Original scientific paper

Opportunities to Use Thinning Wood as Raw Material for Wood Pellets

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Abstract

This article presents the opportunities to use small size round wood as a raw material for wood pellets. Article is aimed to give an insight to results of the study and to initiate discussion related on topical questions among pellet industry: what is the quality of pellets produced of undebarked young thinning wood (pine and pine-birch mixture) or debarked young thinning wood. Other topics of the study are to find out: has felling timing or growing habitat any influence to the chemical composition of pellets. Fuel quality indicates that high quality pellets can be produced of alternative raw materials. Key findings of this study are that there is a big opportunity to use undebarked small diameter pine and undebarked small diameter pine pine-birch mixture as a raw material for wood pellets. According chemical analysis small diameter thinning wood with bark is useful raw material for EN 14961-2 (2011) A1 wood pellets. In Finland traditionally small diameter wood has been used as a raw material for wood chips and for pulp and paper industry. Due to the changes in of pulp and paper industry new production opportunities for using small diameter wood should be found. In the future using small size thinning wood as a raw material for pellets can boost the demand of thinning wood and so help to manage young forests in Finland.

Keywords: Wood pellets, thinning, bioenergy, combustion, biofuel

1. Introduction

In Finland chemical and mechanical forest industry is under big changes and that will have a strong influence to the markets of thinning wood. In Finland it is very typical to manage forests using thinning harvesting. Thinning harvesting means that extra trees are taken out from forest and only those trees which has opportunities to grow to stems are left to forest. In practice that means that after first thinning (done when trees are about 30–40 years old) only 900–1 100 of trees/ha are left to grow and after second thinning (done when trees are 50–60 years old) only 500–600 trees/ha are left to forest. Thinning harvesting technique will secure more space, nutrients, water and sunlight to those trees which have the best opportunities to grow for best quality stems valuable for sawing industry. Using thinning harvesting forest owner can get profit when selling thinning wood to pulp industry (Kellomäki 1991, Metsätalouden kehittämiskeskus Tapio 2006, Metsäntutkimuslaitos 2010). Big international pulp and paper companies are moving from Finland to countries where economic factors of making pulp and paper are better. In the future situation could be that there will be no strong demand for thinning wood in Finland and lower demand for thinning harvesting will have an influence to the quality and number of mature trees for sawing industry.

There is a real fear that in the future there will be lower demand of young thinning wood in Finland than it has been recently years. One opportunity is to use young thinning wood as raw material for wood pellets. Other thing is the sufficiency and price of the traditional raw material (dry shavings from planning mills and wet saw dust from saw mills) for wood pellets. Availability of an important fuel cannot be connected only with strongly fluctuating saw milling industry.

Pelletizing woody raw material is known quite well (Kytö and Äijälä 1981a, Kytö and Äijälä 1981b, Kallio and Kallio 2004, Obenberger and Thek 2010, Kallio 2011). General opinion is that round wood with bark is not good raw material for EN 14961-2 (2011)

A1 pellets because of fairly high amount of ash and low melting point of ash (Alakangas 2000, Lehtikangas 2001, Obenberger and Thek 2010). Different growing sites have different chemical characteristics and these might have influence to the chemical characteristics of the trees. The use of wood from first thinning (debarked round wood and round wood with bark) as a raw material for wood pellets has been interesting issue. Most challenging factors have been ash behavior (e.g. low ash melting temperature and amount of ash) and economical profitability. Other interesting question is possibilities to use hard wood as a raw material for wood pellets (Kytö and Äijälä 1981a, Kytö and Äijälä 1981b, Okkonen et al. 2009, Obenberger and Thek 2010, Paukkunen et al. 2010).

The aim of this study is to find out:

⇒ If it is possible to make EN 14961-2 (2011) A1 pellets using young pine with bark as a raw material;

⇒ If there are opportunities to use birch (*Betula pendula* Roth) as a raw material for wood pellets;

⇒ The influence of bark when using young Scots pine (*Pinus sylvestris* L.) as a raw material for wood pellets?

⇒ If harvesting dates any influence to the chemical composition of wood pellets;

⇒ If growing site has any influence to the chemical composition of wood pellets.

2. Materials and methods

The starting point of the study was to find two forest plots which needs first thinning harvesting. Also growth habitat of forests should be different. Stora Enso Ltd did find four forest plots for the purpose of study.

Forest plots were selected and invented 30.5.2011–10.6.2011 and plots were harvested 13.6.2011–15.6.2011 and 5.9.2011. Forests are situated in Easter-Finland:

⇒ Area VT: N = 62°34.126', E = 31°6.944'

⇒ Area MT: N = 62°34.654', E = 31°8.67'

Both plots were inventored using line method. There were two lines 50 m from each other and both lines contained 5 basal area sample areas. Distance between sample areas was 50 m. At the end from both forests 10 basal area sample areas were inventored. Forest stand information before thinning is presented in table 1.

