Thermal characteristics of wood of some common native species

Kamperidou, Vasiliki [1*]; Lykidis, Charalampos [2]; Barmpoutis, Panagiotis[1]
[1] Lab. of Wood Products and Furniture Technology, Faculty of Forestry and N. E., AUTH, Thessaloniki, Greece
[2]ELGO/Demeter, Forest Research Institute of Athens, Greece
[*]Corresponding author: vkamperi@for.auth.gr

ABSTRACT

The investigation of thermal characteristics of several wood species seem to be of great importance for the comprehension of their behavior as bio-fuels and implementation of their proper utilization. Aim of this work is the examination of some basic thermal characteristics, such as heating value and ash content of wood and bark material of some native species, found commonly in Mediterranean area, as well as Europe. The species of kermes oak, an evergreen hardwood shrubs species and beech, the broadleaf species with the largest wood production in Greece are traditionally used in energy production and participated in the specific research work, as well as, black locust wood, which will be in abundance next years due to the foundation of new plantations, in the frame of financial support programme for cultivation by the European Union and the corn seeds, which is one of the main agricultural products in Greece and its presence could improve the consistency of fuel/ pellet. Additionally, the characteristic of bark percentage of each species was determined according to each species diameter, and the ratio of all these species in mixture was also investigated, in order to approach the ratio that meets in the best way the standards requirements in ash percentage and heating value.

Key words: ash content, beech, black locust, corn seeds, heating value, kermes oak

1. INTRODUCTION

It is expected in the near future the population to be doubled every 20 to 30 years, and this increase is intertwined to the increase in energy requirements and the reduction of natural resource reserves and fossil fuels (Hannum, 2009). Nowadays, it is becoming more urgent the need of alternative energy production methods that will not contaminate the environment and the atmosphere and will not contribute to further reduction of natural oil, coal, gas, etc. As part of the commitment of European countries to reduce emissions of air pollutants that contribute to global warming from 2008 to 2012 (Kyoto Protocol - 2007), by approximately 5.4%, it is even more necessary the turn of humanity to the option of renewable energy sources, such as the use of forest biomass.The European Union's objective is to increase the use of biomass for energy production by 98 Mtoethat was about 2007, to 220 Mtoe by 2020 and almost full implementation of bioenergy systems for main heating in homes, 25% for electricity and 10% for cooling, until 2050.Furthermore, strategic objective is a 20% penetration of renewables in meeting energy needs by 2020 and a 10% increase in the use of liquid biofuels in our country. Wood biomass is an extensive source of renewable energy and its use could put a restriction on CO2 emissions and other harmful gases into the atmosphere (Hakkila, 2001).

The biomass (wooden or not), which may be derived from forest biomass, wood-based industries residues, crop residues etc. is one of the ways of ecological energy generation. It has been flagged that large amounts of wood coming from harvesting residues or wood that is considered to be of not acceptable quality for use in construction, woodwork which has ceased to offer their services due to wear, old furniture, undesirable logs of small diameter, etc., are left unexploited (Hakkila, 2001). Furthermore, this offer in wooden biomass is continuous and in sufficient quantities, because of its constant accumulation, which means that it could cover greatly the energy needs of the world.

One of the main benefits of using wood biomass for energy production is the fact that it can contribute significantly to reducing dependence on imported fuels and ensuring energy supply. In addition, new forms of employment and new jobs for rural and forest populations are generated, who will have the opportunity to work in harvesting, collection, storage, transportation of wood biomass (Telmo and Lousada, 2011). Also, the ability to clean the logging areas is given, as well as, protection of forest areas, and better management of forest areas associated to the proper collection and utilization of forest biomass (Barboutis and Lykidis, 2014).By reducing the rural population over the years, there has been a parallel reduction of forest biomass use (for heating, cooking, etc.), which inevitably leads to an accumulation of biomass, both in total amount per unit area, and horizontal and vertical continuity in the forest area, which increases the possibility of fires in forest area. Effective control and prevention of the accumulation of forest biomass could be achieved through its utilization in power generation. Only a few types of biomass such as wood can be used directly to energy combustion, since usually the refinement would be required for their conversion into appropriate fuels. Besides the above, the wooden biomass in contrast to other renewable energy sources (sun, wind), is available 24 hours a day, without being influenced by uncontrollable factors (Hannum, 2009).

