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Firewood calorific value and species preference among mestizos in Campo Verde District in the Peruvian Amazon

M.Sc. Thesis

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ABSRACT

This study was carried out to determine the combustion properties of forty woody species traditionally used as firewood in Campo Verde District in Peruvian Amazon to explore woody perennials with the potential for feasible firewood production in this area. Research is based on the previous ethnobotanical study. For each species, Fuelwood Value Index (FVI) was calculated from net calorific value, wood density and ash content. Measured energy values were compared with firewood species preferences of small-scale farmers in mestizo villages in Campo Verde District. Certain correlation was proved for species preferences and energy value of the species investigated. Study showed that *Inga umbellifera, Dipteryx micrantha, Tabebuia serratifolia* and *Inga pruriens* have the most promising firewood properties from both preferences and combustion values point of view, and *Jacaranda macrocarpa*, due to high energy value is suitable. These species may be recommended to sustain in agroforestry systems in this region.

Key words: agroforestry, energy value, fuelwood, Amazon, Peru

ABSTRAKT

Tato studie, která se zabývá určováním energetické hodnoty čtyřiceti druhů dřevin, tradičně používaných jako palivové dříví v oblasti Campo Verde District v peruánské Amazonii, byla provedena za účelem zjištění, které dřeviny jsou v těchto místech potenciálně vhodné pro udržitelnou produkci. Analýza vychází z předešlé etnobotanické studie. Na základě laboratorně zjištěné výhřevnosti, hustoty dřeva a podílu popela byl určen Fuelwood Value Index (FVI) pro každý vzorek. Naměřené hodnoty byly porovnány s preferencemi palivového dříví farmářů ve vesnicích v Campo Verde distriktu. Bylo zjištěno, že zde existuje určitá korelace mezi preferencemi a skutečnou energetickou hodnotou zkoumaných druhů. Studie ukazuje, že *Inga umbellifera, Dipteryx micrantha, Tabebuia serratifolia* a *Inga pruriens* jsou slibné z hlediska preferencí a kvality a *Jacaranda macrocarpa* prokázala vysoce kvalitní palivové dříví s vysokou výhřevností. Uvedené druhy jsou nejvhodnější a v tomto regionu mohou být doporučeny ke kultivaci v agrolesnických systémech.

Klíčová slova: agrolesnictví, výhřevnost, palivové dříví, Amazonie, Peru

DECLARATION

I, Romana Lembacherová, declare that this thesis, submitted in partial fulfilment of requirements for the MSc. degree at the Faculty of Tropical AgriSciences of the Czech University of Live Sciences, is wholly my own work unless otherwise referenced or acknowledged.

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Romana Lembacherová

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CONTENTS

PREFACE

In tropical developing countries, biomass is the main source of energy. Fuelwood, charcoal, crop residues and animal wastes forms the big proportion of energy requirements of people living in rural and peri-urban areas for cooking and heating. However, with the increasing population, sources of firewood are subsequently diminishing and the wood is becoming even scarcer. Moreover, the rate of deforestation is high and firewood collection contributes partly to this value.

Therefore, it is necessary to develop systems, which ensure sustainability of firewood resources and also transmit the knowledge to people living in developing countries. This requires studies targeted on the characteristics of traditionally used firewood species identified as preferred or used by the locals, usually based on the knowledge gained from ethnobotanical field studies. The evaluation and results of the research and following determination of the species with desirable properties and energy values can contribute to incorporation of given woody species into agroforestry systems and thereby, provide the opportunity of feasible production of firewood. In addition, it may influence positively carbon sequestration, deforestation, biological diversity and ecosystems protection.

This study presents the determination of energy value and firewood quality of some of the species used traditionally in Campo Verde District in the Peruvian Amazon. Furthermore, this research shows how much the firewood species prioritization among local farmers corresponds to firewood quality.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

FVI – Fuelwood Value Index

1. INTRODUCTION

1.1. Area of interest

The Republic of Peru (República del Peru) is situated on the western (Pacific) coast of South America. It has a surface area of 1,285,216 square kilometres, which make it the fourth largest country of Latin America. It is also the largest Andean country. Peru borders with Colombia and Ecuador in the north, Brazil and Bolivia to the east and Chile to the south (Vera, 2001). It is divided into 25 regions (Amazonas, Ancash, Apurimac, Arequipa, Ayacucho, Cajamarca, Callao, Cusco, Huancavelica, Huánuco, Ica, Junín, La Libertad, Lambayeque, Lima, Loreto, Madre de Dios, Moquegua, Pasco, Piura, Puno, San Martin, Tacna, Tumbes, Ucayali (INEI, 2007).

Field work for this study was undertaken in seven mestizo villages (24 de Diciembre, Agua Dulce, Antonio Raymondi, Nuevo Belén, Pampas Verdes, Pimental, Tupac Amaru) situated within Campo Verde District near Pucallpa city in the Amazon basin of Peru (Figure 1) in the city of Pucallpa (geographic coordinates 8°23' S latitude, 74°31' W longitude, altitude 154 m above sea level), the administrative centre of Coronel Portillo Province and the capital city of Ucayali Department, lying on the river Ucayali's banks, 860 kilometres east from the capital city of Lima (Polesna *et al,* 2011). The location is characterized by a hot and humid climate with a slight variation in weather parameters throughout the year. Annual precipitation in Pucallpa ranges from 1 500 mm/year to 2 100 mm/year (a mean of 1 546 mm/year, with rainfall increasing towards west of Pucallpa). Annual average temperature is 25.7 °C, whereas mean annual relative humidity reaches up to 80% (Fujisaka *&* White 1998; MINAG, 2002).

Majority of people in the studied communities are small-scale, migrant crop farmers (Smith *et al,* 1999) who practice slash-and-burn agriculture to produce annual crops such as rice, maize, cassava and beans, while farmers convert primary tropical forest lands to other uses, including pastures for cattle production, perennial crops, and fallows for subsequent annual cropping. Slash-and-burn cultivation has highly contributed to deforestation and loss of biological diversity and moreover, emissions of atmospheric carbon (Brady 1996; Fujisaka *et al.* 1998 and 1999; Fujisaka *&* White 1998).

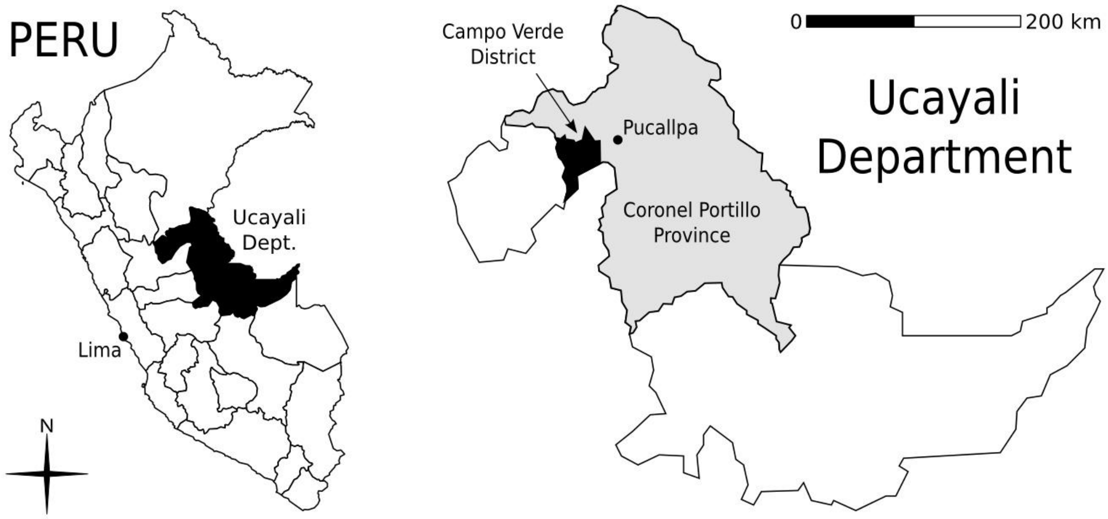

Fig.1 Location of the area of interest (Campo Verde District, Peruvian Amazon)

1.2. Biomass energy

Since the fire was discovered by the humans, biomass became the main source of energy worldwide (Vargas-Moreno *et al*, 2012). Biomass is a renewable source of energy, which is expected to be increasingly asked in the future. According to Núñez-Regueira *et al* (2001), biomass is defined as the biologically originated group of materials used as energy sources. Not only for provided energy but also for its carbon neutrality, this source of energy is attractive (Vargas-Moreno *et al*, 2012). Biomass accounts for approximately 14% of total energy which used globally worldwide and it is the largest energy source for the three-quarters of the world´s population (Scurlock, 1990).

In developing countries, especially in rural areas, biomass (fuelwood, charcoal, agricultural waste and animal dung) is crucial to meet energy requirements for cooking of 2.5 billion people and in many countries over 90% of household energy consumption originate from these resources (IEA, 2006; Bhatt & Tomar, 2002). Nowadays, the society have replaced the use of biomass with the use of fossil fuel, but due to its scarcity and also urgency to reduce CO_2 emissions from the climate change point of view, the world is forced to use renewable energy, including biomass (Vargas-Moreno et al, 2012). Reported by IEA (2006), the number of people dependent on energy from biomass will increase to over 2.6 billion in 2015 and 2.7 billion by 2030.

1.2.1. Firewood

Energy and fuel use are important for the welfare of households. Using energy for cooking, lighting and lighting is essential to humans (Heltberg, 2003). In developing countries, the majority of the population lives in the rural areas where the most of the energy requirements are consisting of fuelwood, charcoal, crop residues and animal wastes (Bhatt & Tomar, 2004; Borah & Goswami, 1997). Firewood is presently still central of livelihoods in developing countries, therefore it is necessary to sustain practicable production and know which species should be selected for its wood properties as calorific value, moisture content and sustainability to be used by local population for cooking and heating (Erakhrumen, 2009; Vargas-Moreno *et al*, 2012). Firewood and charcoal production is often predominant use of woody biomass in countries of the third world (FAO, 2012). With increasing population and economic development in these developing countries, it can be expected that the demand for biomass will increase in the coming years (IEA, 2006; Bensel, 2008). Extensive farming for firewood could be the alternative to bridge the gap between the demand and supply of better fuelwood quality resources (Jain & Singh, 1999). Therefore suitable species with high energy value and good quality may be selected for firewood production (Goel & Behl, 1996).

FAO (2012) considers the wood as primary source of energy for humankind and most important source of renewable energy, which is providing over 9% of the global total energy supply. Wood is forest product that is as important as all other renewable energy sources altogether (hydro, wastes, biogas, solar and liquid biofuels) (FAO, 2012).

According to FAO (2003) firewood is rough wood from trunks, and branches of trees, which is used as fuel for cooking, heating or power production and it may be divided to coniferous and non-coniferous wood. Erakhrumen (2009) says that consumption of fuelwood for domestic and also commercial cooking and heating is still basic for households not only in rural areas, but also some peri-urban and urban areas in countries of third world. Firewood is also used as firebricks, distil spirits, care fish and charcoal production (Tabuti, 2003). Over two billion people depend on wood energy for cooking and heating since it is considered as the only domestically available and affordable source of energy (FAO, 2012).