Number of stems series from basal area sample plots were calculated using formula (1.27324*q)/d2, were q = basal area gauge factor and d = diameter (measured at 1.3 m height) of chosen wood in meters (Kangas and Päivinen 2000).

Every harvested tree were measured and inventory data of harvested trees is presented in tables 2 and 3. Every harvested tree were used for raw material of pellets.

Table 1 Forest stand inventory data. Data is collected before harvesting

Area VT													
Median trees	Plot	Plot	Plot	Plot	Plot	Plot	Plot	Plot	Plot	Plot			
	1	2	3	4	5	6	7	8	9	10	Avg.	Max.	Min.
Diameter, cm	16.5	15	16.5	17	12.5	14	15.5	15	14.5	15	15.15	17	12.5
Height, m	15.5	13.5	13	13.5	13.5	12.5	13.5	14.5	12.5	11.5	13.35	15.5	11.5
Age, year	32	30	34	34	32	34	34	32	32	30	32.4	34	30
Number of stems per ha	2 300	1 411	1 717	664	1 011	3 108	1 578	1 749	2 094	1 048	1 668	3 108	664
Area MT													
Median trees	Plot	Plot	Plot	Plot	Plot	Plot	Plot	Plot	Plot	Plot			
	1	2	3	4	5	6	7	8	9	10	Avg.	Max.	Min.
Diameter, cm	15	14	16	17.5	16	16	14.5	12.5	17	17	15.55	17.5	12.5
Height, m	15.5	12.5	14.5	14.5	11.5	14.5	13.5	12	14.5	15.5	13.85	15.5	11.5
Age, year	28	28	28	28	28	29	29	27	30	29	28.4	30	27
Number of stems per ha	2 050	1 174	1 166	1 007	1 488	1 236	1 098	1 406	1 153	1 376	1 315	2 050	1 007

Table 2 Inventory data on harvested trees, VT

	Unit	Area VT, summer pine With bark $n=36$	Area VT, summer pine Without bark $n=49$	Area VT, autumn pine With bark $n=10$	Area VT, autumn pine Without bark $n=11$
Diameter, avg.	cm	12.1	12.4	13	13.0
Diameter, max.		18	22.5	18.5	19.5
Diameter, min.		7.5	6	9	9.5
Thicknes of bark, avg.	mm	4.3	N/A	5.4	5.5
Thicknes of bark, max.		8	N/A	9	9
Thicknes of bark, min.		1	N/A	3	3
Height, avg.	m	13.5	13.5	14.8	14.5
Height, max.		15	16.2	16	17
Height, min.		8.5	9.9	13	13
Age, avg.	year	35	N/A	40	42
Age, max.		38	N/A	46	48
Age, min.		31	N/A	36	38
Volume, avg.	m^3	0.084	0.0928	0.0977	0.0958
Volume, max.		0.1889	0.3128	0.2112	0.2473
Volume, min.		0.0234	0.015	0.0424	0.472

Table 3 Inventory data on harvested trees, MT

	Unit	Area MT, summer pine with bark $n=35$	Area MT, summer pine without bark $n=48$	Area MT, summer birch with bark $n=15$	Area MT, summer birch without bark. $n=12$
Diameter, avg.	cm	12.3	13.1	11.4	10.7
Diameter, max.		21	19.5	18	25.5
Diameter, min.		8.5	6	7.5	5.5
Thicknes of bark, avg.	mm	4.6	N/A	N/A	N/A
Thicknes of bark, max.		7	N/A	N/A	N/A
Thicknes of bark, min.		3	N/A	N/A	N/A
Height, avg.	m	13.1	13.3	N/A	N/A
Height, max.		16.5	16.0	N/A	N/A
Height, min.		8.5	8.4	N/A	N/A
Age, avg.	year	28	N/A	N/A	N/A
Age, max.		30	N/A	N/A	N/A
Age, min.		26	N/A	N/A	N/A
Volume, avg.	m^3	0.0872	0.1028	N/A	N/A
Volume, max.		0.2780	0.2343	N/A	N/A
Volume, min.		0.0155	0.0131	N/A	N/A

Heights of trees (pine with bark) were measured using hypsometer (Suunto PM5/1520). Height of trees (pine without bark, both cases) were calculated using Näslund`s formula (Näslund 1936, Kangas and Päivinen 2000).

Näslund`s formula for calculating height of tree:

$$h=\frac{1.3+d^2}{(a+b*d)^2} \quad (1)$$

where:

h height of tree, meters;

d diameter (in centimeters) of tree measured from 1.3 meters height;

a, b variables, calculated from measured trees using linear regression method.

Statistics for calculation were taken from measured trees (pine with bark). Volumes of pines (every cases) were calculated using Laasasenaho`s formula number 2 (Laasasenaho 1982, Kangas and Päivinen 2000).