Nowadays, the use of wood in energy production can be carried out traditionally in raw form of firewood, but often turns into processed form compact for easier use, packaging, storage and transportation, such as wood particles (crushed wood, sawdust), chips, pellets or briquettes. A managed forest land for energy production from wood biomass, is connected in the knowledge of the value it contains. Furthermore, the rational use of biomass for energy production requires precise knowledge of the physical, chemical, energy and other properties of various kinds and forms of biomass. The calorific value varies between forest species and between parts of the same species, and depends on many factors (Ince, 1979). Therefore, the investigation of thermal characteristics of several wood species seem to be of great importance for the comprehension of their behavior as bio-fuels and implementation of their proper utilization.

Aim of this work is the examination of some basic thermal characteristics, such as heating value and ash content of wood and bark material of some native species, found commonly in Mediterranean area, as well as Europe. The species of kermes oak, an evergreen hardwood shrubs species and beech, the broadleaf species with the largest wood production in Greece are traditionally used in energy production and participated in the specific research work, as well as, black locust wood, which will be in abundance next years due to the foundation of new plantations, in the frame of financial support programme for cultivation by the European Union and the corn seeds, which is one of the main agricultural products in Greece and its presence could improve the consistency of fuel/ pellet. Additionally, the characteristic of bark percentage for each species, and the ratio of all these species in mixture was also investigated, in order to approach the ratio that meets in the best way the standards requirements in ash percentage and heating value

2. MATERIALS AND METHODS

This experiment was carried out using stems from some native species, found commonly in Mediterranean area, as well as Europe: wood of kermes oak (*Quercus coccifera* L.), beech (*Fagus sylvatica* L.) and black locust(*Robinia pseudoacacia* L.), as well as the material of corn seeds (*Zea mays*). For each species, 15 stems were collected from a firewood yardof East Chalkidiki forests (in Greece), the ones with the largest diameter among the stems of the yard. For each stem the barked diameter and bark thickness was measured at both ends of the stems. The proportion of bark was calculated as the ratio of bark area in a transverse section to the total stem area of this section according to equation (1):

$$Z = 100\frac{f(2R - f)}{R^2} \qquad (1)$$

Z – bark percentage (%)
f – bark thickness in cm
R – barked stem radius in cm

For the determination of bark percentage it was considered that the transverse surfaces were circular. 30 measurements were carried out for each species. Consequently, bark and wood were separated and the materials were ground by means of a portable chipper.

The bulk samples were reduced by coning and quartering to a representative sample of about 0.5 kg. The samples were subsequently air-dried and ground using a rotating-blade Wiley mill with a 0.7 mm sieve. All materials were gently dried for at least two weeks in a ventilated oven at 60 ± 1 °C until steady mass was achieved.

For the determination of ash, the methodology described in EN 14775:2010 was used. The samples with mass of at least 1g were weighed to the nearest 0.1mg in the 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 50 min and the temperature was kept constant for 60 min. In the next step, the temperature was increased to 550 °C within 60 min and was maintained at that level for 3 h. Consequently, the crucibles were transferred to an empty desiccator without lid for 5 min followed by 15 min with closed lid and then weighed. To ensure complete incineration the samples were reloaded in the hot furnace for 30 min intervals and were reweighed according to the above procedure until the mass changes were lower than 0.2 mg. The ash content on dry basis was calculated according to equation (2):

$$Ad = \frac{m_3 - m_1}{m_2 - m_1} * 100 \qquad (2)$$

Ad – ash content (%)
m1 – mass of the empty crucible in g
m2 – mass of the crucible plus the dried test sample in g
m3 – mass of the crucible plus ash in g

The ash measurements were carried out in 3 replicates for each material. Moisture content was determined according to EN 14774-3:2009. The calorific value was expressed with Higher Heating Value (HHV) which is the absolute value of the specific energy combustion, in calories per 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 EN 14918:2009. Sample pellets with mass of 1.0 ± 0.1 g and diameter of 13 mm were produced using a hydraulic pellet press applying a load of about 7t for 1min. The pellets were weighed to the nearest 0.0001 g in a crucible and then placed inside a Paar 1108 oxygen combustion bomb in contact with 10 cm of pre-weighed platinum ignition wire. The bomb was subsequently charged with oxygen (purity of 99.7 %) at 30 ± 2 bar and submerged in a stainless steel bucket containing 2000.0 ml of distilled water. Prior to filling the bucket, the water was conditioned in a waterbath at 33 ± 0.5 °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 beginning 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 were not carried out because they are present in low concentrations in wood fuels (Lehtikangas, 2001).

