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The Effects of Bark on Fuel Characteristics of some Evergreen Mediterranean Hardwood Species

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Abstract

A significant proportion of Mediterranean forest vegetation consists of evergreen small diameter hardwood trees and shrubs which are traditionally used as fuelwood for domestic heating purposes. Nevertheless, their utilization in the form of pellets or briquettes could increase their energy efficiency. Due to differences in chemical structure, bark and wood present different fuel characteristics. In this study the higher heating value, lower heating value and ash content of wood and bark of five Mediterranean evergreen hardwoods (*Quercus coccifera*, *Quercus ilex*, *Arbutus unedo*, *Phillyrea latifolia* and *Erica arborea*) and two deciduous species (*Fagus sylvatica* and *Ostrya carpinifolia*) growing in northern Greece were investigated. For each species the stem diameter, bark thickness and wood : bark ratios were also determined. The results showed that the bark of all tested evergreen hardwood species presented significantly higher ash content than deciduous species did and can be used in pellet production only when carefully mixed with wood in order to keep ash content lower than 3%. *Quercus coccifera* bark showed the highest ash content values. All of the tested evergreen hardwoods showed heating values higher for wood than for bark, except for *Phyllirea latifolia* which showed significantly higher bark than wood heating value. The highest heating value of all investigated wood samples was presented by *Erica arborea*. Correlation of ash against higher and lower heating values for all species was found to be weak.

Keywords: Evergreen hardwoods, bark, wood, fuel, ash, heating value

Introduction

The constant quest for energy resources is one of the main characteristics of modern civilization. Nowadays, under the effects of global climate change, replacing fossil fuels with renewable energy sources is of key importance to meet the growing energy needs. The use of sustainable woody biomass for energy production might be an efficient way to fulfill the above requirements because there are many sources of such materials while at the same time, pelletizing of biomass

increases energy density, improves storability and reduces handling and transport costs (Telmo and Lousada 2011). Various alternative biomasses have been proposed or are already used as solid biofuels including sawdust, wood and other organic waste, agricultural waste, nonfood energy crops and forest biomass. (Haberl and Geissler 2000, Hoogwijk 2003, Perlack et al. 2005, Demirbas 2007, Filbakk et al. 2011.). The use of forest biomass originating from Mediterranean forest vegetation in particular has been acknowledged not only as a potential means to cover energy needs but also to prevent forest fires (Viana et al 2012). In Greece, many evergreen forests are short rotation (25-30 years) coppices and are exploited mainly with clear cuttings for the production of firewood and charcoal. Nevertheless, this widening of raw material base for biofuel utilization along with the opportunities it provides, also increases the need for detailed analysis and better understanding of the various proposed biomasses. This need is particularly important when it comes to forest biomass (logging residues, fire-prevention removals etc) which might contain various types of different plants and plant parts with different chemical composition and therefore differences in their thermal properties and handling efficiency. A representative example of this variability is the presence of bark, which has different chemical composition and generally higher ash content than pure wood does. It should also be noted that during traditional charcoal production bark is passively removed and therefore is wasted. On the other hand, in the case of pellet production bark could also be used.

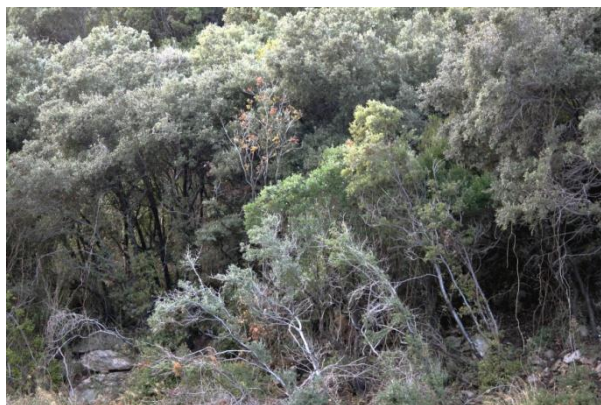


Fig. 1. Evergreen hardwoods forest



Fig. 2. Fuelwood from evergreen hardwoods for traditional production of charcoal

Concerning the effect of bark on the quality of biofuels Filbakk et al (2011) reported that the presence of bark in solid biofuels is related to increased tendency towards sintering during combustion and is therefore related to combustion problems. Concerning ash, Lehtikangas (2001) reported that increasing ash content results to lower heating value of the biofuel, implies the risk of sintering and negatively affects processing equipment. For this reason, in the recent related European norm for the quality characteristics of pellets the threshold ash content value is 3% (EN 14961-2:2011, European Pellet Council, 2013).

