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Fuel-wood energy properties of *Prosopis juliflora* and *Prosopis pallida* grown in Baringo District, Kenya

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Kenya depends on fuel-wood for cooking and heating in most households. Over 80% of both rural and urban households in the country use fuel wood for cooking. These *Prosopis* plant species provide excellent fuel wood. These plants were introduced in the arid and semi-arid areas of Kenya in the early 1970s as a source of woodfuel and also for the rehabilitation of degraded lands. Prosopis is a prolific seeder and has invasiveness behaviour that results in a number of social, ecological and economic concerns to the local communities, and challenges to development partners. Now with the Kenyan Forest Policy 2005 which proposes strategies and actions to enhance sustainable and efficient production of wood-fuel, *Prosopis* species is a suitable candidate. The Kenya Forest Service is now issuing permits allowing charcoal burning of *Prosopis* species in an effort to manage and curb uncontrolled spread. There is a national ban on charcoal making from unsustainable wood sources which include the woodlands and natural forest reserves. The aim of this project was to determine the energy values from *Prosopis* fuel-wood. The moisture content, volatile matter, ash content, carbon content and calorific values were determined from *Prosopis* fuel-wood plants. The calorific values for *Prosopis juliflora* and *Prosopis pallida* wood are 4.952 and 4.862 Kcal respectively. The calorific values for *P. juliflora* and *P. pallida* charcoal are 7.854 and 7.797 Kcal, respectively.

Key words: *Prosopis juliflora, Prosopis pallida*, fuel-wood energy, carbon content, ash content, volatile matter, moisture content.

INTRODUCTION

Biomass fuels are the most important source of primary energy in Kenya with woodfuel consumption accounting for over 68% of the total primary energy consumption (Republic of Kenya, 2004a). Current supply sources of fuelwood are on-farm production, which accounts for 84%, trust lands and gazetted forests each with 8% (Republic of Kenya, 2005). Kenya depends on fuel-wood for cooking and heating in households. Over 90% of rural households in the country use firewood for cooking while 80% of urban households depend on charcoal as a primary source of fuel (ESDA, 2005). This charcoal is produced in the rural areas inefficiently and often done in an unsustainable manner. About 2.5 million people in Kenya depend on charcoal trade either directly or indirectly and that charcoal contributes KSh. 32 billion to the national economy of the country (ESDA, 2005). Many rural people depend on charcoal for income generation (ESDA, 2005). A study carried out showed there are 200,000 charcoal producers (ESDA, 2005). This figure is comparable to the government's teaching work force of 234,800 (Republic of Kenya, 2004b). If transporters and vendors are considered, it is estimated that the total number of people involved in the charcoal trade annually could be as high as 500,000 (ESDA, 2005).

The *Prosopis* species were first introduced to rehabilitate quarries near the coastal town of Mombasa (Maghembe et al., 1983) with seed sourced from Brazil and Hawaii (Ngunjiri and Choge, 2004) in the arid and

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semi-arid areas of Kenya in the early 1970 as a source of fuelwood and later, in the rehabilitation of degraded lands (Ngunjiri and Choge, 2004). Out of the different species tested, *P. juliflora* and *P. pallida* were the most adaptable. Owing to their tolerance to water stress, fast growth and multipurpose uses, the species emerged as ideal candidates for reforestation of the ASALs in the country (Choge et al., 2002). In the early 1980s *P. juliflora* was introduced in the Lake Baringo area through the Fuelwood Afforestation Extension Project (Kariuki, 1993; Lenacuru, 2004). The major objectives of the project was to involve the local people in tree planting to overcome problems such as lack of firewood and overgrazing (Kariuki, 1993; Lenacuru, 2004). The *P. juliflora* emerged as the most popular among the local communities as a source of fodder and fuelwood (Choge et al., 2002).

However, because it is a prolific seeder and grows vigorously especially near water sources, the species has become a formidable invader of other land use systems along river courses, around lakes, swamps, farmlands and pints. Additionally, massive ingestion of the pods results in tooth decay and sometimes death of livestock (Choge et al., 2002; Lenacuru, 2004). This has resulted in a number of social, ecological and economic concerns to the local communities and challenges to development partners. There is need for a fresh approach to the management and sustainable utilization of the Prosopis resources that will take into account the benefits while addressing the negative impact of the species to the community and environment. The Kenyan Forest Policy 2005 proposes a number of strategies and actions to enhance sustainable and efficient production of wood fuel. These include:

1. Promotion of sustainable production and efficient utilisation of wood fuel,
2. Promotion of efficient fuel-wood energy technologies and the use of alternative forms of energy,
3. Regulation of the production and marketing of charcoal.

