Proximate, Ultimate and Calorific Analysis of European Beech Tree (*Fagus sylvatica*) Components for Fuel

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Aims: The three different above ground biomass components (branch, crown, bark) of European Beech (*Fagus sylvatica*) were evaluated, regarding energy and combustion properties.
Study Design: The proximate, ultimate and calorific analysis conducted on components of European Beech tree from three different age stands (10-, 20-, 30 years old). For each group of sample, separate experiments were carried out under similar conditions and experimental findings presented comparatively. The results obtained may be suggested for the selection of the best parts and age group for the improvement of fuel properties of selected tree and could provide useful evaluation of the test methods employed.
Methodology: The three different above ground biomass components (branch, crown, bark) of European Beech (*Fagus sylvatica*) were selected for the investigation. For comparatively determining the combustion behavior and energy properties of the of European Beech tree components, the chips were prepared. These chips were dried (air dried, 12%) in laboratory conditions at 20 °C and 50% relative humidity before being subjected to evaluations. Typically, the combustion is preceded by evaporation of the moisture, distillation and burning of the volatiles before the fixed carbon burns. However, fixed carbon is the solid combustible residue that remains after a wood or bark are heated and the volatile matter is expelled. It is determined by

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subtracting the percentages of moisture, volatile matter, and ash from the sample. The combustion properties of a given substrate can be found by ultimate and proximate analysis. For determining volatile and ash contents, a TGA instrument (Leco TGA701 Thermogravimetric Analyzer) was utulized according to the ASTM D 5142 protocol. The moisture content determined at 105 °C, ash at 750 °C, volatiles at 950 °C in this experimental process. The heat values were determined by a calorimetry bomb instrument (Leco AC–500). At the end of the process, the energy levels of samples were found in calorific value (Kcal/Kg). The sulfur and carbon content were determined by using a carbon/sulfur analyzer instrument (Leco SC-144) and was determined at 1350 °C at 3.0 min durations.

Experimental Findings: It has found that selected variables (European Beech components and age groups) have influenced combustion and calorific properties in some level. However, bark was found to be show the lowest fixed carbon ratio of 13.7% in 10 years old samples. The highest volatile matter content of 84.6% was obtained with a 30 years old branch wood sample. Moreover, the highest level of ash content (3.7-9.9%) was found to be with bark samples in all three age groups, regardless of conditions. The measured calorific values looks like very similar in crown wood (4207.8 kcal/kg to 4263.8 kcal/kg) and branch wood samples (4137.8 kcal/kg to 4563.5 kcal/kg) while considerably lower for bark (3776.6 kcal/kg to 4200.7 kcal/kg). It is also important to note that European Beech tree have only showed trace amount of sulfur element (0.03-0.13%) in regardless of maturity and parts of tree.

1. INTRODUCTION

Wood is one of the oldest material since human beings. In early times, it was directly burned to produce heat energy. But in these days, many new technological utilization methods has already been developed from wood substrate [1-4]. However, heavy utilization of forests for supplying wood materials for forest product industry has become an emerging issue on protection of natural environment [5,6,7]. Moreover, the interest in wood obtained from forests will be predicted to continue to increase in the future [5]. On the other hand, huge amount of woody residues generated in forests as a result of maintenance or harvesting activities. These are usually less than 5.0 cm diameter wood proportions from branches, trunks and crowns, or wastes from barks, needles, cones that are not considered to be has an economical value rather than direct burning and/or leftover on forests [5,8,9,10,]. Although some economical situations have been restricted to collect and transport these secondary low value biomass sources, but these residues could be potential source for spontaneous combustion, ignition, methane gas release while staying in forest lands [1,5,11].