More than 70% of total energy in households in developing countries is generated from fuelwood from the forest biomass (FAO, 1984) and still continues to play a major role in national energy supply for the next decades (Erakhrumen, 2009a). Osei (1993) labelled firewood as one of the most serious causes of the forest decline. However, it was mentioned for example by Bensel (2008) that forests are not the only one source of the firewood, since other landscape such as shrub lands, farmlands, orchards and agricultural plantations, agroforestry systems, tree lines and hedges, trees outside the forest, etc. contain potential for fuelwood and charcoal production as well.

The contribution of fuelwood to the total energy which is consumed can be different from place to place and it is mainly determined by the level of development and availability (Munalula & Meincken, 2009). It has been observed that the firewood consumption differs according to family size, family income, amount cooked and burning time (Miah *et al*, 2009). The firewood consumption is also influenced by the climate, season of the year and a period of festival celebration (Bhatt & Sachan, 2004).

1.2.2. Firewood in the Peruvian Amazon

Generally, in 2011 Peru produced 7.425 million of cubic meters of fuelwood (FAO, 2011). According to ITTO (International Tropical Timber Organization) (2006), firewood collection is the main extractive use of the Peruvian natural forests. According to INEI (2007), 30% of all households in the country depend on firewood and 2.5% on charcoal for cooking. In the study area, 75% of households depend on firewood (Table 1). Moreover, the households' dependence on firewood is higher in rural (92%) than in urban (33%) areas (INEI, 2007). Campo Verde District is one of the most affected areas in Peru by firewood consumption (ITTO, 2006).

Table 1 People depending on firewood as an energy source in Peru and its administrative departments (INEI, 2007)

Source of energy used for cooking	**Percentage of people using each energy source**			
	Peru	**Ucayali Department**	**Coronel Portillo Province**	**Campo Verde District**
LPG	55,6	47,6	55	20,2
Firewood	**30,2**	**42,7**	**33,9**	**75,6**
Animal dung	4,2	0,1	0	N/A
Kerosene	3	0,8	1	0,8
Charcoal	2,5	4,5	5,4	1,1
Electrification	1,5	0,6	0,7	0,4

In previous ethnobotanical MSc. study (Tůmová, 2010) it was found that in Campo Verde District in Peruvian Amazon local people prefer firewood with good combustion properties (hot, strong coals, long lasting flame), small smoking intensity and ability to lose moisture fast. Generally, in tropical developing countries, the choice of firewood is usually given by availability, the burning duration and amount of ash (Raliseo, 2003). Special attention during selection of the species for energy plantation should be given to the indigenous species which are traditionally preferred for fuel by the local people. To succeed in application of species to be potentially used as firewood for sustainable planting, it is necessary to have knowledge of the quality of the plant (Chettri & Sharma, 2009).

1.3. Deforestation and biodiversity loss related to firewood

1.3.1. Deforestation worldwide

In 1993, fuelwood has been identified by Osei as one of the most significant causes of forest decrease in many developing countries. Deforestation is significantly related to the rate of population growth (Allen & Barnes, 1985). Excessive use of firewood (by small scale farmers) as primary source of energy for domestic purposes and dependence on it, often coupled with shifting cultivation (slash-and-burn system) is causing severe deforestation (Bhatt & Todaria, 2002; Bhatt & Sachan, 2004; Lojka, 2012) and it has been identified as one of the most significant causes of forest decline in many tropical developing countries (Bhatt & Sachan, 2004). On the other hand in the study of Bensel (2008) it was shown that firewood collection could not be fatal reason of worldwide tropical forests decline, although it can have negative effects at the local level in developing regions of Africa, Asia and Latin America. Also it was mentioned by Arnold *et al* (2006) that large portion of the fuelwood and charcoal used in developing regions originates from trees and shrubs grown beyond the forest. The study of Bensel (2008) confirms the origin of some fuelwood is from trees and shrubs growing outside the forest (fallow lands, brushland, private woodlots). Also definition by FAO (2012) complements that fuelwood originates from multiple sources as forests, other wooded land and trees outside the forests. Munalula & Meincken (2009) say that as the species commonly used become scarcer, people often begin to use whatever fuelwood is available, with no consideration of sustainability, ecological factors or the environmental impact. In the absence of firewood, anything that is burning is used (crop residues, twigs, barks) (Ndayambaje, 2005). When animals requiring cooked fodder are integrated into the household, firewood consumption decreases as well (Bhatt *et al*, 2004).

Nevertheless, lack of fuelwood and also lack of basic information about energy supply and consumption pattern and its impact on forest resource (Bhatt & Sachan, 2004), is still ongoing and it is necessary to design programmes to support local communities to grow proper and feasible woody species to have sufficient amount of fuelwood for cooking, heating and other energy supplements.

Further, deforestation may cause growth of price for fuelwood and charcoal (Allen & Barnes, 1985).

There is no single solution to firewood shortage, but some manner of fuel conservation, tree planting and new technologies could partly deal with the problem of deforestation and fuelwood scarcity (Ndayambaje, 2005).

In Latin America, mainly Amazonia, deforestation is caused by harvesting of timber and colonization (Lambin *et al*, 2001). Nevertheless, FAO (2011) reported that forest decline in Latin America has slowed and in percentage it is relatively stable since 1990.

Redundant use of traditionally used fossil fuels is causing ecological damages (besides economic problems), deforestation, air pollution and land degradation (Bensel, 2008; IEA, 2006). Fossil fuel reserves are limited, thus searching of alternative sources of energy is one of the world wide priority objectives (Núñez-Regueira, 2001).

The conversion of natural forest into agricultural land is considered as the largest single cause of biodiversity loss (Lambin *et al*, 2001). Even if the knowledge on forest ecology of tropical forests is becoming available, there is still lack of information to establish management and conservation efforts (Nebel & Meilby, 2005). Published by IEA (2006), unsustainable harvest is inefficient and can cause environmental damage as land degradation or air pollution. One of the solutions for improving this situation is sustainable use of traditional biomass (IEA, 2006).

1.3.2. Deforestation in the Peruvian Amazon

Deforestation rate (about 269 000 ha per year) in Peru is one of the highest in the region of South America and it is caused mainly by the influx of settlers coming from the Andes, expanding urban centres such as Iquitos or Pucallpa and subsequent clearance for agriculture and cultivation of coca (*Erythroxylum coca*) as well (ITTO, 2006; FAO, 2011). In the Peruvian Amazon, the deforestation rate during the last fifty years is estimated to 100 000 ha per year and the process is irreversible (Baluarte, 1995). Baluarte (1995) reported that only small proportion (5%) of deforestation in Peruvian Amazon is a result of timber extraction, the main cause is slash-and-burn agriculture. To reduce these problems connected with slash-and-burn agriculture, effort for promotion of the adoption of agroforestry systems among small-holders is still increasing (Fisher & Vasseur, 2002). Agroforestry can help to reduce deforestation and pressure on woodlands while it provides firewood (Sharma *et al*, 2007). According to Iturregui *et al* (2001), 54% of Peruvians live below the poverty line, therefore agroforestry projects are priority for government plans.

1.4. Firewood as a component of agroforestry systems

Agroforestry has a potential to improve households as it offers opportunity to increase farm production and incomes and it also provides productive and protective forest functions, for instance biodiversity protection, soil and water sheds resources protection, terrestrial carbon storage or healthy ecosystems (Sharma *et al*, 2002). Agroforestry systems can be advantageous over conventional agricultural and forest production methods due to increased productivity, economic benefits, social outcomes and the ecological goods and services provided. Biological diversity in agroforestry systems is even higher than in conventional agricultural systems (Umrani & Jain, 2010). Moreover, agroforestry can increase carbon sequestration and protect watersheds and soil (Naughton-Traves, 2004).

'Agroforestry is a collective name for land-use systems and technologies where woody perennials as trees, shrubs, palms, bamboos and others, are purposely used on the same land units as agricultural crops and/or animals, in kind of spatial arrangement or temporal sequence and there are ecological and economical interactions between different components' (Lundgren & Raintree, 1982). In other words it means that agroforestry involves two or more species of plants (or plants and animals) and at least one woody perennial, it has to have two or more outputs, the cycle lasts more than one year. These practices are used mainly in tropical developing countries and were developed in response with special needs and conditions of these areas (Nair, 1993). Many multipurpose tree species are studied in relation to the agroforestry to provide high quality fuel, fodder, timber, green manure, fruits and above that, many of them have nitrogen fixing ability (Ndayambaje, 2005; Goel & Behl, 1996). Thus, an agroforestry system can produce firewood, fruits, traditional forestry products and fodder for grazing animals and it is considered as one of the possible solutions to fuelwood scarcity problem (Umrani & Jain, 2010; Erakhrumen, 2009a).

When appropriate species on appropriate sites are used, energy from firewood can be produced as any farm crop. Also good silvicultural practices for increasing of firewood production and optimising the benefits are needed (Ndayambaje, 2005).

For the usage of energy value in terms of selection for agroforestry systems, it is necessary to inform fuelwood consumers about the species with high energy (Erakhrumen, 2009). The identification of traditionally used firewood species and measuring of firewood quality indicators could contribute to local people to know which species of woody perennials are suitable to plant in agroforestry systems and consequently help to reduce deforestation and pressure on remaining forests (Tumova *et al*).

According to Ndayambaje (2005) it would be appropriate to plant more trees on farms, along the roads, in shelterbelts and on used lands throughout the rural areas. The selection of the agroforestry species with potential of firewood could result in shortening of unproductive period of the woody plant component which would make agroforestry systems more attractive then slash-and-burn cultivation for small-scale farmers in the Peruvian Amazon (Tůmová *et al).* For instance, agroforestry fuelwood production, improved fallow or multipurpose trees and shrubs on farmlands, which are used in Latin America commonly (Nair, 1993), could be suitable for this region.

Multipurpose tree species can be considered as the most distinctive component of agroforestry as a viable land-use possibility and it is depending on exploiting of their potential. Fodder trees, fuelwood species and fruit trees are widely distributed in agroforestry systems (Nair, 1993).

ITTO (2006) states Peru has a large resource desirable potential for sustainable management and for agroforestry as well.

1.5. Firewood quality indicators

The quality of fuelwood depends on both qualitative and quantitative properties. Quantitative properties include calorific value, wood density, moisture content, ash content, silica content, drying rate and chemical composition (Bhatt *et al*, 2004, Munalula & Meincken, 2009). Some of these characteristic (calorific value, moisture content) are also one of the important factors for fulfilment of conditions to be considered as climate neutral and socially viable source of renewable energy (FAO, 2012). Wood quality plays important role in terms of selection appropriate species for the production of fuelwood (Goel *&* Behl, 1996). Suitable characteristics for quality firewood are high calorific values, low moisture content, high wood density and low ash content (Kumar *et al*, 2011; Bhatt *&* Tomar, 2002; Goel *&* Behl, 1996; Tharakan *et al*, 2003).

1.5.1. Calorific value

Calorific value is an important indicator of firewood quality; it depends on the chemical composition, moisture content and ash-producing compounds in the wood and also it can vary with the age and part of a stem and wood type within the stem (heartwood/sapwood) (Lemenih *&* Bekele, 2004). Genetic character and biochemical composition is crucial as well (Kataki *&* Konwer, 2002). Other names used for calorific values can be heat of combustion, heat(ing) value, or heat of reaction (Wang *et al*, 1982). In theory it is an amount of energy which is released by each unit of combustible mass (Núñez-Regueira *et al*, 2001). The International System of Units indicates kilojoules per kilogram as a basic unit (Wang *et al*, 1982). It can be related to chemical composition and varies between 17 and 20 kJ/g (Fengel *&* Wegener, 1983). Approximate average value of tropical hardwood species is about 20 kJ/g (Montes *et al*, 2011). Shackleton (1993) reported that hardwoods are preferred in general, because their coals last longer, yield more heat and emit less smoke and sparks.