Ground samples from growing sites were collected 15.9.2011 and samples were sent for analysis 16.9.2011 to Viljavuuspalvelu LTD, Mikkeli, Finland. Samples were collected from 10 different places from both forests. Humus layer and mineral soil layer were separated from samples. From collected samples mixed samples were taken resulting in 4 samples which were sent to Viljavuuspalvelu LTD: Humus and mineral samples from Area VT and humus and mineral samples from Area MT. Information from growing site is presented in table 4.

Soil mineral and pH consistence of growth habitats were typical compare to literature (Urvas and Erviö 1974, Mälkönen 1979). It is normal that MT growing habitat has higher pH value and mineral amounts are higher than in VT growing habitat (Urvas and Erviö 1974, Mälkönen 1979).

At June 2011 harvesting was operated using two machines. Wood without bark was harvested using harvester which was equipped with barking felling head and extra attention was put to avoid the contamination of harvested wood. Wood with bark was harvested using Klapimaster, which is very new model of harvester. Klapimaster is made by HaVel Ltd. Klapimaster is harvesting trees straight to the container as chopped wood (HaVel 2012). This method avoids the risk of contamination. Chopped wood was packed straight from the container to big sacks waiting for the transportation. Harvested and chopped wood was transported to Mekrijärvi research center 15.6–16.6.2011 using medium size lorry car.

In September harvesting was done manually using motor saw. Stems were carried near the road, transported to Mekrijärvi using tractor and forest trailer. Stems were secured from contamination (sand and dust from road) using covering plastic, and then debarked using debarking tool.

Chopped wood was chipped using disc chipper driven by a tractor to the dryer trailer. Wood chips were dried using trailer based batch dryer. Loaded trailers (volume 3 loose cubic meter) were situated to sea container and heated air (temperatures max 65°C) was blew through wood chips batch. Drying from 55% moisture content to 10% moisture content (on wet basis) took about 64 hours per each load. Extra heat derived from district heating using heat exchanger to avoid contamination during drying (Öhman et al. 2004).

Table 4 Information from forest plots

Humus layer													
Growth habitat	Ash	Grade of organic matter	Soil type	pH	N	P	K	Ca	Mg	B	Zn	Fe	Cd
	%				%	g/kg				mg/l			mg/kg
VT	97	Low	Sandy till	5.2	1.66	10.3	11.5	10.2	21.9	4.3	41.3	9 740	1.4
MT	96	Low	Fine sandy till	5.4	2.15	8.2	12.6	12.9	31.5	5.6	27.8	7 330	1.7
Mineral soil layer													
Growth habitat		Grade of organic matter	Soil type	pH		P	K	Ca	Mg	N/A	N/A	N/A	N/A
						mg/l							
VT	–	Low	Sandy till	5.2		2.3	29	130	<20	N/A	N/A	N/A	N/A
MT	–	Low	Sandy till	5.4		3.1	50	180	28	N/A	N/A	N/A	N/A

Dried raw material was milled to suitable particle size using Miller 20 hammer mill equipped with 6 mm sieve was used. Raw material was pelletized with SPC PP300 pelletizer equipped with 50 mm long press channels die. For pelletizing any extra binding materials, water or steam were not used.

Standards which has been followed in this study:

⇒ Determination of mechanical durability of pellets and briquettes EN 15210-1(2010);

⇒ Moisture content of raw material and pellets: ENEMEN 002 (Savonia University of Applied Sciences), EN 14774-1(2010), 14774-2(2010) and 14774-3(2010);

⇒ Sampling: EN 14778-1(2005), EN 14778-2(2005);

⇒ Calorific values EN 14918(2010);

⇒ Ash content SFS-EN 14775.

3. Results and discussion

In table 5 are presented shares of bark from undebarked raw materials.

Table 5 Shares of bark from undebarked raw materials

	Bark %, dry basis
Area VT, pine with bark	8.6
Area VT, pine with bark autumn	8.2
Area MT, pine with bark	12.6
Area MT, birch with bark	18.9

For pine the share of bark (dry basis) should be about 10.5% (Hakkila et. al. 1995, Alakangas 2000,) so in this study share of bark was little smaller than average.

Chemical analysis was done by University of Eastern Finland, Joensuu and Savonia University of Applied Sciences, Varkaus. Chemical analysis was done in University Of Eastern Finland, Joensuu using Inductive coupled plasma mass spectrometry (ICP). Results of the chemical analysis (ICP) are presented in table 6.

Amounts of Ca, Mg, Fe, Zn and Si are similar that earlier reported in literature (Alakangas 2000, Sippula 2007, Okkonen et al. 2009), but there are some differences e.g. in amounts of P and S witch were 10 times lower in this study (Lehtikangas 2001, Sippula et al. 2007). Also amount of K was about 0.5 times lower compared to the average level. The different amounts of minerals in wood are presented in literature (Obenberger and Thek 2010, Fillbakk et al. 2011).