Taking into account the above facts, aim of this research was the assessment of calorific value and ash content for bark and wood of some Mediterranean hardwood species.

Materials and Methods

For the purposes of this work, wooden biomass from evergreen hardwood forest species was used namely: *Arbutus unedo*, *Quercus ilex*, *Quercus coccifera*, *Erica arborea* and *Phillyrea latifolia* samples consisting of stems having a mean diameter not larger than 10 cm was collected from the forests of East Chalkidiki, Greece. For comparison reasons material from *Fagus sylvatica* and *Ostrya carpinifolia* stems was also assessed because those species are present in the same forests and are also traditionally used as fuelwood. This bulk sample was reduced by a coning and quartering procedure to a representative sample of about 0.5 kg. The samples were subsequently air-dried and ground using a rotating-blade Wiley mill to pass a 0.7 mm sieve. All materials were gently dried for at least two weeks in a ventilated oven at $60\pm 1^\circ\text{C}$ until steady mass was achieved. The proportion of bark was calculated as the ratio of bark area in a transversal plane to the total stem area for the same plane. 30 measurements were carried out for each species.

For the determination of ash, the methodology described in EN 14775:2004 was used. The samples with mass of at least 1g were weighed to the nearest 0.1mg in pre-weighed porcelain crucibles and transferred in a cold muffle furnace (Heraeus MR 170) with a ventilation rate of about 5 changes per minute. The samples were then heated to 250°C within 50min and the temperature was kept constant for 60min. In the next step, the temperature was increased to 550°C within 60min and maintained in that level for 3h. Consequently the crucibles were transferred to an empty desiccator without lid for 5min followed by 15min with closed lid and then weighed. To ensure complete incineration the samples were reloaded in the hot furnace for 30min intervals and were reweighed until the mass changes were lower than 0.2mg. The ash content on dry basis was calculated using the following formula:

$$Ad = \frac{m_3 - m_1}{m_2 - m_1} \times 100$$

where:

m_1 : The mass (g) of the empty crucible

m_2 : The mass (g) of the crucible plus the dried test sample

m_3 : The mass (g) of the crucible plus ash

The ash measurements were carried out in 3 replicates for each tested material. The calorific value was expressed with Higher Heating Value (HHV) which is the absolute value of the specific energy combustion, in calories for unit mass of a solid biofuel burned in oxygen in a calorimetric bomb under specified conditions. HHV was determined in a Parr 1261 isoperibol bomb calorimeter according to the method described in the European Standard CEN/TS 14918:2005. Sample pellets with mass of $1.0\pm 0.1\text{g}$ and diameter of 13mm were produced using a hydraulic pellet press applying a load of about 7tn for about 1min. The pellets were weighed to the nearest 0,0001g in a stainless steel crucible and then placed in contact with 10cm of pre-weighed platinum ignition wire inside a Paar 1108 oxygen combustion bomb. The bomb was subsequently charged with oxygen (purity of 99.7%) at $30\pm 2\text{bar}$ and submerged in a stainless steel bucket containing 2000.0ml of distilled water. Prior to filling the bucket, the water was conditioned in a waterbath at $33\pm 0.5^\circ\text{C}$. The calorimeter jacket was maintained at constant temperature by circulating water at 35°C to maintain slightly higher temperature than the final temperature of the calorimeter and assure that evaporation losses were minimized. The HHV measurements were carried out in 6 replicates for each material. Prior to starting the above measurements, the calorimeter was calibrated and validated with 6 individual calibration runs

using benzoic acid pellets. HHV values were expressed in cal/g. Sulphur and chlorine adjustments we not carried out because they are present in low concentrations in wood fuels (Lehtikangas 2001).

Results and Discussion

The results of the determinations carried out in this research are presented in Tables 1-2 and Figures 3-5.