Calorific value is often determined with an oxygen bomb calorimeter. But it can be analysed also thermochemically on the basis of heat of formation from each individual chemical reaction (Wang *et al*, 1982).

In conformity with the study of Munalula *&* Meincken (2004), the wood with the highest calorific value does not necessarily constitute the best option of firewood, if environmental factors are taken into account.

1.5.2. Moisture content

Effective calorific value can depend on moisture content. As the moisture content is higher, wood is less efficient and desirable as fuel, insomuch as the net calorific value for heating is reduced (Bhatt *et al*, 2004). The negative effect of moisture content on its calorific value was proved also by Kataki *&* Konwer (2002), Senelwa *&* Sims (1999) and Munalula *&*

Meincken (2009). Wood moisture causes heat loss during the combustion (energy must be consumed to vaporize humidity) (Wang *et al*, 1982). For total combustion there is a need to evaporate the water in the wood (Munalula & Meincken, 2004). Moisture content varies with the dimension of branches, season of the year and area (Bhatt & Todaria, 1992).

1.5.3. Wood density

Abbot *et al* (1996) confirmed that a higher wood density increases the calorific value and also the burning rate gets slower. Heavy woods (with higher density) are desirable for fuelwood (Wang *et al*, 1982). Firewood of lower density ignites more easily, however in burns more quickly (Abbot & Lowore, 1999). Wood density may vary with the species, age, climate, geographical location, etc. (Gongales, 1990). Significant relationship between wood density and moisture content was observed (Ramos *et al*, 2008b), that the higher the density, the lower moisture content. According to Munalula & Meincken (2009), the higher density relates directly to a higher calorific value.

One of the methods for determination of wood density is dividing the ovendry weight by volume (done by water displacement method) (Chave, 2005; Montes *et al*, 2011). It is possible to determine it with the Smith method (Abbot *et al*, 1997), to avoid the need to measure the exact volume of the samples (Kumar *et al*, 2011; Munalula & Meincken, 2009).

1.5.4. Ash content

Ash is the only one remaining inorganic part of wood matter that is not possible to burn. For most of the woody species it is about 1%. When the ash content is high, it can make plant part undesirable, because a substantial part of a volume cannot be converted into energy and also reduces the heat of combustion (Munalula & Meincken, 2004; Goel & Behl, 1996; Kataki & Konwer, 2002).

1.5.5. Fuelwood Value Index

Fuel Value Index (FVI) has emerged as an important tool for classifying species according to the physical properties of their wood. The principal parameters used to construct this index include the calorific value of the wood, wood density, production of ashes, and the moisture content of the branches or trunk wood of each species (Goel & Behl, 1996, Bhatt *et al*, 2004). In many studies, moisture content was left out from calculation of FVU, while due to its variability it cannot be considered as decisive (e.g. Bhatt & Todaria, 1992; Bhatt *et al*, 2004). FVI is important indicator for screening desirable firewood species (Purohit & Nautiyal, 1987).

1.6. Previous studies concerning firewood species

Studies for firewood characteristics in many other part of the world were undertaken. For instance, studies from many parts of India (Kumar *et al*, 2011; Kataki & Konwer, 2002; Bhatt & Tomar, 2002; Bhatt *et al*, 2004; Bhatt & Sachan, 2004; Jain & Singh, 1999; Chettri & Sharma, 2009), for caatinga vegetation in Brazil by Ramos *et al* (2008b), some African areas, such as Malawi (Abbot & Lowore, 1999) or Nigeria (Erakhrumen, 2009ab; Fuwape & Akindele, 1997). In Peruvian Amazon, mainly charcoal was studied as energy source and firewood has been studied a little (Labarta, 2008).

Quercus spp. in India (Jain & Singh, 1999; Chettri & Sharma, 2009; Kataki & Konwer, 2002), *Acacia* spp. in Africa and India (Munalula & Meincken, 2009; Kumar *et al*, 2011, Kataki & Konwer, 2002; Ndayambaje, 2005; Goel & Behl, 1996) and *Eucalyptus* spp. in Africa (Munalula & Meincken, 2009; Lemenih & Bekele, 2004; Wang *et al*, 1982) or *Leuceaena leucocephala* in Nigeria (Fuwape & Akindele, 1997), in rural areas of Bangladesh (Jashimuddin *et al*, 2006) and Philippines (Bensel, 2008), *Prosopis* spp. (Ramos *et al*, 2008a; Montes *et al*, 2011; Kumar *et al*, 2001) and *Gmelina arborea* in India (Bhatt & Tomar, 2002), Philippines (Bensel, 2008), Bangladesh (Jashimuddin *et al*, 2006) and in Nigeria (Fuwape & Akindele, 1997) are used as firewood commonly and were determined from the energy value point of view. In Europe, cultivars of poplar (*Populus* spp.) and willow (*Salix* spp.) are investigated for their energy production (Petráš *et al*, 2012; Tharakan *et al*, 2003).

In the study for Aravally mountain trees and shrubs in Western India, It was documented, that the most suitable woody species concerning combustion value, were *Miliusa tomentosa, Lanneam Acacia leuocophloea, Madhuca indica, Acacia nilotica, Wrightia tinctoria, Butea monosperma, Zizyphus nummularia, Sterculia urens, Boswellia serrata, Acacia nilotica, Grewia tanax*, *Syzigium cuminii, Tectona grandis* and *Dalbergia sissoo* (Kumar *et al*, 2011). *Prosopis Africana* and *Balanites aegyptica* were documented by Montes et al (2001) in the

West African Sahel and the relationship among the tree growth, wood density and rainfall gradients was investigated. *Gliricida sepium, Parkia biglobosa* and *Triplochiton scleroxylon* were identified as a good fuelwood species for implementing to agroforestry systems in Nigeria (Oyo state) and the average net calorific value for twelve species was 18.25 kJ/g (Erakhrumen, 2009a). Indigenous woody species were investigated by Bhatt *et al* (2004) in Himalyayan region in India and for this region most promising species are *Gaultheria fragrantissima, Litsea citrate, Myrica esculenta, Aesculus assamica, Daphniphyllum himalemse, Mesua ferrea* and *Wendlandia tinctoria. Acacia nilotica, Acacia auriculiformis, albizzia lebbeck, Albizzia procera, Pinus kesiya* and *Elaeognus umbellata* have been considered as the most promising species for energy plantations in north-east India (Kataki & Konwer, 2002). *Acer oblongurn, Betula alonoides, Greviilea robusta, Limonia acid&ma, Lyonia ovalifolia, Madhuca indica, Melia azedarch, Motinda tinctona, Myica sapida, Ptunus comuta, Pyrus pashia, Quercus langtnosa, Rhamnus triqueter* and *Stereospennum xylocarpum* provide excellent fuelwood qualities in central India (Jain & Singh, 1999). Bhatt & Tomar (2002) documented *Betula nitida, Machilus bombycina, Itea macrophylla, Cryptomeria japonica, Gmelina arborea, Simingtonia populnea, Macaranga denticulata and Schima wallichii* as a species with desirable firewood properties in Indian mountain. Munalula & Meincken (2009) investigated fuelwood species commonly used in South Africa (*Acacia cycylops, Acacia erioloba, Eucalyptus cladocalyx, Pinus patula, Vitis vinifera*) and evaluated environmental impact of combustion and it was found that the highest calorific values does not have to be best option from the environmental point of view. Ramos et al (2008b) described significant relationship between plants with highest FVI and the most preferred fuelwood species in the region of caatinga (dryland) vegetation in Brazil and *Croton blanchetianus, Allophylus quercifolius, Caesalpinia pyramidalis* and *Anadenanthera colubrina* were found as the best quality wood from a technical point of view. In the research of Puri *et al* (1994), energy values of indigenous and exotic species in arid region in India were compared, while it was found that indigenous tree species are better suited as fuelwood species as they contain high-density wood, low ash content and *Acacia nilotica, Casuarina equisetifolia* and *Zizyphus mauritiana* are the most promising in this area and the calorific ranged from 18.7 to 21.77 kJ/g for the indigenous tree species, and 16.3 to 20.0 kJ/g for the exotic tree species.

An ethnobotanical study from the Peruvian Amazon by Kvist *et al.* (2001) reported as many as 230 potential firewood species, whereas firewood is actually extracted from 12% of all documented woody plants. More recent studies performed within native communities in the Peruvian Amazon, have recorded more than 30 species used as fuelwood (Valdivia 2008). However, the fuelwood use of plants in mestizo communities has been little studied, documenting mostly their use for charcoal production (Labarta *et al,* 2008), whereas firewood species remain undocumented.

1.7. Ethnobotanical Research the Peruvian Amazon

1.7.1. Plants Used as Firewood

Reported by Tumova *et al*, the most plants utilized for firewood by local people in Peruvian Amazon are woody species (trees and shrubs) and the majority of them are multi-purpose trees used for timber, construction, food, medicinal purposes and environmental services and most of documented species have other than firewood uses. Mentioned by Umrani *&* Jain (2010), also fodder for grazing animals is provided by multipurpose trees. Some of the firewood species introduced to the region are cultivated mainly for food production (Tůmová, 2010). In this area, more than 150 native species are used by the farmers and managed in small-scale agroforestry plantations (Sotelo Montes *&* Weber, 1997). The *Bignoniaceae* family (well known for the timber industry) (including *Jacaranda* spp., *Tabebuia* spp.) is very common in the tropics of South America (Gachet *&* Schüly, 2009) with the family *Fabaceae* (e.g. *Inga* spp.) and *Rutaceae* family (*Citrus* spp.) (Tůmová, 2010). According to previous ethnobotanical study, preferences of the local people are based on their combustion properties and suitable species are described as plants with hot, strong coals, long lasting flames, ability to lose moisture fast and producing less smoke during the cooking. Also low ash content is desirable (Bhatt *et al*, 2004). Criteria used by the locals for selection of preferred species are often not understood in the terms of the science (Chettri *&* Sharma, 2009).

1.7.2. Species preferences

The most frequently preferred species in mestizo village in Campo Verde District were *Inga* spp. (*I. acreana, I. alba, I. edulis, I. oerstediana, I. pruriens, I. sapindoides, I. striata, I. thibaudiana* subsp. *peltadiana* and *I. umbellifera), Calycophyllum spruceanum, Citrus aurantifolia* and *Dipteryx micrantha.* Other plants preferred for firewood are *Citrus* spp., *Cordia lomatoloba, Mangifera indica, Poraqueiba sericea, Psidium guavaya, Swartzia Polyphylla* and *Tabebuia chrysantha* (Tůmová, 2010). Firewood species in Campo Verde District are commonly multipurpose trees, cultivated for fruits (Tůmová, 2010).