Typically, trees are composed of dry matter and water. It is well established that the chemical portion of the tree are carbon (45-50%), oxygen (40-45%), hydrogen (5.0-6.0 %) and the rest of are some inorganic substances (nitrogen, sulfur and ash) [12,13]. However, all components of a tree (branches, trunks, crowns, barks) have usually more less similar chemical constituents and morphological structures. In this context, it has already become to consider all tree parts for production of energy called as bioenergy [5,8-11,13]. There are numerous studies has already conducted that the lignocellulosic sources (bark, branch, root, dust, chips) could be used with or without normal wood (trunk wood) to produce energy in the similar workflow process [5-9,11-17]. Although lignocellulosic could be used by burning directly to transform it into fuels, this type is low level benefits from these sources. Thanks to technological developments, many new techniques has already been developed for energy production from biomass [1-5]. Thereby a number of reports have already proposed that wood or other secondary forest sources (tree components) can be used in heating boilers, power plants and gasification boilers in successfully [4-5,11-17].

However, fossil fuels are the main energy source at present days in worldwide. But it must need to reduce those sources in order to meet emissions standards in terms of toxic gas emissions. Hence, many studies have include conducted for investigating new environmentally friendly technologies with sustainable sources for energy productions. In one suggestion, forest biomass, forest and woodworking residues and agricultural wastes may be a potentially important sources of renewable energy [1,4,11-14]. Since the

chemical properties of lignocellulosic more less similar to each other, it could be possible to obtain energy from these sources with economic ways. It has already suggested that selection of species and fractions can help to improve fuel quality and the efficiency of the combustion processes, and to minimize atmospheric emission [6].

In this study, the energy potentials of European Beech tree's components have been investigated. In this sense, it is aimed to investigate in detail the combustion behaviors of selected European Beech's tree parts of thin branch- and crown woods and barks in terms of energy properties. Because after primary wood production of logs, mine poles, industrial woods, fiber-chip woods in forests, some tree parts have not been considered to be economical value especially diameters lower than 5.0 cm parts. In this context, the proximate, ultimate and calorific analyses of European Beech tree's components were conducted and results presented comparatively.

2. MATERIALS AND METHODS

The three different above ground biomass components (branch, crown, bark) of European Beech (*Fagus sylvatica*) were selected for the investigation. These sources were collected from three different age stands of 10-, 20- and 30 years old (± 5 years) from the forests that are managed by Bursa Forest Regional Directorate, in Turkey.

The samples of wood and bark particles were prepared using two-stage crushing. In the first step, raw materials was crushed (primary crushing) to a size of 0.2–1.0 cm. These samples were dried in an oven at 105 °C in 3 hours for determining moisture contents. For further experimental measurements (volatile-, carbon-, ash- and sulfur content), further crushed (secondary crushing) into dusts particles in order to conduct suitable size for proximate analysis of a lignocellulosic material. The proximate analysis provides the amount of the material that burns in a gaseous state (volatile matter), in the solid state (fixed carbon), and the percentage of inorganic waste material (ash).

However, the elemental analysis provides to determine ultimate carbon (%), sulfur (%) content from on a moisture, volatile and ash free basis. For volatile and ash content measurements,1.0 gr samples placed in a TGA instrument (Leco TGA701 Thermogravimetric An alyzer) and the ASTM D 5142 protocol conducted for determining moisture content at 105 °C, ash at 750 °C, volatiles at 950 ºC. The heat values are measured with 1.0 gr dust samples were placed in calorimetry bomb instrument (Leco AC–500), then 400 bar oxygen injected inside for 10 minutes of durations. At the end of the process, the energy levels of samples were determined in calorific value (Kcal/kg). The sulfur and carbon contents were determined with 0.25 gr sample placed in an carbon/sulfur analyzer (Leco SC-144) and was determined at 1350 °C at 3.0 min durations.

3. RESULTS AND DISCUSSIONS

Forest biomass that have been used for energy production, have potential for carbon sequestration even taking into account the fossil fuels used for energy productions. Comprehensive characterization of the above ground biomass in relation to its physicochemical properties is an important issue for assessment of fuel properties in a given substrate. To carry out proximate analysis of European Beech from three different age stands (10-, 20-, 30 years old) within three different parts (crown, branch, bark), separate experiments were carried out under similar conditions. The experimental findings are comparatively presented in Table 1.