Table 1: Stem diameter, bark thickness and bark:wood bulk ratio for the tested species

Species	Stem diameter^a (cm)	Bark thickness^a (mm)	Bark (%)	Wood (%)
Quercus coccifera	6.2 (2.3)	1.7 (0.20)	10.7	89.3
Quercus ilex	7.5 (1.6)	1.5 (0.19)	7.8	92.2
Phillyrea latifolia	6.8 (1.3)	2.0 (0.28)	11.4	88.6
Arbutus unedo	6.4 (2.1)	1.3 (0.15)	7.9	92.1
Erica arborea	4.1 (0.9)	1.7 (0.22)	15.9	84.1
Fagus sylvatica	15.7 (3.2)	3.5 (0.34)	8.7	91.3
Ostrya carpinifolia	8.8 (1.9)	2.4 (0.41)	10.5	89.5

^a : Average of 30 measurements.
(S.D. in parentheses)

Table 2: Mean, standard deviation and coefficient of variation of ash and higher heating values of the samples

		Quercus coccifera		Quercus ilex		Phyllirea latifolia		Arbutus unedo		Erica arborea		Fagus sylvatica		Ostrya carpinifolia	
		wood	bark	wood	bark	wood	bark	wood	bark	wood	bark	wood	bark	wood	bark
Ash (%)	mean	1.62%	12.18%	1.14%	9.15%	0.67%	4.97%	0.83%	7.16%	0.39%	5.24%	0.50%	7.73%	0.44%	6.63%
	SD	0.06%	0.09%	0.03%	0.11%	0.05%	0.12%	0.06%	0.14%	0.04%	0.13%	0.07%	0.53%	0.09%	0.01%
	CV	3.53%	0.78%	2.25%	1.21%	7.96%	2.40%	6.99%	1.89%	9.55%	2.49%	14.43%	6.92%	20.69%	0.22%
	n	3	3	3	3	3	3	3	3	3	3	3	3	3	3
HHV (cal/g)	mean	4454.56	4228.35	4467.70	4121.77	4583.43	4956.91	4575.29	4334.84	4751.48	4764.42	4589.90	4442.59	4589.20	4382.1
	SD	18.31	10.25	10.81	15.22	7.77	30.77	14.53	2.93	14.96	21.64	9.62	1.90	12.30	3.92
	CV	0.41%	0.24%	0.24%	0.37%	0.17%	0.62%	0.32%	0.07%	0.31%	0.45%	0.21%	0.04%	0.27%	0.09%
	n	6	6	6	6	6	6	6	6	6	6	6	6	6	6

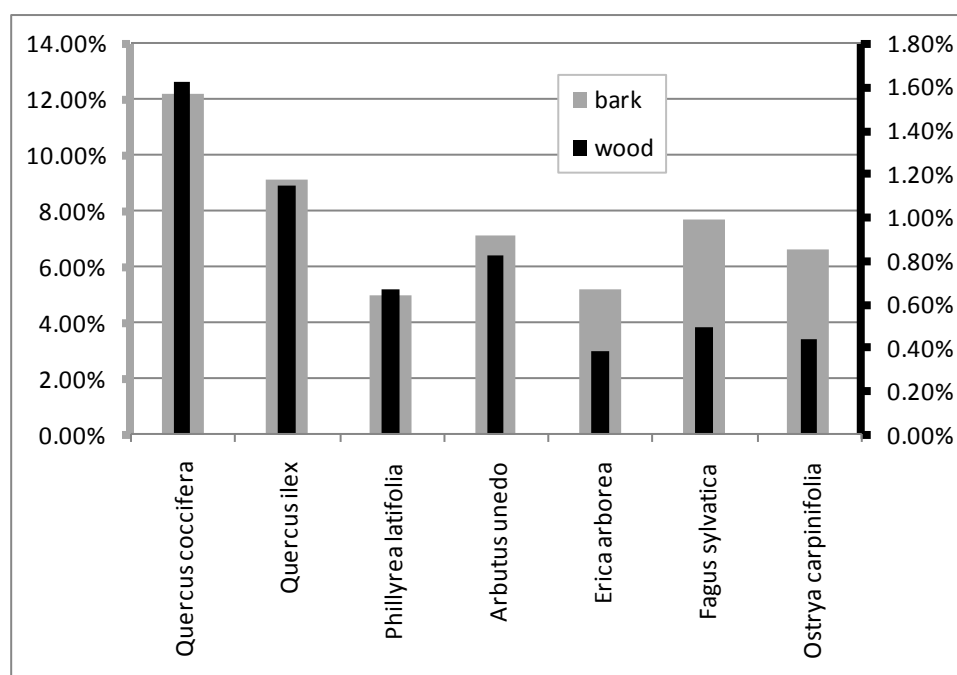


Fig. 3: Ash content of bark (left axis) and wood (right axis) for the tested samples