It is interesting to notice that the amount of Na is higher in the pellets which were made from autumn harvested trees. According the literature normal amount of Na should be about 0.02–0.08 g/kg (Sippula 2007, Okkonen et al 2009). After all, results from this study are quite similar to former study (PELLETime-project) concerning round wood with bark. In former study pellets were made from undebarked pine and undebarked pine-birch mixture. Results from the fuel analyses indicate that both pellet assortments have low ash contents (0.3%, analyzed as ignition residue at 550°C) (Okkonen et al. 2009, Paukkunen et al. 2010).

Table 6 Results of chemical analysis of pellets

Results (dry basis) of chemical analysis														
	Ash	N%	Al	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Si	Zn
	%	Kjeldahl	mg/kg												
Area V, pine without bark	0.26	0.071	10.3	1.65	546	0.804	31.4	321	123.6	93	13.6	34.3	41	12.0	8.3
Area VT, pine with bark	0.35	0.087	27.3	1.34	750	0.782	25.0	396	145.4	99	13.9	57.5	51	7.7	11.0
Area MT, pine without bark	0.25	0.075	6.8	1.03	556	0.768	15.8	368	137.4	83	14.0	44.4	45	4.6	7.5
Area MT, pine with bark	0.31	0.087	32.2	1.35	763	0.789	17.3	474	147.3	80	13.6	71.3	62	5.8	8.7
Area MT, pine without bark 45%, birch without bark 55%	0.27	0.085	1.8	1.18	591	0.791	16.2	377	146.0	95	15.6	60.8	48	4.9	16.9
Area MT, pine with bark 66%, birch with bark 33%	0.33	0.108	22.5	1.40	772	0.826	17.0	476	146.3	84	19.0	74.6	59	5.2	15.0
Area VT, pine without bark. autumn	0.26	0.055	<LQD	1.16	531	0.857	15.1	319	122.8	87	60.0	37.5	46	7.3	5.2
Area VT, pine with bark. autumn	0.32	0.082	56.3	1.49	799	0.993	12.8	412	139.4	106	54.2	60.8	61	9.3	7.0

The elements Ca, Mg, Si and K are the main ash forming elements in wood. The concentrations of Ca, Mg, K and Na in the ash influence the melting behavior, which is directly related to the reliability of the plant. Ca and Mg usually raise the ash melting point whereas K and Na lower it. A low ash melting point can lead to slagging and deposit formation in furnace and boiler. Si also influences the ash melting behavior main as low melting K silicates may be formed. A high concentration of K prompts the formation of aerosols during combustion, which not only raises the emission of fine particulate matter but also increases fouling of the boiler. Na behaves in a very similar way as K (Obenberger and Thek 2010). There are other studies where ash contents of hard woods are detected to be higher than CEN standard requirements (e.g. Obenberger and Thek 2010). Results from this study are slightly different. Assumption is there might be possibility to use hard wood as a raw material to CEN standard A1 pellets at least mixture to soft wood. Normal stem wood without any contamination should contain very limited amounts of Si and thus, it is less prone to form sticky silicates at typical temperatures in residential pellet burners (1000–1100°C), whereas contamination leads to the formation of sticky silicates and slagging problems (Öhman et al. 2004).

After taking samples for analysis remained pellets were given for heating purposes. Pellets were used as a fuel to heat domestic house where gasifying burner (type name Pyro-Man) was used.