It is clearly confirmed that each fraction of European Beech tree has shown various level of differences during combustion. When Table 1 carefully analyzed, bark samples have showed some variables that the highest amount of fixed carbon was obtained at 20- (17.3%) and 30 years old samples (18.6%) while the lowest ratio of 13.7% found at 10 years old bark sample. This could be expected considering bark's chemical properties to be much more complex than woods. These could be further influenced by age and less homogeneity of barks during combustion.

Volatile matter is an important parameter measured in biomass combustion. It is measured as the weight percent of gas (emissions) from a biomass sample that is released during an oxygen-free environment, except for moisture, at a standardized temperature. However, forest biomass has considerably different level of volatile matters, directly influence the energy properties of given substrates [1,3,13]. It is interesting that the

lowest volatile matters were observed for barks in all three age groups. It was found to be 79.6%, 73.6% and 78.60% at 10-, 20- and 30 years old samples, respectively. Moreover, the highest volatile matter of 84.6% was found to be at 30 years old branch sample.

The extractives are volatile components that influenced ultimate carbon (U%) content of biomass. When ultimate carbon contents from volatile free samples are evaluated, the bark samples have shown great differences. However, it was found to be the lowest carbon in both 10- (35.07%) and 20- (35.67%) years age groups while the highest carbon content of 37.79% has also obtained with bark in 30 years old sample. This is another evidence that bark of the European Beech tree has shown some level heterogen combustion behavior in terms of different age groups. It has also reported numerous researchers that tree barks have usually a higher percentage of carbon and hydrogen than wood, resulting less homogenous combustion properties [6,10-11].

Changes in ash content (%) with maturity (age group) for three different components of European Beech tree are shown in Fig. 1. It is clearly shown that all bark samples have shown considerably higher amount of ash (%) regardless of maturity while woods from branch and crown show more less similar amount but decreasing tendency as maturity increases. The highest ash content of 9.9% was obtained with 20 years old bark while the lowest ash content of 1.4% was obtained with 30 years old branch wood. This results totally expected considering bark of trees has generally showed the

highest amount of inorganic substances and elemental fractions [13,16-18]. Numerous studies have shown that the barks have usually higher inorganic substances, influenced higher ash content than other parts of the tree. It has alreday reported the ash content of wood is about 0.6 to 2.0% and %3.0 or higher for barks [2,4,6,13]. In a similar research but for Eucalyptus tree, the ash content of wood fraction of Eucalyptus hybrids were reported to be between 0.4 and 1.1% and 0.8% for the same fraction in Eucalyptus nitens [18-19]. Although the results were found for bark is considerably higher than other components of European beech tree, the systematic trend and results are partially consistent literature information.

Fig. 2 shows the energy value (calorie, kcal/kg) of samples. It can be seen that the measured calorific values looks like very similar in crown- (4207.8 kcal/kg to 4263.8 kcal/kg) and branch woods (4137.8 kcal/kg to 4563.5 kcal/kg) at all three age groups. As expected, considerably lower calorific values were calculated for barks (3776.6 kcal/kg to 4200.7 kcal/kg). However, the highest calorific value of 4563.5 Kcal/kg was found in branch wood from 30 years old tree. It could be concluded that selection of tree components or fractions could help to improve fuel quality and the efficiency of the combustion processes. Moreover, since forest biomass are a natural organic matter, many variables including type of substrate, grown properties, maturity, atmospheric situations could be influenced in ultimate energy levels. Thereby there is not any simple procedure to predict energy properties of forest biomass in a simple way like coal or petroleum sources.