It is on that note that the Kenya Forest Service is issuing permits to allow charcoal burning of Prosopis plants in an effort to manage and curb uncontrolled spread. The aim of this project was to determine the energy values for *Prosopis* wood and its charcoal.

TESTING METHODOLOGY

Determination of fuel-wood energy properties of *Prosopis*

The energy properties determined were calorific values, ash content, fixed carbon and volatile matter for the wood.

Determination of moisture content, volatile matter and ash content

The procedures followed are from British Standards BS: 3631 of 1973. Recondition the crucible by putting into a muffle furnace at 900±25ºC for 2 min. Cool in a desiccator for 10 to 15 min and weigh to the nearest 0.1 mg. Weigh into the crucible 1.000 g of the test sample in triplicate. Place the crucibles with test samples in the oven set at 100±3ºC for 12 h. The moisture content is expressed as a percentage of the initial wet weight.

$$\text{Moisture content} = \frac{\text{Initial weight - oven dry weight}}{\text{Oven dry weight}} \times (100) \qquad (1)$$

Then using the muffle furnace tongs transfer the crucibles into the muffle furnace ensuring that the maximum clearance between crucibles is between 0.5 and 1.00 mm. Close the furnace door. After exactly 7 min (from the time of putting the crucibles into the muffle furnace) remove the crucibles. Cool in desiccators for about 15 min and re-weigh. Then calculate the volatile matter given as:

$$\text{Volatile matter} = \frac{\text{Weight of oven dry sample (g) - residue}}{\text{Original weight}} \times (100) \qquad (2)$$

To determine the ash content return the crucibles and their residues into the muffle furnace set at 900±25ºC for one hour. Cool the crucibles in desiccators for 15 min and re-weigh. Then calculate the ash content using the formula:

$$\text{Ash content} = \frac{\text{Final weight of the residue}}{\text{Original weight of the sample}} \times (100) \qquad (3)$$

To determine the fixed carbon, get the sum of moisture content, volatile matter and ash content then subtract from 100. The balance is the fixed carbon content.

Determination of calorific value

The following procedures from Nelkon and Parker (1995) are used. The gross calorific value or heat of combustion is the amount of heat energy released per unit mass when combustion is completed and the products have cooled to the initial temperature. This is determined on adiabatic bomb calorimeter model 1013-B having a working power of 100 v. Grind the test samples in a grinder. weigh 1 g of the sample in triplicate and wrap with tissue paper of a known calorific value and weight. Then tie with an ignition wire (platinum) of known calorific value. Both ends of the wire are connected to the bomb calorimeter electrodes (+,-) and placed in a bomb and firmly closed. Introduce 30 kg of oxygen into the bomb and immerse the bomb into a cylinder filled with distilled water up to 2100 g. The bomb calorimeter is calibrated with benzoic acid of a known calorific value.

Use the following formula to calculate the calorific value of the test samples:

$$\text{CV (Cal/g)} = \frac{\text{[water equivalent (g) + Water quantity of inner cylinder (g)]} \times \text{rise in temperature (ºC) - correction value}}{\textit{Quantity of sample (g)}} \qquad (4)$$

Where, CV = calorific value.

The correction value is the sum of the calorific values for the tissue paper and the ignition wire.

The water equivalent was computed as follows:

$$\textit{Water equivalent} = \frac{\textit{[c v of benzoic acid (cal/g)} \times \textit{weight of benzoic acid (g)] - Water quantity of inner cylinder (g)}}{\textit{Rise in temperature (ºC)}} \qquad (5)$$

Figure 1. Empty (modified) drum kiln.

Figure 3. A fully loaded drum kiln.

Figure 2. Partially filled drum kiln.

Figure 4. Loaded drum kiln closed with lid fitted with firing door.

Determination of density

Densities were determined using block samples or cylindrical samples. Each sample was marked L for length, W for width and h for height and then the initial weights and the length, width and height were taken so as to calculate the volumes of the samples which was then used, plus the weight (mass) to calculate the densities.

Densities of green (wet) samples and dry samples were calculated separately. Formula used for calculating densities is:

Density = mass/ volume (D = M/V)

Determine energy values of charcoal from Prosopis

Carbonisation was carried out using a drum kiln, which was fabricated using a used oil drum. Fuel-wood of length of 80 cm, maximum and a diameter of 10 cm was stacked for 4 weeks to dry to about 20% moisture content. Wood pieces of diameter larger 10 cm were split using an axe or power saw. The drum was set in the same direction as the wind direction; the entrance of the kiln was parallel to the wind direction. The dry fuelwood was first weighed and then closely fitted into the drum until it was fully loaded (Figures 1 to 3).