One of the most widely distributed and economically useful woody species in the region of Amazonia is *Inga edulis* Mart (*Fabaceae* family). This valuable multipurpose tree has high potential to be integrated in the local agroforestry systems (Lojka, 2012). It was researched by Sotelo Montes & Weber (1997) that *Inga edulis* is agroforestry species preferred by the farmers and it is main species for agroforestry research development. Reported by Kvist (2001*), I.edulis* is the second most important species for the firewood provision. Together with other *Inga* spp. it performs big proportion of species preferred for firewood in Campo Verde District (Tůmová, 2010). *Calycophyllum spruceanum* is considered as an important tree for quality timber, charcoal and firewood (high calorific value) in Peruvian Amazon (Sotelo Montes & Weber, 2003). Kvist (2001) claim *C. spruceanum* is the most important species, while it is providing more than a half of firewood in Peruvian Amazon. *Mangifera indica* and *Psidium guavaya* are also preferred by the locals for example in Kenya, where they care mainly about availability with less concentration on firewood properties (Kituyi *et al*, 2001). Mango tree is planted increasingly also in islands of Philippines (Bensel, 2008) and frequently used by rural families in Bangladesh villages (Miah *et al*, 2009).

1.7.3. Relationship between energy value and species preferences

In the study of Chettri & Sharma (2009) it was found that energy values play an important role in the preferences of the local people, while the intensity of heat produced by the fuelwood is considered as indicator of energy value. Further, according to local people in Sikkim, India, ideal firewood species gives comparatively better heat during combustion and long lasting fire, it must be heavy and with low moisture content and finally must not pruduce too much ash (Chettri & Sharma, 2009). Ramos *et al* (2008b) reported a significant relationship between preferences and the Fuelwood Value Index, when the species with the highest amount of citation, have the highest FVI as well as Erakhrumen (2009a) found high positive correlation between local preferences of species for agroforestry systems and calorific value, therefore, respondents will adopt species with high energy values easily for incorporation into agroforestry systems and their knowledge should be part of a criteria for selecting potential firewood species. Most of the highly preferred species were found to have high values for firewood and a significant correlation was found between the community scores and the FVI (Chettri *&* Sharma, 2009). Ramos *et al* (2008b) reported that all of four fuelwood species (with the exception of one) with the highest energy value have had also the largest number of positive fuelwood attributes and were therefore considered to be the best firewood species and the most preferred for collecting.

2. OBJECTIVES

The principal aim of this thesis is to determine characteristics fuelwood quality of forty woody plant species traditionally used as firewood in Campo Verde District in Peruvian Amazon and calculate Fuelwood Value Index (FVI), based on net calorific value, wood density and ash content. Accessory objective of the research is to compare preferences of local communities for firewood species with real combustion values.

Obtained data from laboratory measurements and the results from statistical analyses may be applied to define woody species for sustainable firewood production and application to agroforestry systems in given area.

3. MATERIALS AND METHODS

Forty wood samples were obtained from previous ethnobotanical study from the area of Campo Verde District in Peruvian Amazon near Pucallpa city in the Amazon basin of Peru.

3.1. Data collection and analysis

Research was carried out between the July and September 2009. Semi-structured interviews and participant observation (Martin, 2004) were conducted with 36 randomly selected households. Ethnobotanical information on firewood plants was collected through interviewing the household head present at the time of visit, regardless of sex or age. Accordingly, 27 women and 9 men whose age ranged from 22 to 80 years were interviewed. Each household was visited at least twice in order to confirm reliability of ethnobotanical information and to collect plant material mentioned in the interviews.

During the first visit, the semi-structured questionnaires solicited information on household composition, land use systems and land tenure. Subsequently, interviewees were asked questions related to their knowledge on plants used for firewood and/or charcoal (species used, which plant parts are collected, state of collected firewood (e.g. fresh or dead wood), location of collections, person responsible for collecting, preferred season for firewood collection, preferred species and reasons for preferences). To determine species preference, each participant was asked to name his/her most important firewood species (Kvist *et al.*, 2001) and the preference reason(s). To document preparation and type of firewood use, participants were also asked to provide information on cooking habits, such as: whether they use other types of fuel beside firewood, how they light a fire, how frequently they cook and what other purposes firewood is used for.

During subsequent visits, respondents were asked to show the plant species mentioned on site for reference voucher specimen collection. Plant specimens were collected during field observations through "walks-in-the-woods" (Alexiades, 1996) with each informant. Specimens collected were supplemented with digital photographic documentation to facilitate subsequent taxonomic determination of the species. All plant material was collected by the author of previous study and subsequently authenticated in cooperation with M.E. Chuspe Zans. Voucher specimens and their duplicates were deposited at the Regional Herbarium of the Ucayali IVITA (*Instituto Veterinario de Investigaciones Tropicales y de Altura*) of the *Universidad Nacional Mayor de San Marcos* and at the *Universidad Nacional Intercultural de la Amazonía* in Pucallpa. Species names were verified on the Tropicos - botanical information system of the Missouri Botanical Garden (Tropicos, 2010).

To evaluate informant consensus on use and preference of firewood plants, Relative Frequency of Citation index (RFC_s) was calculated for each species. The index was obtained by dividing the number of informants who used/preferred a given species, also known as frequency of citation (FC), by the number of informants participating in the survey (*N*) using the following formula (Tardio & Pardo-de-Santayana, 2008):

$$RFC_s = \frac{FC_s}{N}$$

Subsequently, RFC_s values were statistically tested through the Spearman correlation to determine the relationship between species use and preferences (Ramos *et al.*, 2008a).

The plant species selected for physical analyses were chosen from the list of plants used and preferred as firewood. Branch cuttings of approximately 2 – 3 cm diameter and 4 – 7 cm length were used to analyse the physical properties of the firewood.

3.2. Firewood analyses

Firewood analyses were undertaken in the laboratories (Institute of Tropics and subtropics and department of Botany and Plant Physiology on the Faculty of Agrobiology, Food and Natural Resources) of Czech University of Life Sciences Prague during the January – June 2012.

Families and proper names were verified according to Tropicos - botanical information system of the Missouri Botanical Garden (2012). Twelve of forty species were not taxonomically identified, insomuch as they were known only under the local names, which can signify more species for one local name. Those which were not identified remained named with the local designation.

3.2.1. Moisture content

Obtained samples exhibiting 40 woody species were marked with code numbers for easy identification with initials originating from Latin names. Each sample of fresh wood was split into two pieces and each of them was weighted. The properly coded samples were placed in regulated oven at a temperature range 95 ± 3 ºC until a constant weight was achieved. Moisture content (MC), was calculated from the following formula

$MC(\%) = \frac{\text{Fresh weight} - \text{Ovendry weight}}{\text{Fresh weight}} * 100$ (Erakhrumen, 2009a).

3.2.2. Volume and wood density

The volume of both samples of each species was measured by water-displacement method (Chave, 2005; Purohit & Nautiyal, 1987). Each sample was submerges into the beaker and the difference between original weight and weight with the sample was calculated Afterwards wood density was determined. Wood density can be calculated according to basic formula

$\text{Wood density} = \frac{\text{Ovendry weight}}{\text{Volume}}$.

3.2.3. Calorific value

The samples were subsequently oven-dried again at a temperature range 95 ± 3ºC until attaining constant weight (Ramos *et al*, 2008b). The oven-dried wood samples were cut into pieces smaller than 4 cm, hashed and hammer milled to fine powder. It was necessary to use two types of grinder machines to reach required fine texture of firewood powder. Powder of each sample was placed into plastic vial for safe storage and transport. Every vial was marked with correct code.

Approximately 0,5 - 1 gram of each sample was placed in steel capsule of the oxygen bomb calorimeter LAGET MS 10A and completely combusted in excess oxygen to determine net calorific value (NCV) in three replications (Erakhrumenn, 2009b). Firewood powder was sprinkled into small pieces of special paper and tied with metal wire. The metal wire is used to conduct discharges during combustion. Before the combustion, heat resistant glass cup was weighted. Than it was placed into capsule, fixed with metal wire, pressurized and placed to calorimeter. After few minutes (approximately 8 minutes) the sample was completely combusted and result from the display of calorimeter was read and recorded. After taking out, cup was removed and weighted again. It was done in three replications for each sample to get accurate results. Netto and brutto energy was evaluated.

3.2.4. Ash content

Ash content (AC) was determined using the muffle furnace. Two grams of ground wood samples were placed in a furnace in heat resistant ceramic pots at a temperature range of 600 ± 25˚C for 4 hours (Bhatt, 2002). All the measurements were done in three replications. Afterwards ash was weighted and the ash content determined according to

$$\text{Ash content} = \text{Weight of ash} \times \frac{100}{\text{weight of sample (2g)}}$$ (Kumar *et al*, 2010).

3.2.5. Fuelwood Value Index

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Fuel value index based on calorific value, wood density and ash content was calculated from the following formula

$$\text{FVI} = \frac{\text{Calorific value} * \text{Density}}{\text{Ash Content}}$$ (Kumar *et al*, 2010, Abbot *et al*, 1996).

According to Bhatt & Todaria (1992), moisture content varies with the dimension of branches, season of the year and so on. Therefore the water content cannot be considered as part of the fundamental value of specie as a fuel. Also it is depending on the state of the sample, if it was fresh or dead wood. Accordingly, this characteristic was left out from the formula, because it cannot be considered as decisive for calculating of Fuelwood Value Index (FVI).

3.3. Data analyses

It was necessary to calculate the error in measurement for moisture content, wood density, ash content, net calorific value and fuelwood value index. All the data were organized into the final table (Table 2).

Then all the characteristics were evaluated to find out, which species has the lowest and highest net calorific value, wood density, moisture content, ash content and fuelwood value index. Also it was determined which families have lowest and highest average energy value and total average energy value.

3.3.1. Relationship between wood firewood quality indicators

Correlation coefficient (r) for some of wood quality indicators was calculated to find out how much they are influencing each other. Relationship between the wood density and moisture content (Ramos *et al*, 2008b), wood density and net calorific value and finally, moisture content and net calorific value, was calculated. Correlation between values within the formula for FVI calculation was left out because the relationship is already given.

Correlation coefficient (r) was calculated with help of Microsoft Excel program by pasting the function “CORREL”. The figures (graphs) for each relationship between given characteristics were generated and the regression line was calculated and interspaced into the graph. It is done to illustrate graphically, how significant is the relationship between these characteristics and if there is direct or inverse relationship.

3.3.2. Relationship between energy value and species preferences

Correlation coefficient (r) was calculated also for fuelwood value index and preference and fuelwood value index and use (with the values from the previous ethnobotanical study). The same Excel function as for previous calculation was used. Then figure for both relationships were generated to see, if the species with the highest fuelwood value index are preferred and/or used as fuelwood (Ramos *et al*, 2008b) in the area of Peruvian Amazon.

4. RESULTS

Firewood characteristics of twenty eight identified species belonging to eighteen families and twelve unidentified woody species known under the local name, traditionally used in Peruvian Amazon were measured and net calorific value and subsequently, Fuelwood value Index (FVI) was determined. The relationship between firewood properties and use and/or preference was statistically evaluated.

The most abundant were species of family *Fabaceae* (*Inga* spp., *Dipteryx micrantha*, *Apuleia leiocarpa*), followed by *Bignoniaceae* (*Jacaranda macrocarpa*, *Tabebuia chrysantha*, *Tabebuia serratifolia*), *Rutaceae* (*Citrus aurantifolia, Citrus paradise, Citrus reticulata*) and *Anacardiaceae* (*Anacardium occidentale, Mangifera indica*). Other families (*Rubiaceae, Urticaceae, Meliaceae, Boraginaceae, Euphorbiaceae, Annonaceae, Malvaceae, Apocynaceae, Sapotaceae, Myrtaceae, Simaroubaceae, Asteraceae, Myristicaceae, Hipericacea*e) were represented only by one species.