From Table 1 it can be drawn that the bulk bark content of the tested species varied between 7.8% for Quercus ilex and 15.9% for Erica arborea. As can be observed in Table 2 and Figure 3,

the ash content values among the tested materials varied between 0.39 - 12.18% while the HHV varied between 4121.77 - 4956.91 cal/g. The highest ash content among the tested species was presented both for bark (12.18%) and wood (1.62%) by *Quercus coccifera* while the lowest were presented by *Erica arborea* for wood (0.39%) and by *Phyllirea latifolia* for bark (4.97%). Among all tested species only *Erica arborea* showed lower wood ash content than *Fagus sylvatica* and *Ostrya carpinifolia*. In terms of bark ash content *Erica arborea* and *Phyllirea latifolia* showed lower values than *Fagus sylvatica* and *Ostrya carpinifolia*.

In terms of heating values, all tested materials met the requirements concerning the lower threshold values set by EN 14961-2 (ENplus-A1 class = 3940.96 cal/g, ENplus-A2 class = 3893.19 cal/g, EN-B class = 3821.53 cal/g). The highest HHV among the tested species was presented by *Erica arborea* for wood (4751.48 cal/g) and *Phyllirea latifolia* for bark (4956.91 cal/g). The lowest HHV was presented by *Quercus coccifera* for wood (4454.56 cal/g) and by *Quercus ilex* for bark (4121.77 cal/g). With the exception of *Phyllirea latifolia*, all tested species showed higher HHV for wood than for bark. For *Erica arborea* the HHV differences between bark and wood were not significant ($\alpha=0.05$). *Erica arborea* was the only one species among the ones tested in this work which showed heating value higher than than *Fagus sylvatica* and *Ostrya carpinifolia*. In terms of bark heating value *Erica arborea* and *Phyllirea latifolia* showed higher values than *Fagus sylvatica* and *Ostrya carpinifolia*.

