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Heating value and ash content of downy birch forest biomass

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Abstract

Biomass from forestry sector provides an important contribution to meet the government's targets for increasing bioenergy production and utilization. Characterization of forest residues is critical for exploiting and utilizing them for energy production purpose. In present work, stem wood, stem bark, branches, top of trees from downy birch forest were sampled from different sites in South Norway and subjected to heating value and ash content measurement. Properties of different parts of trees vertically along the tree trunk and radially along the branch and crown level were assessed via the statistical model. The heating value of stem wood was in range 18.14-18.57 MJ/kg, of stem bark 18.50-18.72 MJ/kg and of branch wood 18.21-18.50 MJ/kg. The vertical dependence of heating value of downy birch stem wood was similar to that of stem bark. Regular decreasing of heating value towards the tree top was observed. Significantly higher heating value at level $p<0.05^*$ of stem bark than the one of stem wood was observed. The ash content of downy birch branch wood did vary axially along the branch whereas there are only slight differences of ash content of branch within the crown. The stem bark has the highest ash content in range 2.0-2.5 %, followed by branch wood in range of 1.0-1.6 % and the lowest for stem wood in range of 0.3-0.5 %.

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Keywords: Ash content; Heating value; Downy birch; Site index quality.

1. Introduction

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The European Union (EU) has set a target to increasing production and utilization of renewable energy to the year 2020. According to the EU Directive [1] on the promotion of renewable energy sources, the EU Member States should increase the use of renewable energy to 20 % of final energy consumption and 10% renewable energy in the transport sector by 2020. Bioenergy will play a crucial role in meeting the 20 % target for renewable and GHG emission reduction by 2020. Biomass is expected to ensure at least 14 % in the EU energy mix [2]. About 236 Mtoe[2] of biomass could be available in 2020 and 293.3 Mtoe[2] by 2030 in the EU [3]. The Nordic countries have a good record in bioenergy production and use of forestry biomass, which can be examples of good practice for other EU Member States. Norway is part of the European Economic Area (EEA), which allows Norway to participate in the single European market. The Directive [3] is EEA relevant, but no renewable targets are set yet for Norway. As this legislation applies to Norway under the EEA agreement, similar targets can be expected for Norway. This will require a 72 % share of renewable energy sources in final energy consumption in 2020, compared with the present 58 % share [4]. The aim of this study was to investigate the heating value and ash content of downy birch biomass harvested in two sites in South Norway. Variations of properties of different part of the tree vertically along the stem and radially along the branch were investigated. This research presents preliminary results of selected biomass properties of downy birch tree parts, which can affect the usability of the birch wood for bioenergy production.

2. Experimental

2.1. Material

The stem wood, bark and branch biomass were obtained from downy birch tree species (*Betula pubescens*) harvested during early spring season 2015 in South Norway (Hobøl, latitude 59°43 'N, longitude 10°52 'E). The collected birch material consisted of two stands characterized by two site indexes. Site index 11 (SI11) represents the low forest stand quality while the site index 17 (SI17) corresponds to the high forest site index quality. Five trees per each stand were harvested, transported out of forest carefully, which were then divided into three crown levels (bottom, middle, top), based on the corresponding tree height. The crown base was defined to be the lowest living branch towards to tree top. Three branches with needles in the bottom, middle and top crown were selected and cut respectively. Cross-sectional discs, 5 cm thick, were cut from each tree in the vertical direction of the stem at given height levels (base, breast high (BH), 20 %, 40 %, 60 %, and 80 %). Branches were divided into three parts including base, middle and top branch section (mainly twigs with needles).

2.2. Effective heating value

The samples used for the determination of heating value were grounded to pass a test sieve with an aperture of 1.0 mm particle size. A pellet of mass 0.7 g was pressed with a suitable force to produce a compact, unbreakable test piece. Produced pellets were burned in high-pressure oxygen atmosphere in a bomb calorimeter. The effective heat capacity of the calorimeter was determined in calibration experiments by combustion of certified benzoic acid under similar conditions. The gross heating value was calculated from the corrected temperature rise and the effective heat capacity of the calorimeter, with allowances made for contributions from ignition energy, combustion of the fuse and for thermal effects from side reactions such as the formation of nitric acid. The effective heating value at constant volume of samples was calculated according to [5]. The results were reported as the mean of duplicate determination to the nearest 0.1 %.

2.3. Ash content

The ash content on dry basis (A_d) of samples expressed as a percentage by mass on a dry basis was calculated using the Equation 1:

$$A_d=((m_3-m_1))/((m_2-m_1)) \times 100 \times 100/(100-M_{ad}) \qquad (1)$$

where: m_1 is the mass of empty dish (g); m_2 is the mass of the dish plus the test sample (g); m_3 is the mass of the dish plus ash (g); M_{ad} is the % moisture content of the test sample used for determination [6]. The results were reported as the mean of duplicate determination to the nearest 0.1 %.