4.1. Firewood analyses

Measurements of physical properties were carried out in laboratory and fuelwood quality indicators were calculated from given formulas.

4.1.1. Moisture content

Moisture content ranges between 4.87 ± 0.889 % in *Apuleia leiocarpa* and 7.55 ± 0.040 % in *Inga edulis.* Values are expressed in the Table 2. The average moisture content is 5.98 %.

4.1.2. Wood density

Wood density varies from 0.39 ± 0.009 to 0.93 ± 0.011 g/ccm in *Simarouba amara* and *Tabebuia chrysantha.* Moisture content was highest in *Inga edulis* (7.55 ± 0.040 g/ccm) and the lowest in *Anacardium occidentale* (4.87 ± 0.889 g/ccm) (Table 2). The average wood density is 0.61 g/ccm.

4.1.3. Net calorific value

Net calorific value ranges between 21.76 ± 1.456 kJ/g in *Jacaranda macrocarpa* and 14.85 ± 0.918 kJ/g in *Mangifera indica.* The lowest average net calorific value was found in family *Anacardiaceae* (15.36 kJ/g), on the other hand the highest average net calorific value was found in family *Bignoniaceae* (18.49 kJ/g). Total average energy value is 16.48 kJ/g. All the values are presented in Table 2.

4.1.4. Ash content

The ash content is the highest in *Apuleia leiocarpa* (2.54 ± 0.004 %) and the lowest in *Inga umbellifera* (0.27 ± 0.004 %) (Table 2). The average ash content is 1.452 %.

4.1.5. Fuelwood value index

The quality of fuelwood depends on quantitative and qualitative properties of wood (Kumar *et al*, 2010). The most important quantitative properties in determining the suitability of a wood as fuel are net calorific value, density and ash content, from which the fuel wood index (FVI) was calculated as calorific value*density/ash content. FVI is the highest for *Inga umbellifera* (3227.47 ± 48.350), followed by *Jacaranda macrocarpa* (2493.55 ± 175.739), *Dipteryx micrantha* (1547.38 ± 27.678) and *Tabebuia serratifolia* (1517.37 ± 66.052). FVI of *Cedrela odorata* was 347.12 ± 33.978, which is the lowest one. All the remaining values are presented in Table 2. The average FVI of all the species is 892.99.

4.1.6. Unidentified species

Some results of the unidentified species are noteworthy, for example FVI for hualaja was 2341.71, which was one of the highest, followed by chimiqua and copaiba. On the other hand, macambo has the lowest FVI (338.57) and the highest moisture content at the same time.

4.1.7. Measurement error

Due to replications and possible inaccuracy in determination of firewood properties (net calorific value, wood density, ash content, moisture content and FVI), measurement error, which is shown in the Table 2, may occur.

Table 2. Calorific value and other characteristics of selected traditionally used firewood in Campo Verde District in the Peruvian Amazon

Plant species	Family	Net Calorific value [kJ/g]	Wood density [g/ccm]	Ash %	Moisture content %	Fuelwood Value Index (FVI)
Anacardium occidentale L.	*Anacardiaceae*	15.87 ± 0.109	0.44 ± 0.018	1.33 ± 0.003	4.87 ± 0.889	522.92 ± 16.680
Apuleia leiocarpa (Vogel) J.F. Macbr.	*Fabaceae*	16.78 ± 0.844	0.68 ± 0.013	2.54 ± 0.004	5.53 ± 0.044	449.73 ± 26.427
Calycophyllum spruceanum (Benth.) Hook. f. ex K. Schum.	*Rubiaceae*	16.71 ± 0.300	0.65 ± 0.009	1.31 ± 0.116	5.98 ± 0.022	842.35 ± 82.003
Cecropia engleriana Snethl.	*Urticaceae*	16.19 ± 0.211	0.51 ± 0.009	1.75 ± 0.003	5.66 ± 0.004	474.80 ± 10.323
Cedrela odorata L.	*Meliaceae*	17.34 ± 1.522	0.41 ± 0.009	2.07 ± 0.002	6.52 ± 0.022	347.12 ± 33.978
Citrus aurantiifolia (Christm.) Swingle	*Rutaceae*	18.05 ± 0.293	0.70 ± 0.009	2.13 ± 0.002	5.92 ± 0.022	596.46 ± 12.137
Citrus paradisi Macfad.	*Rutaceae*	16.33 ± 0.540	0.72 ± 0.011	2.43 ± 0.003	5.60 ± 0.004	482.49 ± 16.909
Citrus reticulata Blanco	*Rutaceae*	15.76 ± 0.647	0.81 ± 0.013	1.96 ± 0.002	6.02 ± 0.022	650.00 ± 21.871
Cordia lomatoloba I.M. Johnst	*Boraginaceae*	17.62 ± 0.878	0.93 ± 0.018	1.69 ± 0.002	5.84 ± 0.050	964.65 ± 40.465
Croton draconoides Müll. Arg.	*Euphorbiaceae*	15.47 ± 2.558	0.44 ± 0.009	0.59 ± 0.084	5.60 ± 0.000	1 178.84 ± 148.932
Dipteryx micrantha Harms	*Fabaceae*	16.94 ± 0.209	0.79 ± 0.013	0.87 ± 0.007	5.88 ± 0.020	1 547.38 ± 27.678
Guatteria sp.	*Annonaceae*	16.32 ± 0.524	0.48 ± 0.013	1.15 ± 0.002	6.38 ± 0.022	681.93 ± 28.849
Guazuma crinita Mart.	*Malvaceae*	15.54 ± 0.487	0.45 ± 0.004	1.90 ± 0.002	6.10 ± 0.004	365.58 ± 9.260
Himatanthus sucuuba (Spruce ex Müll. Arg.) Woodson	*Apocynaceae*	16.52 ± 0.269	0.60 ± 0.009	1.76 ± 0.000	5.40 ± 0.000	567.90 ± 5.127

Table 2 Continued

Plant species	Family	Net Calorific value [kJ/g]	Wood density [g/ccm]	Ash %	Moisture content %	Fuelwood Value Index (FVI)
Inga edulis Mart.	*Fabaceae*	16.37 ± 0.053	0.43 ± 0.004		7.55 ± 0.040	646.83 ± 12.503
Inga pruriens Poepp.	*Fabaceae*	15.42 ± 0.358	0.56 ± 0.009	0.59 ± 0.004	6.41 ± 0.012	1475.97 ± 33.664
Inga thibaudiana DC.	*Fabaceae*	15.22 ± 0.600	0.56 ± 0.000	2.22 ± 0.003	5.80 ± 0.000	383.90 ± 14.542
Inga umbellifera (Vahl) Steud.	*Fabaceae*	16.55 ± 0.042	0.52 ± 0.009	0.27 ± 0.004	5.68 ± 0.054	3227.47 ± 48.350
Jacaranda macrocarpa Bureau & K. Schum.	*Bignoniaceae*	21.76 ± 1.456	0.41 ± 0.004	0.36 ± 0.003	5.98 ± 0.022	2493.55 ± 175.739
Mangifera indica L.	*Anacardiaceae*	14.85 ± 0.918	0.52 ± 0.009	0.78 ± 0.000	5.70 ± 0.004	996.90 ± 70.607
Pouteria caimito (Ruiz & Pav.) Radlk.	*Sapotaceae*	16.89 ± 0.782	0.54 ± 0.009	1.86 ± 0.002	6.43 ± 0.044	494.23 ± 19.597
Psidium guayava L.	*Myrtaceae*	17.37 ± 0.671	0.72 ± 0.013	1.84 ± 0.002	6.50 ± 0.000	678.00 ± 20.462
Simarouba amara Aubl.	*Simaroubaceae*	16.97 ± 0.562	0.39 ± 0.009	1.51 ± 0.002	5.80 ± 0.000	441.53 ± 14.877
Tabebuia chrysantha (Jacq.) G. Nicholson	*Bignoniaceae*	17.06 ± 0.431	0.93 ± 0.011	1.69 ± 0.002	5.43 ± 0.040	937.15 ± 12.862
Tabebuia serratifolia(Vahl) G. Nicholson	*Bignoniaceae*	16.65 ± 0.840	0.93 ± 0.013	1.02 ± 0.000	5.70 ± 0.005	1517.37 ± 66.052
Vernonia patens Kunth	*Asteraceae*	16.38 ± 0.407	0.59 ± 0.009	1.04 ± 0.130	6.08 ± 0.022	955.56 ± 140.409
Virola calophylla (Spruce) Warb.	*Myristicaceae*	15.73 ± 0.613	0.44 ± 0.009	2.03 ± 0.016	6.50 ± 0.000	344.15 ± 14.224
Vismia glabra Ruiz & Pav.	*Hipericaceae*	16.60 ± 0.391	0.64 ± 0.013	1.74 ± 0.008	4.97 ± 0.044	611.30 ± 25.023
Atadijo*		16.09 ± 0.116	0.50 ± 0.009	1.28 ± 0.012	6.31 ± 0.009	631.94 ± 5.633
Chimiqua*		15.09 ± 0.093	0.81 ± 0.009	0.75 ± 0.007	6.00 ± 0.003	1 647.34 ± 6.187
Copaiba*		17.93 ± 0.180	0.64 ± 0.009	1.15 ± 0.004	6.24 ± 0.053	1 000.14 ± 17.151

Table 2 Continued

Plant species	Family	Net Calorific value [kJ/g]	Wood density [g/ccm]	Ash %	Moisture content %	Fuelwood Value Index (FVI)
Espintano*		17.25 ± 0.493	0.43 ± 0.022	1.18 ± 0.017	5.73 ± 0.044	636.22 ± 35.506
Frente del toro*		17.44 ± 0.584	0.62 ± 0.009	1.26 ± 0.084	6.28 ± 0.022	866.27 ± 70.284
Huacapú*		16.46 ± 0.487	0.91 ± 0.004	1.73 ± 0.002	4.20 ± 0.000	864.33 ± 26.224
Hualaja*		15.12 ± 0.707	0.49 ± 0.009	0.32 ± 0.002	5.82 ± 0.022	2341.71 ± 78.445
Lífar*		16.27 ± 0.489	0.65 ± 0.013	1.74 ± 0.006	6.10 ± 0.004	607.40 ± 23.873
Macambo*		15.25 ± 0.380	0.44 ± 0.009	2.00 ± 0.002	7.70 ± 0.133	338.57 ± 10.375
Pumaquiro*		18.41 ± 0.427	0.71 ± 0.009	1.70 ± 0.003	5.77 ± 0.046	772.32 ± 14.611
Quillobordón*		16.25 ± 0.984	0.50 ± 0.004	1.71 ± 0.002	5.41 ± 0.073	472.57 ± 30.569
Shapana*		14.29 ± 0.336	0.73 ± 0.013	1.73 ± 0.000	6.33 ± 0.044	604.67 ± 19.863

All the measurements were done in three replications

* Taxonomically unidentified species

4.2. Correlation among the firewood quality indicators

Correlation coefficient (r) for some of characteristics was calculated. For expression of strength of relationship between individual values, methodology of correlation determination is used (Svatošová & Kába, 2008). From the definition of correlation coefficient it is known that r ranges from -1 to, while positive value corresponds to directly proportional dependency and negative value corresponds to inversely proportional dependency (Svatošová & Kába, 2008). For evaluation, approximate scale is usually used. If r = 0 - 0.3, dependency is weak, if r = 0.3 – 0.8, dependency is middle and if r = 0.8 – 1, we can speak about strong dependency (Svatošová & Kába, 2008). When r = 1, we speak about linear functional dependency. If r = 0, the values are linearly independent (Svatošová & Kába, 2008).