Afterwards, a theoretical estimation of the fuel characteristics of pellets produced from the selected species was implemented. This was based on the bark and wood ash content as well as the calorific values that had been determined, taking into account the various barked stem diameters of the raw materials. Hence, the following equations (3, 4) were used:

$$ASH = a_1 \frac{z}{100} + a_2 \frac{100 - z}{100} \quad (3)$$

ASH – total ash content (%)
Z – bark percentage (%)
a1 – ash content of bark (%)
a2 – ash content of wood (%)

$$HHV = b_1 \frac{z}{100} + b_2 \frac{100 - z}{100} \quad (4)$$

HHV – total HHV in cal/g
b1 – HHV of bark in cal/g
b2– HHV of wood in cal/g

Mean values were compared with ANOVA ($\alpha = 0.95$, LSD) using SPSS, the graphs were created in MATLAB program

3. RESULTS AND DISCUSSION

The mean barked stem diameter of the species that participated in this research varied between 6.2 and 15.7 cm, while the mean bark thicknesses from 1.7 to 6.4 mm (*Table 1*) and the differences between the mean values werefound to be statistically significant. In most of the cases, low standard deviations of bark thicknesses were recorded, which indicates that they do not vary significantly within the measured diameter of the selected species.

Table 1. Stem diameter, bark thickness and bark : wood 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
Fagus sylvatica	15.7 (3.2)	3.5 (0.34)	8.7	91.3
Robinia pseudoacacia	11.5 (1.9)	6.4 (0.83)	21	79

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

According to *Figure 1*, referring to the three species (*Quercus coccifera, Fagus sylvatica and Robinia pseudoacacia*), as the barked stem radius increases, and consequently there is a lower ratio of bark:wood in the material, the percentage value of ash content decreases. This decrease is more intensive in the lower values of stem radius. Generally, the ash content is a very significant fuel characteristic and there is the need to maintain the ash content of the material in low levels, since it affects the behavior and properties of the biofuel, according to the requirements of ISO 17225-2 for residential applications.

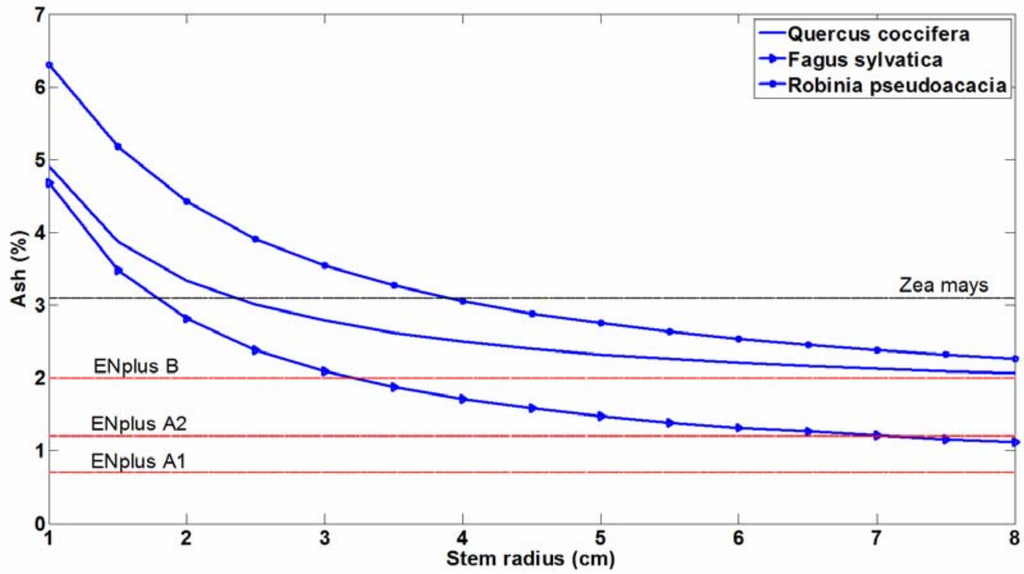

Figure 1. Configuration of ash percentage values related to the stem radius of the tested species