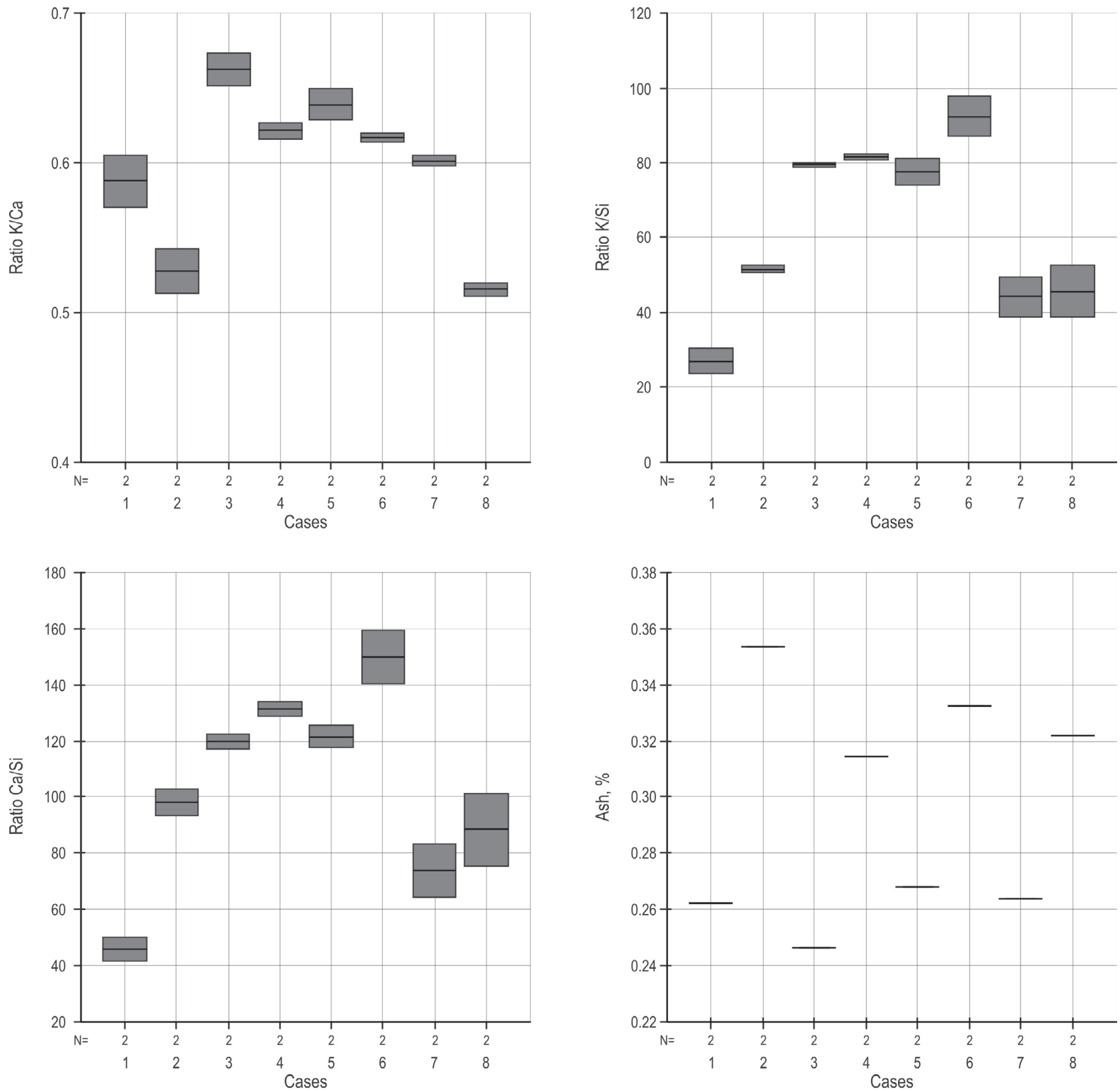
Tables 7 and 8 presents characteristics of chipped raw material and made pellets.

Table 7 Characteristics of chipped raw material and produced pellets

	Moisture of chips, wet basis	Moisture of dried and milled raw material, wet basis	Durability of pellets	Bulk density of pellets
	%			kg/ loose m^3
Area VT, pine without bark	55.2	9.2	95.2	565
Area VT, pine with bark	57	14.7	91.8	540
Area MT, pine without bark	56.3	10.5	90.8	592
Area MT, pine with bark	59.1	9.8	93.8	619
Area MT, pine without bark 45%, birch without bark 55%	n.n	10.9	95.2	671
Area MT, pine with bark 66%, birch with bark 33%	n.n	8.7	96.1	736
Area VT, pine without bark, autumn	54	11.9	95.7	593
Area VT, pine with bark, autumn	54.8	12.0	94.3	617

Table 8 Characteristics of chipped raw material and made pellets

	High heating value of pellets – HHV	Low heating value of pellets – LHV	LHV NCT of pellets as reseaved	Moisture of pellets	Ash content of pellets, dry basis
	MJ/kg			Wet basis	
Area VT, pine without bark	20.83	19.5	17.46	9.3	0.2
Area VT, pine with bark	20.8	19.47	17.21	10.3	0.3
Area MT, pine without bark	20.66	19.33	17.45	8.7	0.2
Area MT, pine with bark	20.64	19.31	17.66	7.6	0.3
Area MT, pine without bark 45%, birch without bark 55%	20.45	19.12	17.17	9.1	0.2
Area MT, pine with bark 66%, birch with bark 33%	20.6	19.27	17.63	7.6	0.3
Area VT, pine without bark, autumn	20.92	19.59	17.5	9.5	0.4
Area VT, pine with bark, autumn	21.16	19.83	17.56	10.2	0.6