2.4. Statistical analysis

One-way ANOVA was used to assess differences in qualitative properties of biomass vertically in sectional discs and in branches axially towards top crown using JMP version 9.0 software. Properties of samples cut from trees located in sites with different indexes were compared. The results were carried out using the F-test to verify the significant variation to the level of 95 % expressed as "p value".

3. Results and discussion

3.1. Effective heating value of stem wood and stem bark

The axial dependences of the downy birch effective heating value of stem wood and stem bark are listed in (Table 1).

Table 1. Average values of effective heating value in dry basis (MJ/kg) and standard deviations of downy birch stem wood and stem bark along the tree trunk.

Site index	Stem wood						Stem bark					
	Tree height (%)						Tree height (%)					
	Base	BH	20	40	60	80	Base	BH	20	40	60	80
SI17	18.36 (1.48)	18.54 (2.22)	18.50 (1.36)	18.61 (3.11)	18.43 (2.51)	18.18 (1.46)	18.76 (2.22)	18.68 (1.21)	18.72 (2.00)	18.72 (1.26)	18.68 (3.34)	18.68 (1.16)
SI11	18.25 (1.26)	18.57 (2.60)	18.54 (3.19)	18.36 (3.25)	18.36 (2.22)	18.14 (1.49)	18.68 (3.15)	18.65 (3.46)	18.50 (2.16)	18.58 (2.84)	18.61 (2.06)	18.54 (1.38)

Effective heating values did differ in raw material origin. Heating value for stem wood was in range 18.14-18.57 MJ/kg and for stem bark 18.50-18.72 MJ/kg, respectively. The vertical dependence trend of heating value for downy birch stem wood was similar to that one of stem bark. Regular decreasing pattern towards the tree top was found. We observed significantly higher calorific value at level $p<0.05^*$ for stem bark than that of stem wood. Normally, the heating value of biomass is correlated to lignin content in it. It was reported that lignin contents are normally higher in leaves and young shoots than the stem wood for different trees. In addition, the higher energy content of stem bark may be due to its different chemical compositions, which contains more its content of energy rich components – lignin and extractives (resins, fats, oils, etc.) [7]. There was found no significant dependence of the site index for heating values of stem wood and stem bark. Contrary, the model proved a significantly strong vertical dependence of the heating value for stem bark at level $p<0.0001^*$. These statistical differences present (Table 2).

Table 2. p value of arithmetic means differences of effective heating value in dry basis of downy birch stem wood and stem bark in relation to the site index and tree height.

Location	Stem wood		Stem bark	
	Site index	Tree height	Site index	Tree height
Hobøl	p=0.5301	p=0.2115	p=0.6199	p<0.0001*

3.2. *Effective heating value of branch wood*

Differences in the effective heating value of branch wood are presented in (Table 3). Heating value of branch wood was in range 18.21-18.50 MJ/kg, respectively. The vertical variations of heating value for branch wood showed a decreasing pattern towards the branch top and upwards the crown top. Decreasing pattern in heating value of branch wood from the branch base towards its top was found. This is primarily related to the lower content of lignin and extractives of the branch wood, compared to stem wood part. It is important to note that the twigs part contained mix of wood, bark, needles (leaves), which all together may influence the heating value. This trend can be partly explaining by the chemical composition of needles, specifically extremely high content of extractives (41.1 %) [8] which gives higher heating value. Statistical analysis presented in (Table 4) proofed that the site index variable did not affect the heating value of downy birch in branch wood.

Table 3. Average values of effective heating value in dry basis (MJ/kg) and standard deviations of downy birch branch wood along the crown and along the branch.

Site index	Bottom crown			Middle crown			Top crown		
	Branch part			Branch part			Branch part		
	Base	Middle	Top	Base	Middle	Top	Base	Middle	Top
SI17	18.50 (1.38)	18.43 (2.54)	18.36 (1.52)	18.43 (1.44)	18.36 (3.16)	18.29 (2.13)	18.36 (2.61)	18.32 (1.50)	18.25 (1.51)
SI11	18.43 (1.24)	18.36 (3.21)	18.25 (2.16)	18.40 (1.06)	18.32 (2.22)	18.22 (3.01)	18.32 (2.41)	18.25 (1.40)	18.21 (1.31)

Table 4. p value of arithmetic means differences of effective heating value in dry basis of downy birch branch wood harvested during the early spring period in relation to the site index, crown level and branch part.

Location	Site index	Crown level	Branch part
Hobøl	p=0.3305	p=0.8087	p=0.0042*

3.3. *Ash content of stem wood and stem bark*

The axial dependences of the ash content for downy birch stem wood and stem bark towards the tree top gives (Table 5).