The loaded drum was closed using the lid that was fitted with a firing door (Figure 4) and the small pieces of the firewood stacked at the firing section and lit (Figure 5). Soil was used to cover the drum kiln to prevent heat loss during carbonisation. The firewood pieces at the lighting section were allowed to burn until the wood inside the drum caught fire (about 6 to 8 h). The door of the firing section was then closed (Figure 6). The burning continued until the release of clear blue smoke from the chimney indicating the wood was fully carbonised (usually after 3 to 5 h). The chimney was

Figure 5. Small pieces of the firewood stacked at the firing section and lit.

Figure 6. Once the wood in the drum has caught fire, the door of the firing section is closed.

removed and the ventilation tightly closed with grass and soil and left for 8 to 12 h to cool. The charcoal was then removed and covered with soil to prevent burning (Figure 7).

Figure 7. Charcoal removed from drum and covered with soil to cool and prevent burning.

RESULTS

Energy values for wood and charcoal of *P. juliflora* and *P. pallida*

The calorific values for the wood and charcoal are shown in Tables 1 and 2. These values are high (the average calorific values for wood ranges from 3.5 to 5.0 kcal whereas that of charcoal range between 5.0 and 9.0 kcal). The densities of *P. juliflora* and *P. pallida* wood are 891 and 834 kgm^{-3} (Oduor and Githiomi, 2004). This is comparable with tree species preferably used for charcoal conversion. The species that have been reported to produce high quality charcoal include *Casuarina equisetifolia*, *Acacia mearnsii*, *Acacia polyacantha* and *Acacia xanthophloea,* and other acacia and combretum species (Mugo and Ong, 2006). The wood densities of these species are: *C. equisetifolia* is 0.820 kgm^{-3} (Chikamai et al., 2006), *A. mearnsii* 0.775 kgm^{-3} (Chikamai et al., 2006), *A. polyacantha* is 0.780 kgm^{-3} (National Biomass Study, 1996) and *A. xanthophloea is* 0.634 kgm^{-3} (Kenya Forestry Research Institute, 2008).

The results for the energy of both wood and charcoal samples are shown in Tables 1 and 2, respectively. *P. juliflora* wood burns evenly and hot due to its high carbon content and high levels of lignin. Reports from India showed an estimated calorific value of 4.216 kcal (Pasiecznik et al., 2001). The superior qualities as firewood are present even in juvenile wood and *P. juliflora* wood burns well even when green (Tewari et al., 2000). This was noted from the communities in Baringo who use the wood for firewood (Oduor and Githiomi, 2004).

Table 1. Energy properties for wood samples.

Sample	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Calorific value (Kcal)
P. juliflora	7.30	76.75	1.13	14.82	4.952
P. pallid	8.11	79.85	1.25	10.79	4.862

Table 2. Energy values for charcoal samples.

Sample	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)	Calorific value (Kcal)
P. juliflora	4.64	15.92	2.34	77.10	7.854
P. pallid	3.40	26.70	2.42	67.48	7.797

DISCUSSION

The energy values of charcoal made from *P. juliflora* and *P. pallida* are high (7.854 and 7.797 Kcal, respectively). The charcoal obtained from this wood is also of very high quality and can be produced as easily from green wood as from dried wood. For instance 10 kg of green wood will make 1 to 2 kg of charcoal using traditional earth kilns normally in 2 to 4 days (Pasiecznik et al., 2001). The wood does not produce sparks while burning nor does it emit much smoke (Oduor and Githiomi, 2004). It burns with a hot and even heat giving high heating value. The wood from this species can be promoted as a source for charcoal as it has high density, which gives high quality charcoal.

Conclusions

The initial aim of introducing the *Prosopis* species in the arid lands of Kenya for the provision of fuelwood was met. However, due to the invasiveness nature of the species, initiatives for the control and management of these species is required. The Kenya Forestry Research Institute (KEFRI) has made some initiatives at managing the invasiveness of the Prosopis species through utilisation of the tree products. Making charcoal from the wood is one initiative that has potential in controlling the spread of the species. The data obtained on the fuelwood energy properties of the two species has shown that these species are comparable or even better for fuelwood just as well known and preferred species, *C. equisetifolia*, *A. mearnsii*, *A. polyacantha, A. xanthophloea* and other Acacia and Combretum species Permits are now being issued by the Kenya Forest Service to entrepreneurs/ community members to burn charcoal from the Prosopis. Community members affected by these species are now able to open up their grazing lands and burn charcoal from the wood material getting an income.

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