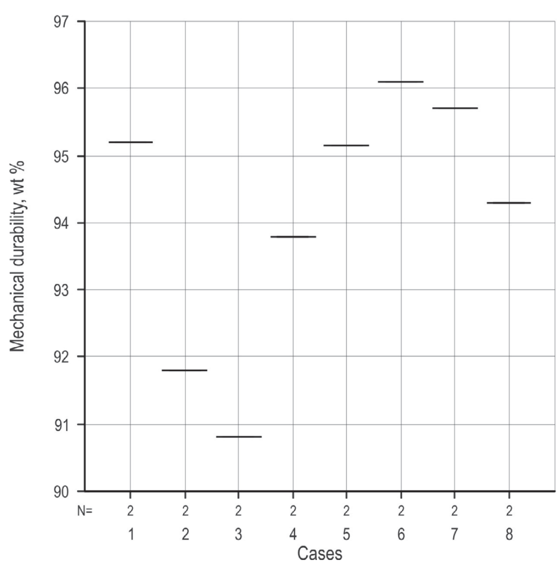


Fig. 1 Amount of ash %, mechanical durability, and ratios of K/Ca, K/Si and CA/Si, measured from made pellets. Cases at the horizontal axis are: 1 = Area VT, pine without bark; 2 = Area VT, pine with bark; 3 = Area MT, pine without bark; 4 = Area MT, pine with bark; 5 = Area MT, pine without bark 45%, birch without bark 55%; 6 = Area MT, pine with bark 66%, birch with bark 33%; 7 = Area VT, pine without bark, autumn; 8 = Area VT, pine with bark, autumn. Ratio K/Ca is higher when raw material has not bark and amount of ash is higher when raw material had bark

