuels is related to the basic density and the superior calorific value of the wood, important attributes in the selection of biomass for wood energy purposes (Ríos *et al.*, 2018). In this regard, Protásio *et al.* (2014) indicate that the basic density is an important characteristic of wood and should be considered as a criterion for the selection of biomass sources, it is also directly related to the energy production per volume unit.

Conclusions

In the municipal head of *San Sebastián Coatlán*, *Miahuatlán*, *Oaxaca*, there are 12 species used as firewood; the three most commonly used are white oak (*Quercus laurina*), followed by black oak (*Quercus glaucoides*) and *yegareche* oak (*Quercus resinosa*). These taxa have a high density and a calorific value of 19.92, 20.20 and 20.28 MJ kg^{-1}, respectively; for this reason, the inhabitants consider them good fuels. The basic density of the species and the calorific power allow us to consider the species with wood energy potential. *Dodonaea viscosa* has the highest basic density (0.81 g cm^{-3}) and the highest calorific value (21.06 MJ kg^{-1}).

The population of *San Sebastián Coatlán* interviewed indicates the exclusive use of firewood in a lower proportion (40 %), compared to those who combine it with the use of LP gas (60 %).

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Conflicts of interest

The authors declare no conflict of interest.

Contribution by author

María Elena Jiménez-Mendoza: research design, field and laboratory measurements, data processing and writing of the manuscript; Faustino Ruiz-Aquino: research design, field and laboratory measurements, and writing of the manuscript; Ciro Aquino-Vásquez: data processing and writing of the manuscript; Wenceslao Santiago-García: data processing and writing of the manuscript; Waldo Santiago-Juárez: data processing; José Guadalupe Rutiaga-Quiñones: drafting of the manuscript; Mario Enrique Fuente-Carrasco: drafting of the manuscript. All authors contributed equally to the review of the paper.

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