4.2.1. Wood density and moisture content

Correlation coefficient (r) observed between the values of wood density and moisture content, is **r = - 0. 40**. It expresses middle mutual inversely proportional relationship. That means, if wood density increases, moisture content decreases and conversely. Logically, when the density is lower, the porosity is higher and pores are saturated with the water, so moisture content is higher as well. It is shown in a Figure 2. The regression line was calculated for the relationship between moisture content and wood density. Even if in our study the moisture content was low (because fresh wood have not been used), the relationship was proved as well.

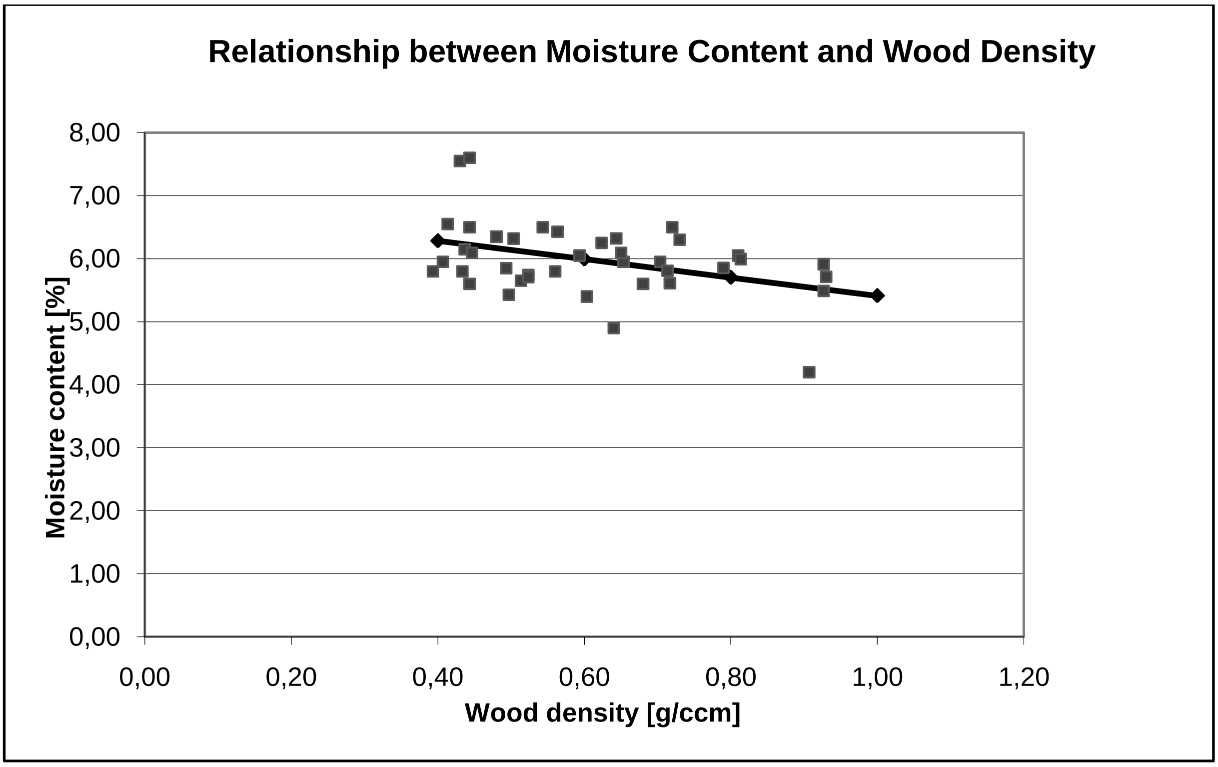

Fig. 2 Relationship between moisture content and wood density

4.2.2. Wood density and net calorific value

Correlation coefficient (r) for the values of relationships of wood density and net calorific value is **r = 0.12**. It expresses weak relationship. It is not necessary to make the figure for this relation, when the relationship between these characteristics is not significant at all in this study.

4.2.3 Moisture content and net calorific value

Correlation coefficient (r) for the moisture content and net calorific value is **r = -0.01**, which means no dependency at all. The same as before, it is not necessary to make the figure for this relation, when the relationship between these characteristics does not exist in this study.

4.2.4. FVI and use

Correlation coefficient (r) for Fuelwood Value Index and use (values from previous ethnobotanical study) is **r = 0.31**. Values from the Table A1 were used for calculation. The relationship is middle directly proportional.

4.2.5. FVI and preference

Correlation coefficient (r) for Fuelwood Value Index and preference citation (also values from previous study) is **r = 0.40**. Values from the Table A1 were used for calculation. Relationship is slightly more significant than the relationship observed between FVI and use, anyway it is middle and directly proportional.

In the following figure (Fig. 3) it is shown, that not all the species cited as used or even preferred have also the highest fuelwood value indexes. Some preferred species, such as *Inga umbellirefa, Tabebuia serratifolia* or *Dipteryx micrantha* are preferred and also have high FVI. However, *Pouteria caimito, Citrus aurantifolia* and *Inga edulis* have lower FVIs, even they are cited as preferred by local communities.

Conversely, some species cited as non-preferred for example *Jacaranda macrocarpa* or *Croton draconoides* have high FVIs and high quality in comparison with some locally preferred woody species, but these species might be of small occurrence or worse availability.

In the Figure 3 the FVI of preferred and non-preferred species is shown. It can be observed that some of non-preferred species have high combustion index and some of the preferred species are of lower combustion quality. Some of non-preferred species are even of better quality than species with higher number of preference citation.

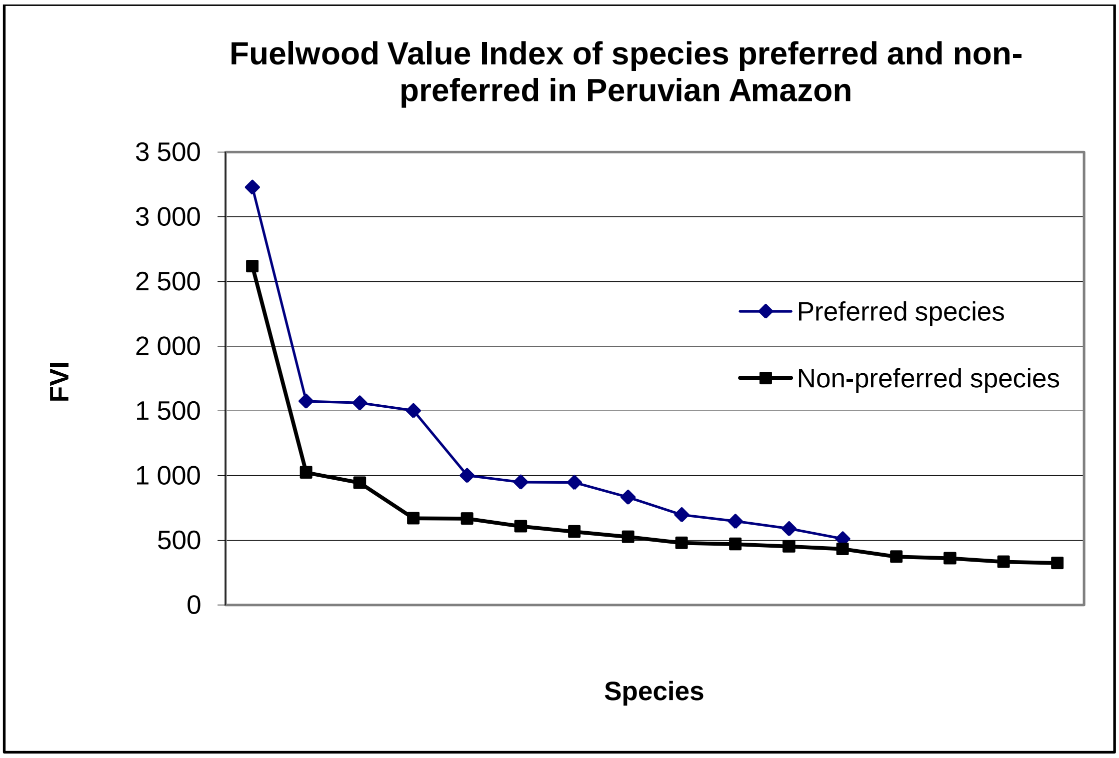

Fig. 3 Fuelwood Value Index of the species preferred and non-preferred in the area of interest

4.2.6. Unidentified species

Fuelwood Value index of some of the unidentified species is worth mentioning. Copaiba was cited as preferred and also FVI is pretty high. Hualaja is sorted between non-preferred and its combustion properties are of a high quality, as well as, chimiqua, frente del toro, huacapú and pumaquiro. The remaining unidentified species (atadijo, espinato, lífar, shapana, quillobordón) are of minor quality properties.

5. DISCUSSION

5.1. Firewood quality indicators

The quality of firewood is influenced by the properties of wood. The most important is calorific value, moisture content, wood density, ash content, silica content, drying rate and chemical composition (Bhatt *et al*, 2004; Munalula & Meincken, 2009). For ideal firewood, high calorific value, low moisture content and low ash content are required parameters (e.g. Kumar *et al*, 2011; Bhatt & Tomar, 2002; Goel & Behl, 1996).

5.1.1. Calorific value

Net calorific value of woody species is depending on chemical composition, moisture content, ash producing compounds and further genetic character, age and type of wood (heartwood or sapwood) (Lemenih & Bekele, 2004; Kataki & Konwer, 2002). According to Fengel a Wegener (1982), calorific value varies between 17 – 20 kJ/g and average for tropical hardwood is 20 kJ/g (Montes *et al*, 2011). Average calorific value from the research of twelve Nigerian species (Erakhrumen, 2009) was 18.25 kJ/g. Studies made in India showed the range of 15.25 – 25.56 kJ/g (Jain & Singh, 1999) and 13.53 – 21.59 kJ/g (Kataki & Konwer, 2002). The result of the present study (average calorific value = 16.48 kJ/g) is slightly lower and ranges between 14.85 - 21.76 kJ/g.

5.1.2. Fuelwood Value Index

On the basis of Fuelwood Value Index, as an indicator of firewood quality and combustion qualities, *Inga umbellifera*, *Jacaranda macrocarpa*, *Dipteryx micrantha* and *Tabebuia serratifolia*, has the most promising properties. According to e.g. Goel & Behl (1996), parameters for computation of FVI is calorific value, wood density, ash content and moisture content. But the higher moisture content causes reduced heat of combustion available (Bhatt *et al*, 2004; Wang *et al*, 1982; Kataki & Konwer, 2002; Senelwa & Sims, 1999; Munalula & Meincken, 2004). Moreover, moisture content varies with the season of the year, dimension of branches and so on, it cannot be considered as part of the interior value of a species for fuels, because it can vary (Bhatt & Todaria, 1993). Also it can vary, if the wood is fresh or dead and cam depend on how long it is stored and how. Therefore, moisture content was left out from the formula, which remained as calorific value*wood density/ash content (e.g. Bhatt *et al*, 2004; Bhatt & Tomar, 2002; Kumar *et al*, 2011).