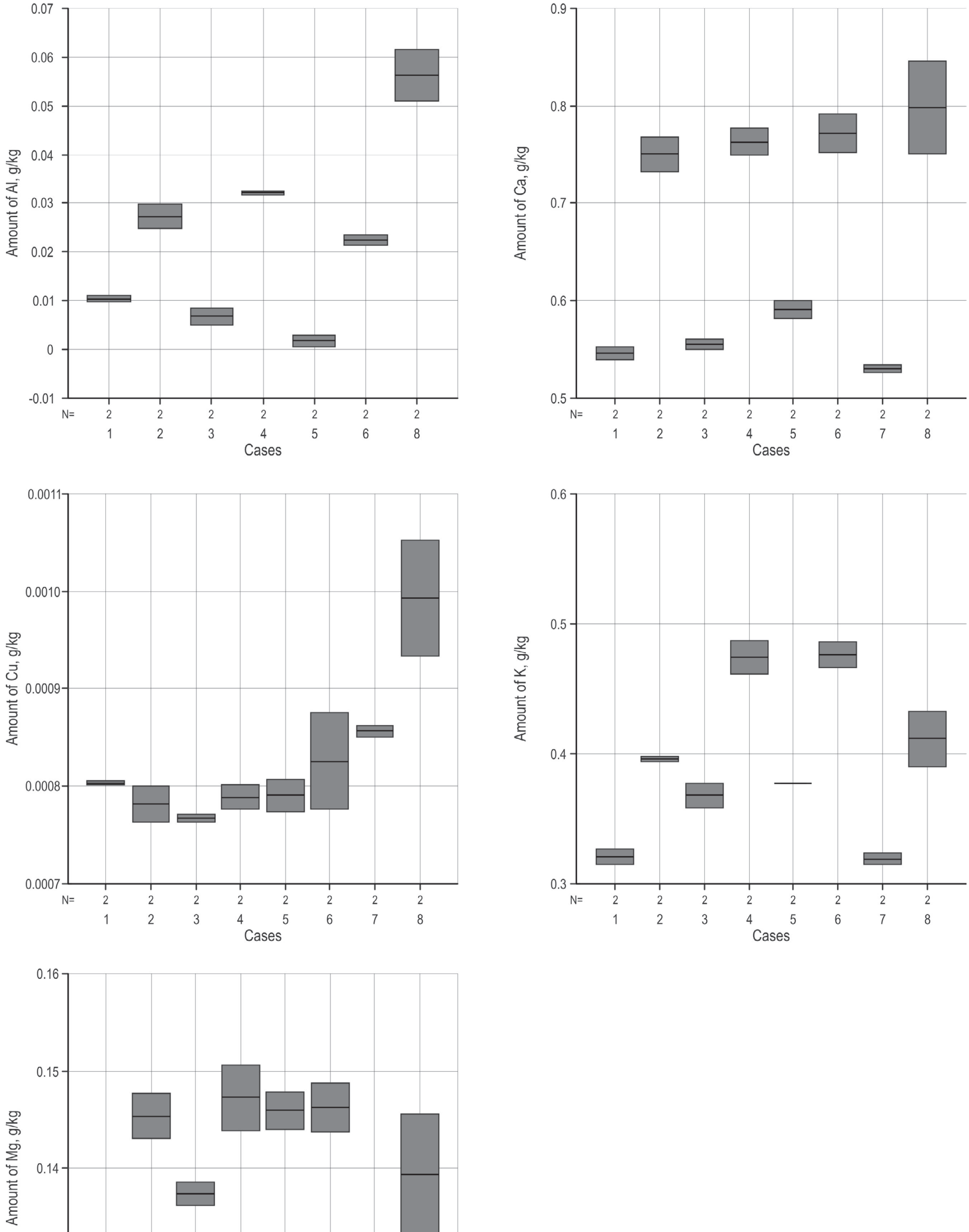
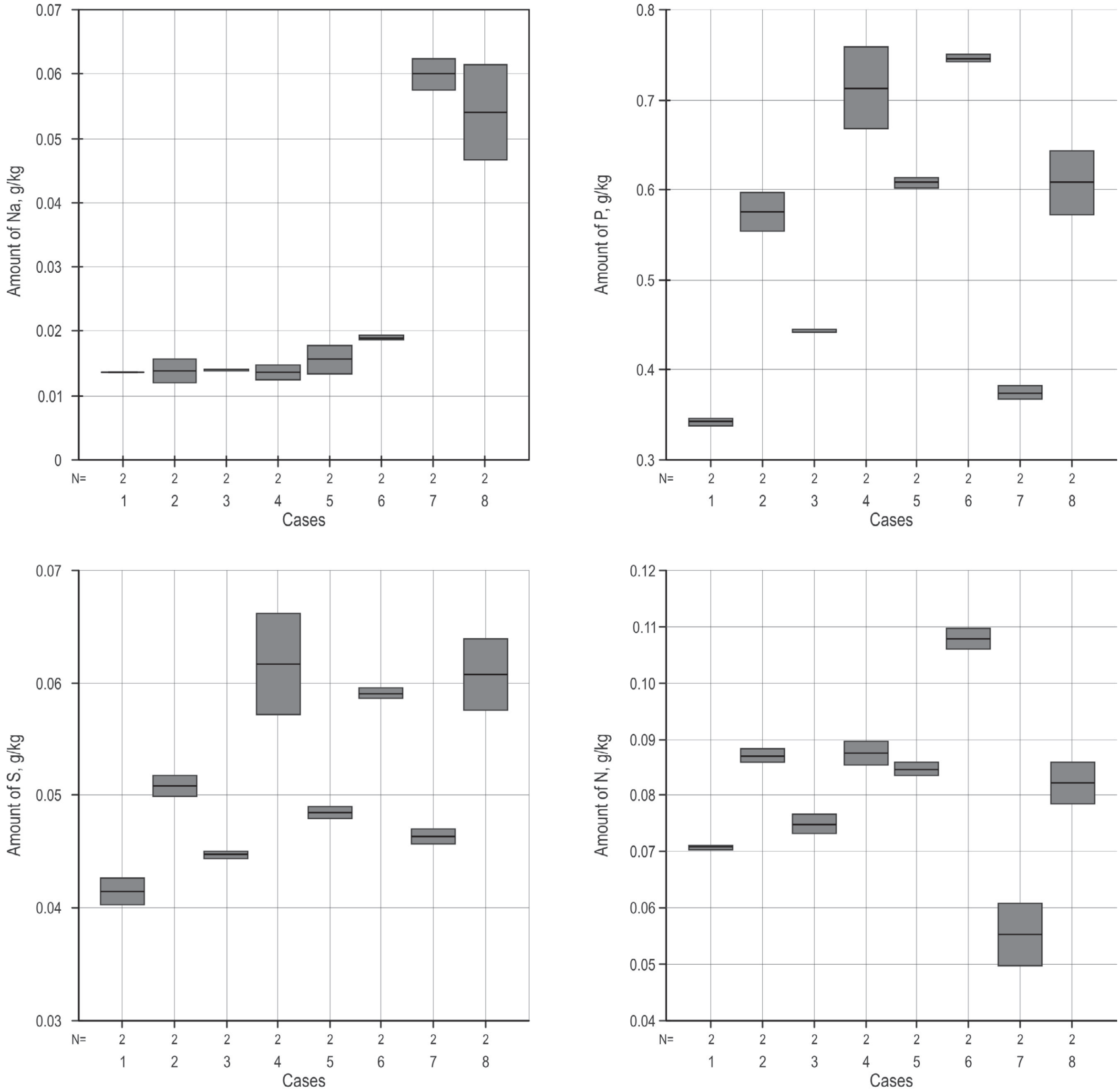


Fig. 2 Amounts of Al, Ca, Cu, K and Mg, measured from produced pellets. Amounts of Al, Ca and K are higher when raw material has bark