According to *Table 2*, all the examined species presented lower ash content percentage value in wood, than the respective value of bark material. Among all the species tested, the highest ash content value of bark (12.18 %) and wood (1.62 %) were recorded by the species of kermes oak, while the lowest values were demonstrated by beech referring to its wood (0.50%) and the highest value was recorded by oak species,referring to bark material (12.18%). Ash content values of wood ranged between 0.50 and 1.62 %, while the content of bark fluctuated in the range of 7.03 to 12.18 %. It should be noted, that for all the tested species the ash content of bark was higher than the requirement of ≤2% (referred for pellets of the category EN plus-B) of ISO 17225-2:2014. Therefore, the tested species can be used for the production of pellets, provided that their barked stem diameter is in a range which corresponds to total ash content values (wood and bark) lower than the above limit. Pellets produced with the material of beech wood stems could fulfill the requirements of the ENplus-A2 class of the respective standard.More specifically, beech wood stems of diameter larger than 6.38 cm could fulfill the requirements of the ENplus-B class, while diameter larger than 14.10 cm of the same species could meet the requirements of ENplus-A2 class (*Table 3*). Generally, the material that originated from all the species used in this research, referring to the specific stem diameters, was proved unable to fulfill the requirements of the bestcategory EN plus-A1 of the pellets production standardISO 17225-2:2014.

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

		Quercus coccifera		***Fagus sylvatica***		***Robinia pseudoacacia***		***Zea mays***
		wood	**bark**	**wood**	**bark**	**wood**	**bark**	**Corn seeds**
Ash (%)	**mean**	**1.62%**	**12.18%**	**0.50%**	**7.73%**	**1.40%**	**7.03%**	**3.10%**
	SD	**0.06%**	**0.09%**	**0.07%**	**0.53%**	**0.04%**	**0.78%**	**0.41%**
	CV	**3.53%**	**0.78%**	**14.43%**	**6.92%**	**2.89%**	**1.69%**	**13.23%**
	n	**3**	**3**	**3**	**3**	**3**	**3**	**3**
HHV (cal/g)	**mean**	**4454.56**	**4228.35**	**4589.90**	**4442.59**	**4226.24**	**4695.93**	**3869.30**
	SD	**18.31**	**10.25**	**9.62**	**1.90**	**12.20**	**13.11**	**12.2**
	CV	**0.41%**	**0.24%**	**0.21%**	**0.04%**	**0.29%**	**0.28%**	**0.32%**
	n	**6**	**6**	**6**	**6**	**3**	**3**	**3**
MC (%)	**mean**	**7.1**	**9.9**	**7.9**	**9.5**	**8.1**	**10.1**	**8.6**
	n	**3**	**3**	**3**	**3**	**3**	**3**	**3**

HHV of the tested species varied between 3869.30 cal/g, recorded by the corn seeds material and 4695.93cal/g, recorded by the bark of black locust species (*Table 2*). This highest HHV value was 11.11 % higher than its respective value of wood. With the exception of black locust, the tested species demonstrated higher HHV in wood, compared to bark. It is also worth mentioning that black locust species presentedthe highest HHV for bark (4695.93 cal/g), while the highest value for wood among all tested species was presented by beech species (4589.90cal/g).