Table 1. The combustion properties of European beech tree's components

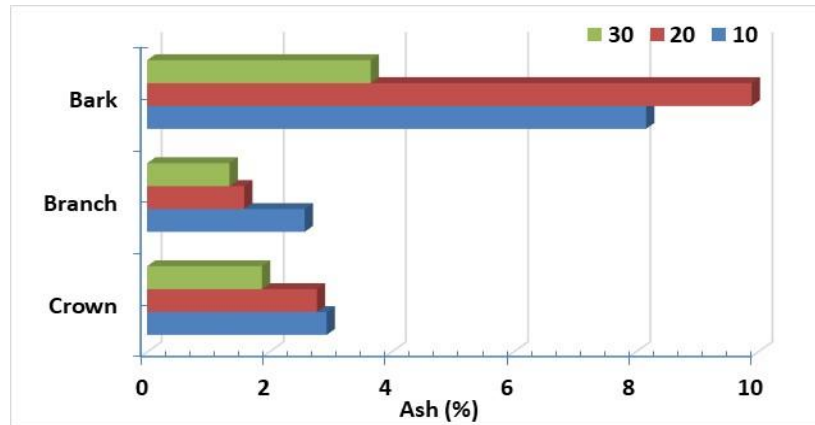| Samples	Fixed carbon (%)	Volatiles (%)	Carbon (%) (Ultimate)
10 years old components			
Crown	15.5	82.9	37.4
Branch	15.6	83.1	37.5
Bark	13.7	79.6	35.1
20 years old components			
Crown	17.4	80.9	35.9
Branch	16.5	82.9	36.7
Bark	17.4	73.6	35.7
30 years old components			
Crown	16.6	82.8	36.7
Branch	15.3	84.6	36.4
Bark	18.6	78.6	37.8

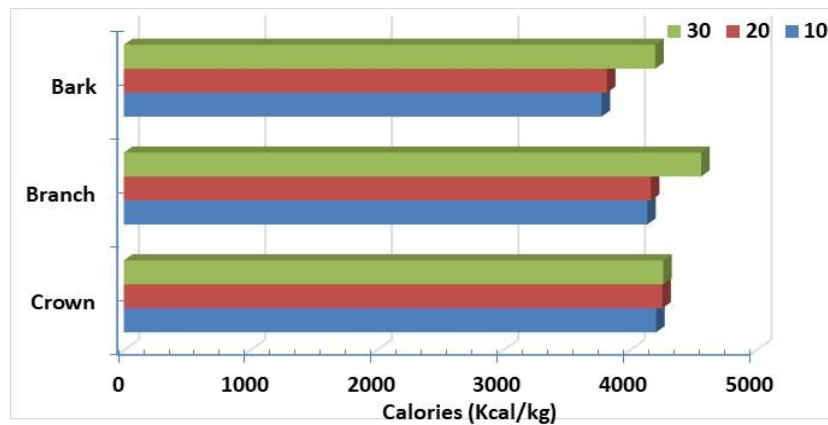**Fig. 1. The ash content (%) of European Beech tree components**

Fig. 2. The fuel properties (calorie, kcal/kg) of European Beech tree components

Fig. 3 shows the comparative ash (%) and sulfur content (%) of European Beech tree fractions. It is clear that both ash and sulfur has a close relationship to each other while the bark samples show the highest amount of ash (3.7% to 9.9%). However, it has already well established by many researchers that forest biomass has generally contain very low amount of sulfur element in their structure [16-19]. This is also confirmed in this study that European Beech tree components have shown only trace or negligible amount of sulfur element (0.03-0.13%) in regardless of maturity and parts of European Beech tree. This certain characteristic of the biomass has an additional important advantage over fossil energy sources.