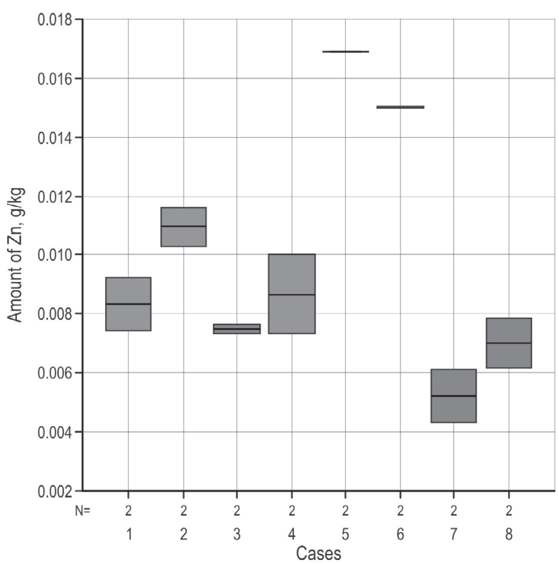


Fig. 3 Amounts of Na, P, S, N and Zn, measured from produced pellets. Amount of Na is higher when trees are harvested in autumn. Amounts of P, S and N are higher when raw material has bark

In this study durability of pellets did not reach the demands of quality of EN 14961-2 A1 pellets. There are many factors which influence the durability of pellets (e.g. particle size of raw material, amount of bark, moisture of raw material, used pelletizing technology and settings, time between harvesting and drying) (Lehtikangas 2001, Kallio and Kallio 2004, Obenberger and Thek 2010, Paukkunen et al. 2010). Durability demands of CEN 14961-2 A1 should be reached when using longer press tunnel (e.g. 55 or 60 mm) and longer aging of the raw material. Using hot steam as a pretreatment method just before pelletizing might also increase the durability of pellets (Kytö and Äijälä 1981a, Kytö and Äijälä 1981b, Obenberger and Thek 2010).

Significance of growth habitat, presence of bark and time of harvesting were tested using one way ANOVA. Growth habitat has significance to the amount of N (p = 0.042), K (p = 0.03), Mg (p = 0.018), Mn (p = 0.007), Na (p = 0.017), P (p = 0.032), Si (p = 0.000), Zn (p = 0.034) and to ratio of K/Si (p = 0.000), Ca/Si (p = 0.000) and to ratio of K/Ca (p = 0.000).

Presence of bark has significance to the amount of ash (higher, p = 0.000), N (higher, p = 0.004), Al (higher, p = 0.001), Ca (higher, p = 0.000), K (higher, p = 0.000), Mg (higher, p = 0.011), P (higher, p = 0.001), S (higher, p = 0.000) and to ratio of K/Ca (lower, p = 0.035).

Harvesting time has significance to the amount of N (lower in autumn, p = 0.049), Al (higher in autumn, p = 0.001), Cu (higher in autumn, p = 0.000), Na (higher in autumn, p = 0.000), and Zn (lower in autumn, p = 0.021).

Tree species has significance to the amount of N (higher in mixed raw material, p = 0.015), P (higher in mixed raw material, p = 0.043), Zn (higher in mixed raw material, p = 0.000), to the ratio of K/Si (higher in mixed raw material, p = 0.016) and Ca/Si (higher in mixed raw material, p = 0.021).

4. Conclusions

It seems that small diameter pine can be used both without bark and with bark as a raw material for EN 14961-2 A1 pellets when only the chemical composition of pellets is taken into account. Drying techniques, costs from drying the raw material and the price of the raw material are the key factors when the economics of pellet industry is evaluated (e.g Flykman 2001, Zakrisson et al. 2002, Obenberger and Thek 2010). It is also sure that contamination of pellet raw material should be avoided in every way.

This study points out that pellet market has big opportunity to use birch as a raw material for wood pellets. Broad-leaved trees are very poorly used as raw material for wood pellets in Finland and using birch could greatly wide the useful raw material base. From the chemical point of view there are no limits to use pine-birch mix pellets as a fuel to the small scale pellet heating units (e.g. households). In this study mechanical durability did not exceed the value 97.5% or more so making durable pellets from pine – birch mix needs more research if the goal is to make EN 14961-2 A1 pellets.

The influence of growth habitat and harvesting time need also more research. In this study there were no big differences in chemical composition of mineral and humus layer between two growing habitats. In the future it might be interesting to compare chemical composition of pellets when raw material is harvested from very different growth habitats. Harvesting time might have an influence to the amount of Na and that has significance to the combustion process. It can be so that late harvesting time (autumn and winter) increases the amount of Na in wood. Increased amount on Na might decrease the ash melting temperature so summer might be the better harvesting time when the purpose is to collect raw material for EN 14961-2 A1 pellets.

In Finland traditionally small diameter wood (energy and thinning wood) has been used as a raw material for wood chips and for pulp and paper industry. Small diameter wood has been harvested because of demand of raw material and also because of the need of forest management (e.g. stems will grow faster to logs). Forest owner can get quicker more profit from the forest which has been managed using thinning method harvesting. In the future using small scale thinning wood as a raw material for pellets can boost the demand of thinning wood and so help to manage young forests in Finland.

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