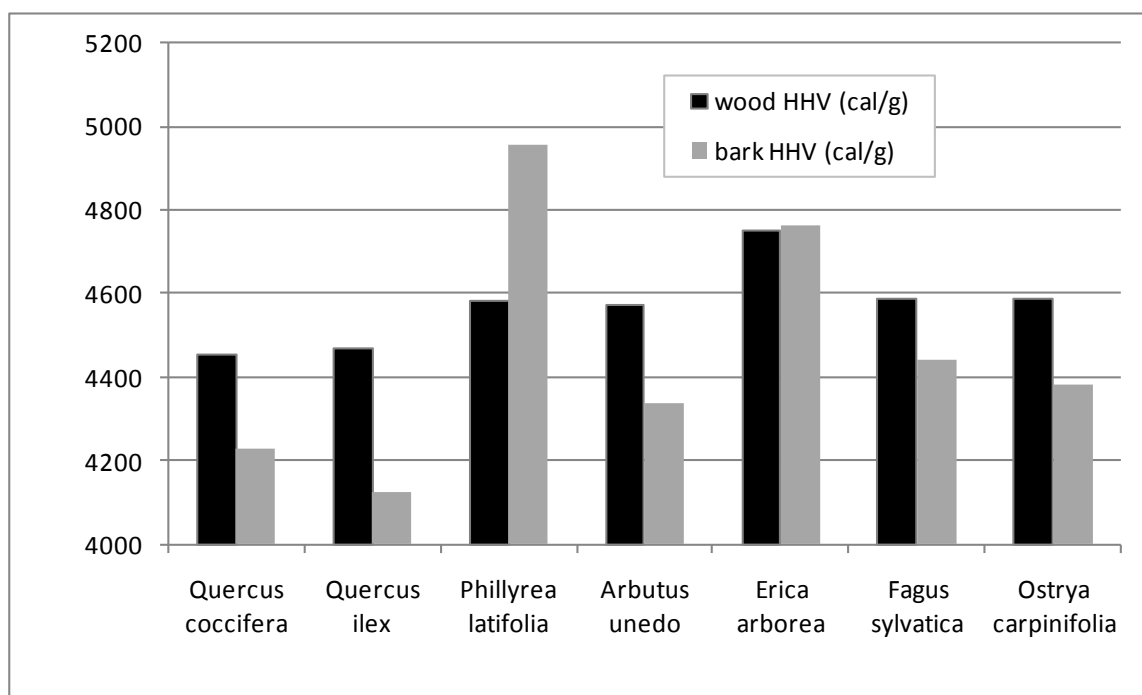


Fig. 4: Higher heating values of bark and wood for the tested samples

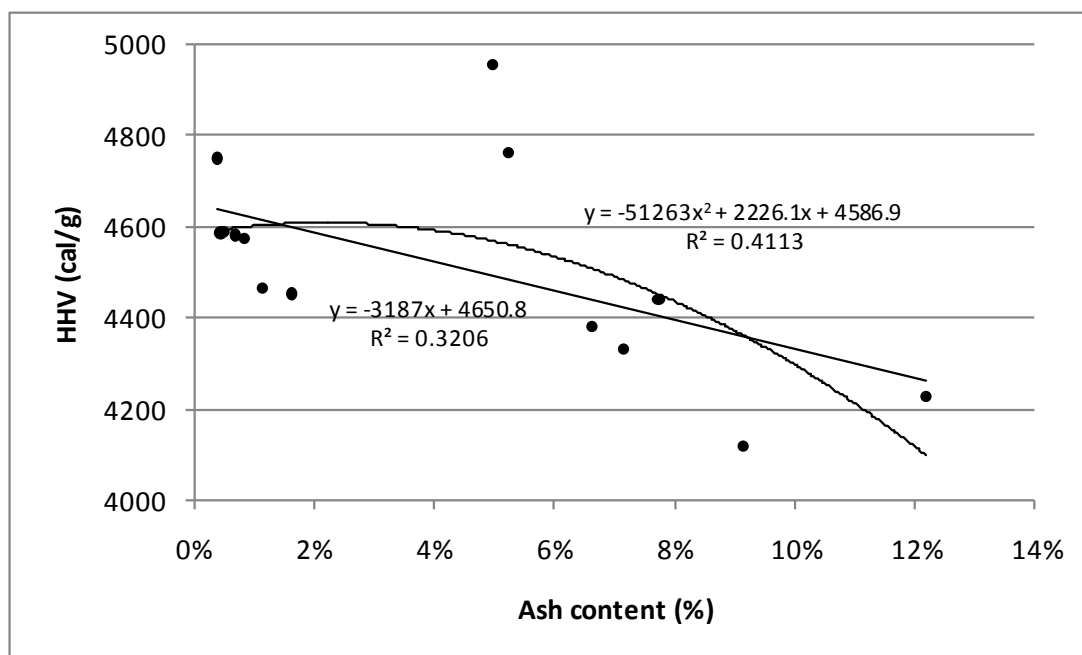


Fig. 5: Scatter graph of ash content against higher heating values and fit lines

Figure 5 represents a scatter graph of HHV against ash content values and 1st and 2nd degree polynomial fit lines. The Pearson correlation coefficient between HHV and ash content values was -0.57 indicating a moderate degree of linear dependence between the two variables for the tested materials. The correlation coefficient for both tested fit lines was low ($R^2 = 0.32$ for linear fit line and $R^2 = 0.41$ for 2nd degree curve) indicating a weak fit of the models to the data and leading to the conclusion that ash content cannot be used as a single means of estimating heating value and that other factors (e.g. other chemical components) should also be considered when constructing related models.

Conclusions

In general it can be concluded that, in terms of ash content and heating value, all wood samples could be used as raw materials for the production of pellets for non-industrial heating purposes since they meet the related threshold values for all three pellet quality classes. On the other hand, even though they all provided adequate heating values, none of the tested bark samples showed ash content values lower than 3% meaning that bark can only be carefully used in adequate mixtures with wood. According to the results *Erica arborea*, despite the lowest stem diameter and largest bark proportion among all tested species, presented the highest heating value for wood and second highest for bark.

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