The combustion behaviors of a biomass are a balance between chemical content and physical structure. Thereby many of the variables influence the energy properties and must be taken into account during evaluation of

the findings. The energy values (Kcal/kg) of experimental samples from three different age groups with combustion variables (fixed carbon, %; volatile matter, %; ultimate carbon content, %) are comparatively plotted in Fig. 4. It appears that relatively a linear relationship for both age and tree fractions for European Beech. However, the lowest energy values (Kcal/kg) and volatile matters (%) are usually determined with bark samples in all age groups. It was proposed that the high ash content in crown and bark fractions of Eucalyptus nitens could be the reason for lower calorific values in comparison with the wood fraction [17]. But, only marginal differences of ultimate carbon content (35.9-37.8%) were observed for all conditions regardless of fractions and ages. Moreover, more less similar tendency was also observed for fixed carbon contents. It is important to note that no any clear correlation was observed between energy values and studied variables for Eurapean Beech wood in this study.
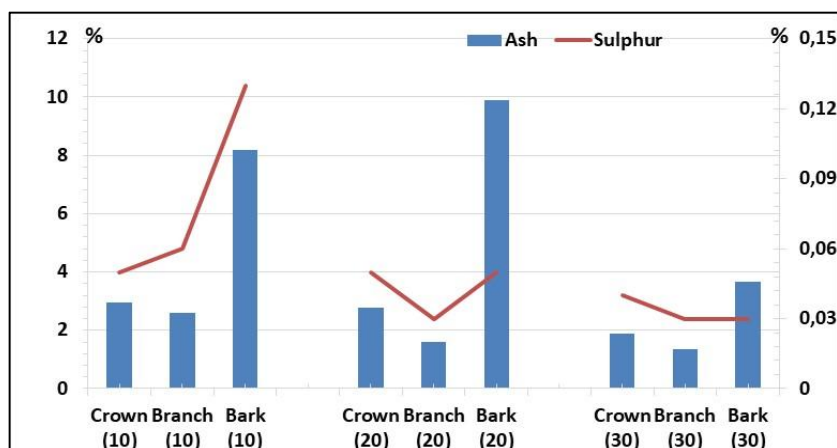
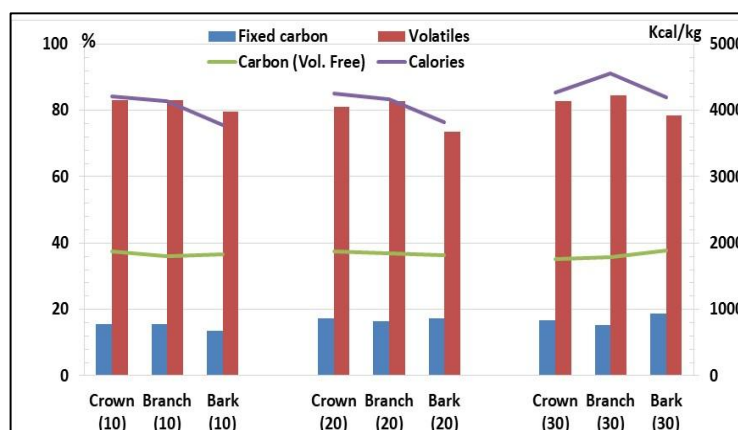**Fig. 3. The ash and sulphur properties of European Beech tree component**

Fig. 4. The combustion variables and energy properties of European Beech tree components

4. CONCLUSIONS

A systematic study of the heating value of selected components of European Beech tree were evaluated in order to measure the fixed carbon (%), calorific value (kcal/kg), ash content (%), ultimate carbon (%), sulfur contents with volatiles which are all important for evaluating the combustion properties. However, the proportion of fixed and ultimate carbon content and volatiles accumulated per components of European Beech tree was broadly similar in all ages of materials studied, although the calorific value was lower and ash content higher in the bark parts than relative to that of the thin branch- and crown wood. But all these are still in acceptable level for all components of European Beech tree. The experimental findings clearly indicates an environmentally friendly an alternative fuel source.

The combustion and calorific analysis of the components of a native forest tree might be provided important information for evaluating the fuel potential. However, the calorific properties and combustion behaviors of tree species are influenced in many variables. These must be taken into account during evaluation procedures. These analysis are only useful when substrates are adequately sampled and tested.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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