5.1.3. Moisture content

Moving to the moisture content, calculated moisture content in this study is incomparable lower than in literature screened. The average moisture content is almost 6 % and ranges from 4.78 % (*Apuleia leiocarpa*) to 7.55 % (*Inga edulis*), even in macambo (unidentified species) it was 7.7 %. The low moisture content is attributed to the fact that firewood in area of interest is usually collected as a deadwood from fallen branches or trunks of dead standing trees or shrubs (Tůmová, 2010). In our case, moisture content could decrease even more due to transport and longer time storage. In the research of Abbot *et al* (1997), sixteen species studied had approximately 70 % of the moisture, Fuwape & Akindele (1997) found the range of 25 - 31% of moisture for three fast-growing Nigerian species, for vegetation of caatinga (dryland) in Brazil, water content varied from 22.7 - 63.5% (Ramos *et al*, 2009b) and in one of the study of Indian firewood species the values ranged between 30.7 - 70.28% (Kumar *et al*, 2011). In the studies mentioned the fresh wood was used and it makes the difference between their and our moisture content significant.

5.1.4. Ash content

Wang *et al* (1989) and Goel & Behl (1996) marked the ash content as important parameter affecting calorific value and simultaneously as negative character for combustion values. Tropical species exhibit higher ash (and moisture content) than temperate species (*Juniperus wallichiana, Taxus baccata, Quercus* spp., *Abies* spp., *Betula* spp., *Prunus* spp.) (Bhatt & Todaria, 1992; Purohit & Nautiyal, 1987). This study represents fairly low ash contents with the average of 1.452 %. It is similar to Kumar *et al* (2011) when the ash content varies between 0.85- 3.38% or ash content of some south African species measured by Munalula & Meincken (2009) in the range of 0.34- 2.75 %.

5.1.5. Correlation among wood quality indicators

Relationship between the characteristics can vary for different species, but they are somehow influencing each other. For the calculation of FVI, the formula calorific value*wood density/ash content is used (e.g. Bhatt *et al*, 2004; Bhatt & Tomar, 2002; Kumar *et al*, 2011). The relationship of values within formula, are already given, so it is not necessary to calculate correlation.

Inspired by Ramos *et al* (2008b), relationship between wood density and water content was done. In comparison with significant inverse proportional relationship between high density and low moisture content (r = - 0.77) (Ramos *et al,* 2008b), in this survey, the relationship was weak or middle (Svatošová & Kába, 2008) while r = - 0.40. Also other studies showed weak or middle relationship (Bhatt *et al*, 2004; Abbot & Lowore, 1999, Abbot *et al*, 1997). When the density is higher, the porosity of the wood is lower and therefore the moisture content is lower as well.

Surprisingly, relationship between net calorific value and wood density and between net calorific value and moisture content was weak or none, though according to Abbot *et al* (1996), higher density increases energy value, in this case the relationship was weak (r = 0.12). Moisture content causes heat loss during the combustion and has negative effect on calorific value (Bhatt *et al*, 2004; Kataki & Konwer, 2002; Senelwa & Sims, 1999; Munalula & Meincken, 2009; Wang *et al*, 1982). Anyway, there was no relationship proved between moisture content and energy value in this case (r = - 0.01) and it might be due to very low moisture content measured for given samples.

5.2. Important firewood in the Peruvian Amazon

5.2.1. Firewood of major importance

Calycophyllum spruceanum, Citrus aurantifolia and other *Citris* species*, Cordia lomatoloba, Dipteryx micrantha, Inga edulis* and *other Inga* spp.*, Mangifera indica, Poraqueiba sericea, Psidium guajava, Swartzia polyphylla* and *Tabebuia chrysantha*, were cited as a preferred fuelwood in mestizo villages in Campo Verde District in the Peruvian Amazon (Tůmová, 2010). In the present study, *Inga umbellifera, Jacaranda macrocarpa,* *Dipteryx micrantha*, *Tabebuia serratifolia* and *Inga pruriens, Croton draconoides* and hualaja were shown as the species with the best quality firewood and therefore are suitable for incorporation to agroforestry systems in this area.

Inga edulis is a multipurpose woody species, frequently cultivated for firewood thanks to its high calorific value, high firewood biomass production, less smoke and good potential for sustainable farm cropping and agroforestry (Lim, 2012; Leblans *&* McGraw, 2006; Lojka, 2012) and together with other *Inga* species it is cultivated for fruits (starchy pods) (Vasquez *&* Gentry, 1989). Reported by Kvist (2001*), I.edulis* is the second most important species for the firewood provision. In the present study it was measured that the calorific value of *I. Edulis* is 16.37 kJ/g. This value is average in comparison with the others species and it is comparable to other *Inga* spp., which can be found also for instance on the fuelwood market in Nicaragua (McCrary *et al*, 2005) or as firewood of excellent quality in the secondary forest of Brazil (Francez *&* de Carvalho, 2002). *Inga umbellifera* has been considered as the most desirable species on the basis of this research (FVI = 3227.74) with very low content of ash. *Inga pruriens* is one of the best quality firewood. On the other hand, *Inga thibaudiana* came from the study as inadequate.

Surprisingly, the second most promising species is *Jacaranda macrocarpa* according to laboratory measurements. It is not preferred by the locals, however energy value is 21.76, FVI is 2493.55 and ash content was very low. There was no study found about *J.macrocarpa* as firewood. In Rwanda, the same genus, *Jacaranda mimosifolia*, was mentioned as fuelwood used (Ndayambe, 2005). Though *Croton draconoides* was not cited as preferred one, in our study it provides good properties with high FVI and low ash content. *Croton blanchetianus* Baill. is frequently used in Brazilian dryland and shows high calorific value (Ramos, 2008b).

In family *Bignoniaceae* the highest average calorific value was found. *Tabebuia chrysantha* is important species mentioned for its use in the villages of Bangladesh (Jashimuddan *et al*, 2006) and frequent occurrence in fuelwood market in Nicaragua (McCrary *et al*, 2005). It takes place between the most preferred firewood species in Campo Verde District and this genus has been commented by one of the local respondents as a species containing some kind of oil which simplifies the combustion (Tůmová, 2010). Species of the same genus, *Tabebuia aurea* (Silva Manso) Benth. And Hook. f. ex. S.Moore, was found in dryland region of Brazil (Ramos, 2008a).

Cordia lomatoloba has desirable calorific value adequate to its high preference in Peruvian Amazon and the wood of *C. alliodora* (Ruiz & Pav.) Cham. and *C. globosa* (Jacq.) Kunth occur in semi-arid region of Brazil (2008a).

Mangifera indica is highly appreciated for firewood worldwide. Common average calorific value is 16.8 kJ/g (ICRAF). In Kenya, it is preferred mainly for the availability (Kituyi, 2001) and in the research of Tabuti *et al* (2003), *M. indica* was mentioned for frequent firewood use as well. Mango tree is planted increasingly also in islands of Philippines (Bensel, 2008) and frequently used by rural families in Bangladesh villages (Miah *et al*, 2009) and Brazilian dryland (Ramos *et al*, 2008a). In present measurement, the energy value was the lowest (14. 85 kJ/g). This species might be required for its multipurpose use, mainly due to fruits production (Vasquez *&* Gentry, 1989) and also for its availability. In communities around Pucallpa city, its use for dying purposes was documented by Polesna *et al* (2009).

Calycophyllum spruceanum is considered as an important tree for quality timber, charcoal and firewood (high calorific value) in Peruvian Amazon (Sotelo Montes *&* Weber, 2003; Weber *&* Sotelo Montes, 2005). Kvist *et al* (2001) claims *C. spruceanum* is the most important species, while it is providing more than a half of firewood in Peruvian Amazon. *Calycophyllum candidissimum* (Vahl) DC. is frequently sold on fuelwood market in Nicaragua (McCrary *et al*, 2005). Yet, the energy value was average and according to results from present research *C.spruceanum* does not belong to the best quality fuelwood in this research.

Frequent occurrence of *Citrus* species was found for example in fuelwood market in Nicaragua (*C.sinensis*) (McCrary *et al*, 2005), in villages of rural Bangladesh (Miah & Hossain, 2002) or rural communities of Ghana (Osei, 1993). *Citrus aurantifolia* is one of the most preferred firewood in Campo Verde District together with other *Citrus* spp. (Tůmová, 2010). Net calorific value of *C.aurantifolia* was high (18.05 kJ/g), but due to combination with higher ash content, FVI is not so promising. *Citrus* species are also required for the fruits provision in the Peruvian Amazon (Vasquez *&* Gentry, 1989).

Dipteryx micrantha was cited as frequently preferred (Tůmová, 201) and also energy value was one of the highest. No previous studies on *D.micrantha* were found, only *Dipteryx rosea* Spruce ex Benth. was documented for cooked seeds consumption in the area of the Peruvian Amazon by Vasquez *&* Gentry (1989).

Poraqueiba sericea and *Swartzia polyphylla* were cited as a preferred firewood in Campo Verde District (Tůmová, 2010), however they have not been involved to this study.

5.2.2. Firewood of minor importance

Guazuma crinita is an important tree species sustainable for agroforestry plantations in Peruvian Amazon (Rochon *et al,* 2007), however, this species was evaluated as non-preferred in Peruvian Amazon (Tůmová, 2010). Determined calorific value was below the average (15.54 kJ/g) as well as FVI, which was 365.58. Ash content is very high and all these factors make *G.crinita* undesirable for firewood.

Some species with minor importance from preference as well as energy values point of view were found in some previous studies. *Cedrela odorata* and *Simarouba amara* is appreciated in Bangladesh rural village or on fuelwood market of Nicaragua (Jashmiddan *et al*, 2006; McCrary *et al,* 2005), while *Cedrela* spp. were domunented in agroforestry systems (Taunguya systems) in the area of southern pacific (Nair, 1993). *Anacardium occidentale* and *Cecropia* spp. in caatinga (dryland) vegetation was investigated as a fuelwood in Brazil (Ramos *et al*, 2008a). *A.occidentale* provides also fruits (Vasquez *&* Gentry, 1989). *Apuleia leiocarpa* was previously documented as used for firewood in Amazonia (Sotelo Montes *&* Weber, 1997). *Vismia* spp. is mentioned by Francez *&* de Carvalho (2002) as firewood of good quality in the secondary forest of Brazil and *Vismia guinaensis* was documented in the secondary forest of Costa Rica (Salazar, 1986). *Pouteria caimito* and other *Pouteria* spp. are appreciated for sweet pulp provision in area of Iquitos (Peruvian Amazon) (Vasquez *&* Gentry, 1989). Fuelwood of *Vernonia patens* and *Pouteria sapota* (Jacq.) were documented in coffee plantations in southern Mexico (Peeters *et al*, 2003) and *Vernonia amygdalina* Delile in Rwanda (Tabuti *et al*, 2003). *Himatanthus bracteatus* (AD. C.) Woodson was mentioned by Kvist et al (2001) in floodplain communities in Peruvian Amazon.