Table 5. Average values of ash content in dry basis (%) and standard deviations of downy birch stem wood and stem bark along the tree trunk.

Site index	Stem wood						Stem bark					
	Tree height (%)						Tree height (%)					
	Base	BH	20	40	60	80	Base	BH	20	40	60	80

SI17	0.4	0.4	0.5	0.6	0.5	0.5	2.2	2.1	2.0	2.5	2.4	2.5
	(0.04)	(0.12)	(0.13)	(0.03)	(0.12)	(0.14)	(0.23)	(1.00)	(0.21)	(0.16)	(0.14)	(0.10)
SI11	0.4	0.3	0.3	0.3	0.4	0.4	2.1	2.0	2.0	2.2	2.2	2.3
	(0.06)	(0.09)	(0.10)	(0.12)	(0.10)	(0.11)	(0.03)	(0.13)	(0.21)	(0.16)	(0.12)	(0.12)

Ash content of samples obtained from different parts of tree was considerably different. The ash content for the stem wood was in range 0.3-0.5 % and for the stem bark was 2.0-2.5 %, respectively. Applied combustion process of stem bark under the oxidative atmosphere resulted in higher residue mass produced at 550±10 °C in comparison to stem wood. The vertical dependence of ash content for stem wood and stem bark showed the same pattern for both materials. The ash content of sampled stem wood and bark increased from bottom towards the tree top. Significantly higher ash content at level $p<0.05$* was found for stem bark than the one for stem wood. The p values originated from statistical models presented in (Table 6) proofed that the ash content of stem wood and stem bark did not vary significantly in relation to the site index. The vertical dependence of ash content in stem wood and stem bark did not vary significantly either, respectively.

Table 6. p value of arithmetic means differences of ash content in dry basis of downy birch stem wood and stem bark in relation to the site index and tree height.

Location	Stem wood		Stem bark	
	Site index	Tree height	Site index	Tree height
Hobøl	p=0.8758	p=0.2205	p=0.1399	p=0.4979

3.4. Ash content of branch wood

The vertical dependences of the ash content for branch wood towards the top crown and branch top are presented in (Table 7).

Table 7. Average values of ash content in dry basis (%) and standard deviations of downy birch branch wood harvested during the early spring period in relation to the site index, crown level and branch part.

Site index	Bottom crown			Middle crown			Top crown		
	Branch part			Branch part			Branch part		
	Base	Middle	Top	Base	Middle	Top	Base	Middle	Top
SI17	1.2	1.4	1.4	1.4	1.5	1.5	1.5	1.6	1.6
	(0.18)	(0.14)	(0.12)	(0.44)	(0.16)	(0.13)	(0.21)	(0.15)	(0.15)
SI11	1.0	1.2	1.2	1.1	1.3	1.2	1.2	1.3	1.3
	(0.24)	(0.11)	(0.16)	(0.06)	(0.22)	(0.05)	(0.12)	(0.15)	(0.16)

Ash content of branch wood is in range 1.0-1.6 %, respectively. Ash content of twigs is higher than the one of branch base. Similar results have been reported in [9, 10]. The increasing trend in ash content towards the needle top (twigs) as well upwards the top crown was observed, respectively. The ash content of branch wood did not vary significantly at level $p>0.005$ within the crown position. On the other hand the ash content strongly varied along the branch towards the needle top (at level $p<0.05$*). As biological reactive part of one tree, concentrations of nutrients like K, P, Ca and Mg considerably higher in the bark, twig and tops, in comparison to stem of the wood. The findings of present work is in good accordance with our previous work [11,12]. The ash content of downy birch branch wood varies axially along the branch whereas the very position of branch within the crown did not affect the ash content. The variations of ash content obtained from statistical models for the site index and crown level dependence showed insignificant effect at level $p>0.05$ (Table 8). One the other hand the model proved that the ash content in branch wood did vary significantly axially at level $p<0.0005$* within the very branch position.

Table 8. p value of arithmetic means differences of ash content in dry basis of downy birch branch wood harvested during the early spring period in relation to the site index, crown level and branch part.

Location	Site index	Crown level	Branch part
Hobøl	p=0.9799	p=0.7022	p<0.0005*

4. Conclusions

From the utilization point of view, the crown mass of downy birch trees in comparison with stem wood has a higher heating value per unit weight. Additionally, crown biomass is plentiful in the form of logging residue and can easily be harvested. The variability in heating value and ash content is very small for the tree with a given site index. Significant correlations between heating value and ash content and different parts of tree are found only when the analysis is done by pooling the data on different high and crown levels. This means that the variability is actually caused by the different properties of the studied tree parts. The number of samples was sufficient enough to give a reliable knowledge on how the heating value and ash content varies within the downy birch tree. However, to make more solid conclusions the number of sampled trees has to be higher.

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