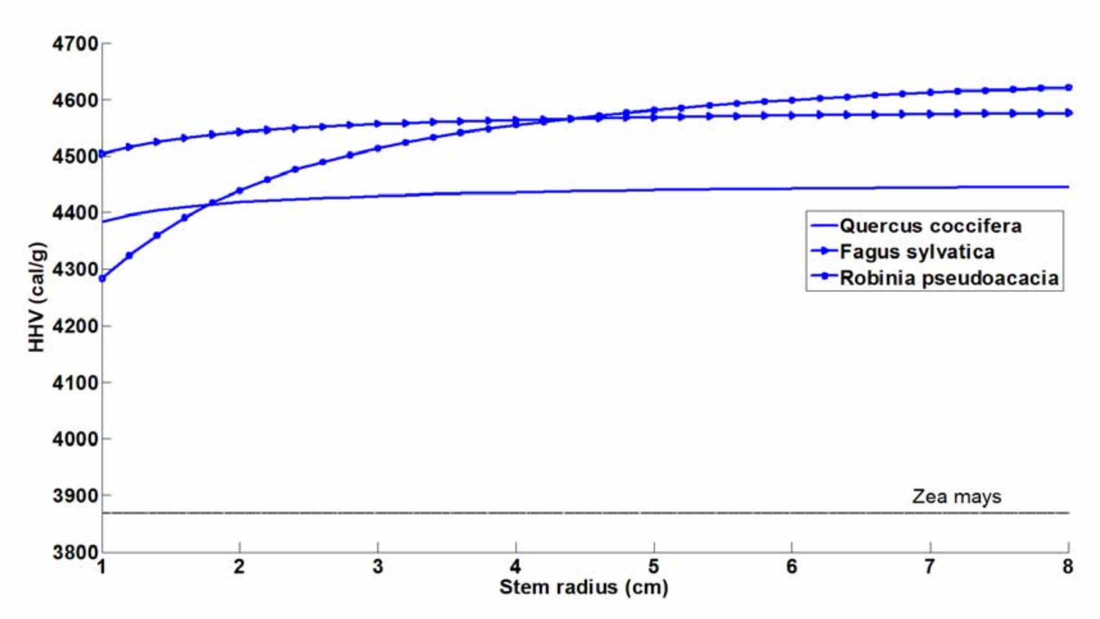

Figure 2. 2Configuration of the HHV values (cal/g) of the tested species related to the stem radius of the species

According to *Figure 2*, as the stem radius increases, all the examined species tend to show higher HHV (cal/g) values. This increase seem to be more intensive for black locust wood and less intensive for beech and kermes oak wood.

Table 3. Minimum barked diameter that meet the requirements of ISO 17225-2 for ash content of pellets production and the respective HHV result

Species	Diameter (cm)	Ash (%)	ENclass	HHV (cal/g)
Q. coccifera	**18.72**	**2**	**ENplus B**	**4446.8**
	5.02	**3**	**I3**	**4425.3**
F. sylvatica	**14.10**	**1.2**	**ENplus A2**	**4574.8**
	6.38	**2**	**ENplus B**	**4558.5**
	3.66	**3**	**I3**	**4538.2**
R. pseudoacacia	**23.36**	**2**	**ENplus B**	**4645.0**
	8.31	**3**	**I3**	**4531.7**

As it is evident in *Table 3*, the best material for pellets production for domestic use, among the species of this research, that meets the requirements of the respective standard in ash content, is the species of beech with minimum diameter of 6.38 cm, for EN plus-B class pellets, whereas the stems of the other two species (oak and black locust) in order to reach the same level of ash content should be of more than triple diameter than beech, which is impossible in practice to find such stem diameters. Based on the standard requirements, these species with smaller diameters could be used in pellets production only for industrial use (I3 class).

Table 4. Estimation of ash content and calorific value in different mixing proportions of the investigated species according to the average diameter of the samples

Species	**Participation percentage in the mixture**											
Q. coccifera	**100**	**0**	**0**	**33.33**	**31.66**	**30**	**28.33**	**26.66**	**25**	**50**	**20**	**20**
F. sylvatica	**0**	**100**	**0**	**33.33**	**31.66**	**30**	**28.33**	**26.66**	**25**	**20**	**50**	**20**
R.pseudoacacia	**0**	**0**	**100**	**33.33**	**31.66**	**30**	**28.33**	**26.66**	**25**	**20**	**20**	**50**
Zea mays	**0**	**0**	**0**	**0**	**5**	**10**	**15**	**20**	**25**	**10**	**10**	**10**
Ash (%)	**2.75**	**1.12**	**2.58**	**2.15**	**2.20**	**2.25**	**2.29**	**2.34**	**2.39**	**2.43**	**1.94**	**2.38**
HHV (cal/g)	**4430**	**4577**	**4325**	**4443**	**4437**	**4386**	**4357**	**4328**	**4300**	**4382**	**4426**	**4351**

According to *Table 4*, where the ash content and the calorific value of different mixing proportions of the tested species are estimated, taking into account the respective mean diameters, the lowest ash content (1.12%) would be recorded by the material coming only from beech species (100%), while the highest one (2.75%) from kermes oak species (100%). By mixing equally (33.33%) the three wood species of the present research, seem to decrease the ash content, recording 2.15%. As the participation percentage of corn seeds increases from 0 to 25%, maintaining each time an equal participation between the other three species, the ash content increases as well, from 2.15 to 2.39%. Respectively, referring to HHV values, the highest value (4577 cal/g) would be recorded by the material coming only from beech wood (100%), while the lowest value (4325 cal/g) would be marked by black locust (100%). The equal mixture (33.33%) of the three wood species of the present research, seem to increase HHV value, recording 4443 cal/g., while as the participation percentage of corn seeds increases from 0 to 25%, the HHV value decreases gradually from 4443 to 4300 cal/g. The different mixing proportions of the tested species that were estimated and presented in *Table 4*, did not achieve to fulfil the requirements in ash content of EN plus-A1 and EN plus A2 classes of the pellets production standard, while only two of them succeed to meet EN plus B class (using 100% or 50% the species of beech). Moreover, all the examined mixing proportions fulfilled the requirements in ash content of the class I3 which corresponds to industrial use of pellets. Therefore, as it is proved, the species of beech should be preferred to be used in pellets production, since it provides higher HHV values and parallel lower ash contents, than the species of black locust and kermes oak that resulted in lower HHV values and higher ash content percentage values. It is very significant though, that these species could be used in different ratios in combination with the material coming from corn seeds, which is in abundance especially in Mediterranean area and the whole Europe, providing satisfying results of HHV and ash content. Parallel, the participation of corn seeds in fuel material, contributes in the reduction of the material costs and probably enhances the cohesion of pellets as it may act like a binder (Kaliyan and Vance Morey, 2009).