Reported by Nebel *&* Meilby (2005), occurrence of *Guatteria* spp. is frequent in Peruvian Amazon as an important timber species and according to energy value measurement has average FVI, therefore it can be fairly suitable as firewood. Nebel & Meilby (2005) recorded presence of some *Virola* spp. (*V. elongata* (Bent) Warb. and *V. pavonis* (A.DC.) A.C. Sm.).

All the mentioned species were documented for their use as firewood in ethnobotanical studies, however almost none were determined in terms of concrete measured energy value. However at least they are known for other uses, in many cases, fruit production and the variability in the use makes them suitable multipurpose species for potential incorporation into agroforestry systems.

5.2.3. Use of unidentified species

Twelve species investigated were not taxonomically identified, they were cited only under the local names and the botanical identification might be controversial. Some of them can signify more different species. Some of them were documented as used for food, timber, medicinal use by e.g. Veiga Junior *et al* (2007), Nebel & Meilby (2005) and Vasquez & Gentry (1989).

Copaiba is the only one fuelwood cited as preferred in Campo Verde District (Tumova *et al*). Described by Veiga Junior *et al* (2007), oil is obtained from copaiba and he posted that copaiba is name for more species of *Copaifera* L. genus. He investigated *C. cearensis* Huber ex Ducke, *C. reticulata* Ducke and *C. multijuga* Hayne for anti-inflammatory activity of copaiba oil. In our study copaiba showed high quality fuelwood. Also it was cited as a medicinally used plant in Campo Verde District (Tumova *et al*).

In the research of Nebel & Meilby (2005) huacapú was identified as *Minquartia guianensis* Aublet. and documented its frequent use as a timber in the Peruvian Amazon, moreover it is cultivated for the fruits production in Iquitos area (Vasquez & Gentry, 1989). In our study, huacapú was not botanically identified. It can be said, that for energy value which is slightly above the average, it could be classified as better quality firewood. Macambo is often identified as *Theobroma bicolor* Bonpl. and it was researched by Torres *et al* (2002) that it has high antioxidant activity macambo extracts could be used as food antioxidants and also was mentioned by Vasquez & Gentry (1989) as species for food in the area of Iquitos. Energy values of macambo signify low fuelwood quality, as the FVI is the lowest one and moisture content was the highest. Zárate (1970) published in forestry journal from Peru pumaquiro as *Aspidosperma macrocarpon* Mart, Quillobordón as *Aspidosperma vargasii* A.DC. and hualaja as *Zanthoxylum juniperinum* Poepp. Chimiqua is mentioned as breadfruit or banana, used for food in the Peruvian Amazon (Vasquez & Gentry, 1989). Huacapú, chimiqua and copaiba exhibits very high FVIs and provides good quality timber. Frente del toro and espinato are mainly used for construction wood or timber (Tumova *et al*) and they even do not exhibit good quality fuelwood. Remaining unidentified species (atadijo, lífar and shapana) also do not show high energy values even they are mainly used for firewood in the Peruvian Amazon (Tumova *et al*).

5.3. Correlation between species preference and energy value

Energy value plays important role in the preferences of local people. They determine energy value and quality of wood pursuant to heat produced by the fuelwood combustion (Chettri & Sharma, 2009), flammability, flame brightness, quantity of smoke and ash, ability to lose moisture, lasting of flame (Bhatt et al, 2004; Abott *et al*, 1997; Wang *et al*, 1982). These socially defined properties serve for perception of suitable qualities of fuelwood (Abbot & Lowore, 1999) and subsequent preference of feasible species. On the basis of a local knowledge, significant relationship between preference and energy value can be found. Ramos *et al* (2008a, 2008b) confirms this relationship by correlation coefficient r = 0.57, which means significant relationship, thus, species with the highest FVI also have the largest number of citations in the area of caatinga (dryland) vegetation in Brazil. Erakhrumen (2009a) published significant positive values (r = 0.868 and r = 0.874) between net calorific values and cumulative values in Akinyele and Ido government areas in Oyo state (Nigeria) and it was recommended that indigenous knowledge of users perspective should be part of the criteria for selection potential firewood species for adopting into agroforestry systems in this area and also areas with similar conditions. According to Chettri & Sharma (2009), local knowledge (and preferences) in combination with scientific knowledge of properties could be the basis for cultivation of high value fuelwood to meet the local´s people present and future demands.

In our study, some of the non-preferred species surprised with very suitable characteristics and energy values and vice versa few of the species frequently preferred disappointed with their poor properties. However, big proportion of species preferred showed also high quality. Correlation coefficient is r = 0.40, which means not very significant relationship, however this result is appreciable and indicated good knowledge of quality firewood on the local level.

Since fuelwood consumers have been known to prefer firewood species with high energy, incorporation of these species into agroforestry systems needs to be well highlighted (Erakhrumen, 2009a).

6. CONCLUSION

This study investigated energy value and firewood characteristics of forty species traditionally used in Campo Verde District in the Peruvian Amazon. Majority of people living in rural communities relies on firewood as the only one source of energy for cooking and heating. Therefore sustainable production of firewood species with quality properties should be implemented to agroforestry systems. To meet local knowledge with energy value and thereby desirable characteristics of these species, Fuelwood Value Index for some preferred species was evaluated on the basis of net calorific value, wood density and ash content. Suitable features for combustion is high calorific value, high density, low moisture content and low ash content. The highest FVI was proved for *Inga umbellifera, Jacaranda macrocarpa, Dipteryx micrantha, Tabebuia serratifolia* and *Inga pruriens* and it makes them suitable for production. The best values were found in family *Bignoniaceae*. It is demanded to introduce and cultivate species, which are locally known and used, accordingly preferred species were determined to recognize the best quality wood to be easily adopted to agroforestry systems. By adopting of sustainable firewood production, the rate of deforestation can slightly decrease, biodiversity might be conserved more easily and carbon sequestration can be influenced positively.

From the evaluation of correlation coefficient of preference and FVI, it is evident, that local people have good knowledge of good quality fuelwood, assessed from the heat produced during combustion, lasting of the flame, flammability and less smoke creation. Some of the species surprised with higher calorific value than expected (e.g. *Jacaranda macrocarpa*) and some preferred failed in the laboratory measurements (e.g. *Mangifera indica*).

There is still lack of knowledge and more studies targeted on the species for firewood production are needed both, in the Peruvian Amazon or globally.

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APPENDIX A

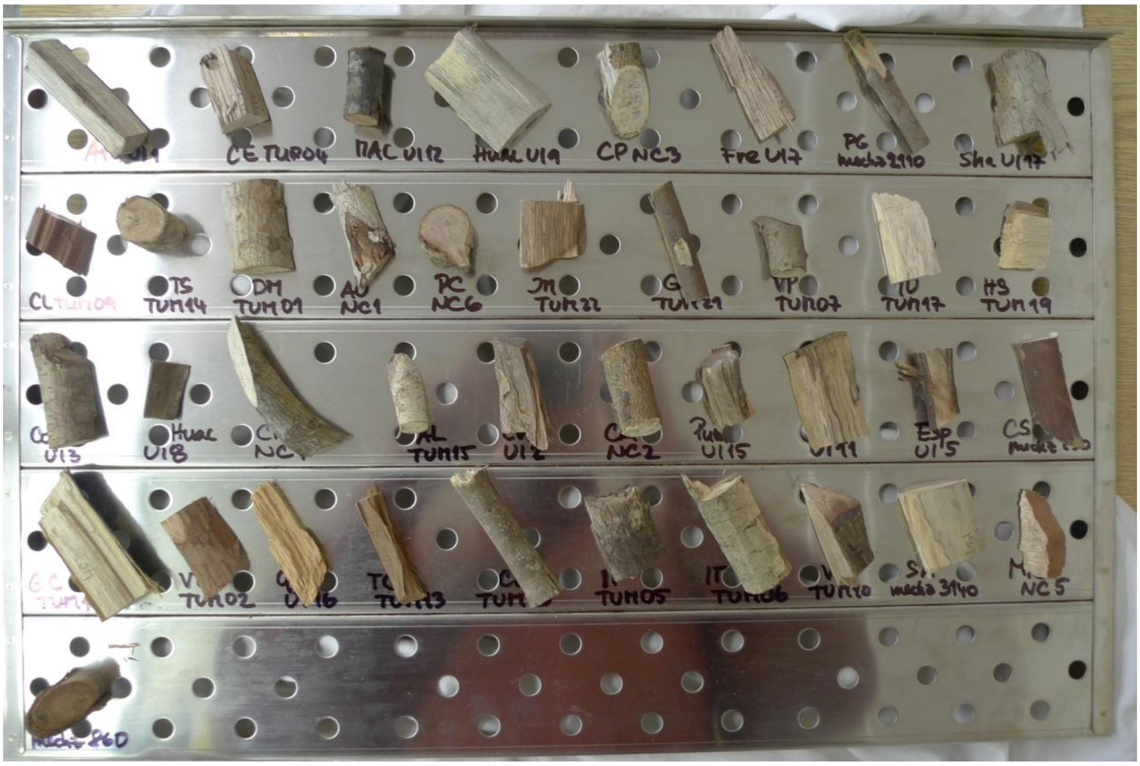

Fig. A1 Samples of firewood species used in Campo Verde District in Peruvian Amazon (1)

Fig. A2 Samples of firewood species used in Campo Verde District in Peruvian Amazon (2)

Table A1 Default values for relationship between FVI and use and FVI and species preference

Species	Fuelwood Value Index (FVI)	Frequency of use	Preference index
Anacardium occidentale	525.81	0.03	x
Apuleia leiocarpa	432.65	0.09	x
Calycophyllum spruceanum	833.44	0.26	0.14
Cecropia engleriana	479.45	0.17	x
Cedrela odorata	323.90	0.03	x
Citrus aurantiifolia	590.04	0.26	0.06
Citrus paradisi	470.64	0.11	x
Citrus reticulata	670.21	0.09	x
Cordia lomatoloba	1 001.07	0.06	0.03
Croton draconoides	1 024.33	0.03	x
Dipteryx micrantha	1 561.73	0.23	0.14
Guatteria sp.	667.33	0.03	x
Guazuma crinita	360.82	0.03	x
Himatanthus sucuuba	567.41	0.03	x
Inga edulis	646.83	0.86	0.2
Inga pruriens	1 501.85	0.63	0.17
Inga thibaudiana	372.58	0.03	x
Inga umbellifera	3 228.74	0.63	0.17
Jacaranda macrocarpa	2 618.13	0.03	x
Mangifera indica	950.39	0.31	0.03
Pouteria caimito	511.53	0.11	0.03
Psidium guayava	698.00	0.14	0.06
Simarouba amara	452.62	0.09	x
Tabebuia chrysantha	947.45	0.09	0.03
Tabebuia serratifolia	1 575.53	0.06	0.03
Vernonia patens	945.05	0.09	x
Virola calophylla	334.03	0.03	x
Vismia glabra	607.48	0.06	x
Atadijo	629.92	0.09	x
Chimiqua	1 647.41	0.03	x
Copaiba	994.01	0.03	0.03
Espintano	622.52	0.03	x
Frente del toro	883.12	0.03	x
Huacapú	846.72	0.03	x
Hualaja	2 425.34	0.06	x
Lífar	595.64	0.03	x
Macambo	344.93	0.03	x
Pumaquiro	785.93	0.03	x
Quillobordón	451.07	0.06	x
Shapana	593.94	0.03	x