4. CONCLUSIONS

The latest standards concerning biofuels require the ash content of the material to be even lower (≤ 2% for non-industrial use), compared to the previous ones. The ash content is one of the most significant fuel characteristics, since it affects the behavior and properties of the biofuel and is significantly influenced by the bark percentage of the fuel material.

Based on the results, all the examined species presented lower ash content in wood, than in bark material and the ash content of bark was found to be higher than the requirement of ≤2% of EN plus-B class of ISO 17225-2:2014. All the tested species could be used in pellets production, provided that their barked stem diameter is in a range which corresponds to total ash content values (wood and bark) lower than the limit. Pellets produced using the material of beech wood stems could fulfill the requirements of the EN plus-A2 and EN plus-B class of the respective standard and specifically, beech stems of diameter larger than 6.38 cm could fulfill the requirements of the EN plus-B class, while diameter larger than 14.10 cm of the same species could meet the requirements of EN plus-A2 class. Therefore, all these species can be used referring to certain stem diameters in the production of pellets of EN plus-B class or the class I3 for industrial use, but only beech wood can be used for the production of pellets of EN plus-A2 or B class, whereas none of the material categories that came from this research (taking into account the specific mean stem diameters used) succeed to meet the requirements of the best category En plus-A1 of the standard.

Except for black locust, the tested species demonstrated higher HHV in wood, compared to bark. Black locust species presented the highest HHV for bark, while the highest value for wood among all tested species was presented by beech species.

The species of beech should be preferred for pellets production, since it provides higher HHV values and parallel lower ash contents, than the species of black locust and kermes oak that resulted in lower HHV values and higher ash content values. It is very significant though, that these species could be used in the ratio 20% Oak: 50% beech and 20% black locust in combination with 10% of the material coming from corn seeds, which is in abundance especially in Mediterranean area and the whole Europe, providing satisfying results of HHV and ash content and decreasing at the same time the fuel material costs.

REFERENCES

Barboutis, I. ; Lykidis, C. (2014): *The Effects of Bark on Fuel Characteristics of Some Mediterranean Forest Species*. In: Proceedings of the 57th SWST International Convention in conjunction with the 7th Wood Structure and Properties and the 6th European Hardwood Conference: "Sustainable Resources and Technology for Forest Products". Zvolen, Slovakia. June 23-27, 2014. 533-540

Hannum, L.C. (2009): *Developing machinery to harvest small diameter woody biomass – transforming a fire hazard into an energy crisis solution*. [M.Sc. Thesis] North Carolina State University, Raleigh, NC, USA p. 101

EN 14775 (2010): Solid biofuels - Determination of ash content

Hakkila , P. 2001 . *Wood energy in the Nordic countries*. In : P. Pelkonen , P. Hakkila , T. Karjalainen & B. Schlamadinger , Woody biomass as an energy source: Challenges in Europe, European Forest Institute , Joensuu, , Finland , 25 – 28 September 2000. EFI Proceedings No. 39, 2001. 7 – 19

Ince, J.P. (1979). *How to Estimate Recoverable Heat Energy in Wood or Bark Fuels*. Forest Products Laboratory, General Technical Report FPL 29.

ISO 17225-2 (2014). Solid biofuels -- Fuel specifications and classes -- Part 2: Graded wood pellets.

Kaliyan, N.; Morey, R.V. (2009). *Factors affecting strength and durability of densified biomass products*. Biomass and Bioenergy 33 (3): pp. 337-359.

Lehtikangas P., 2001. *Quality properties of pelletised sawdust, logging residues and bark*. Biomass and Bioenergy 20: pp. 351–360.

Telmo, C.; Lousada, J. (2011). *The Explained Variation by Lignin and Extractive Contents on Higher Heating Value of Wood*. Biomass Bioenergy 35: pp. 1663-1667.