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Chemical composition and fiber properties of fast-growing species in Latvia and its potential for forest bioindustry

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Abstract. Bioenergy, including energy from wood, currently provides about 9–13% of the total global energy supply. Every fibre of fast-growing wood has a value for its potential use as a material in both pulp and paper and wood chemical industries. The aim of this study was to assess the chemical composition and fibre's properties of fast-growing species in Latvia – aspen, hybrid aspen, lodgepole pine, poplar and willow. Results showed a variation of cellulose, lignin, extractives and ash contents among the species. Kraft pulp yield and amount of residual lignin were measured and properties of pulp fibres determined. Form factor and fine content in pulp were measured. Poplar and aspen wood had the highest content of cellulose, while lodgepole pine had the highest lignin content in wood and the longest kraft pulp fibres. Willow had 20% of fines in pulp. Individual results suggest the most suitable application of each species.

Key words: fiber properties, poplar, aspen, hybrid, lodgepole pine, kraft pulp.

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Introduction

In order to limit global warming through the reduction of CO_2 emissions, the EU target is to reduce the fossil fuel consumption with a view to achieving a share of 20% renewable energy in 2020. To reach this target, national targets were set according to the renewable energy potential of each country (Vanneste *et al*., 2011). The use of biomass for bioenergy significantly reduces greenhouse gas emissions. The carbon dioxide it gives off when it is burned is counterbalanced by the amount absorbed when the plant in question was grown. Bioenergy currently provides about 9–13% of the total global energy supply (Long *et al*., 2013). Within this bioenergy category, wood plays an important role worldwide and also in Latvia (Neimane *et al*., 2011).

Measurements and calculations were done to estimate the energy potential of geographically available abandoned agricultural lands for short rotation wood species production in Latvia to meet EU 2020 renewable energy targets (Abolina *et al*., 2015). In addition to scientific and practical projects, also forestlands' owners are constantly informed about the opportunities in short rotation forestry (Daugaviete & Lazdina, 2014).

In Latvian conditions, most promising fast-growing wood species for bioenergy are willow, poplar, aspen, their hybrids

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and lodgepole pine. Several plantations were planted and short rotation experimental trials were accomplished in Latvia in former farmlands to investigate the influence of fertilizing, cultivation, weather conditions, harvesting and other factors on biomass yield and quality (Lazdina, 2009, 2010; Bārdule *et al.*, 2012; Lazdina *et al.*, 2012).

Nevertheless, every fibre of fast-growing wood has a value for its potential use as a material in both pulp and paper and wood chemical industries. Poplar hybrids wood was intended primarily for manufacture of pulp and paper products, but solid wood products have been recently considered as well (Pliura *et al.*, 2007). In recent years, it has been investigated also from the chemical composition point of view – as a source of different lignins and their derivatives (Kim *et al.*, 2013); thermal decomposition of poplar wood was studied with the aim to convert solid biomass mainly into a liquid product known as bio-oil (Dong *et al.*, 2012). Aspen and hybrid aspen wood and fibres were studied as a source for the pulp and paper industry both in Latvia (Sable *et al.*, 2012b, 2013a, 2013b; Treimanis *et al.*, 2006; Zeps *et al.*, 2008, 2012) and other countries (Francis *et al.*, 2006; Tullus *et al.*, 2011).

The aim of this study was to assess the chemical composition and fibre's properties of fast-growing wood in Latvia – aspen (*Populus tremula* L.), hybrid aspen (*Populus tremuloides* Michx. × *Populus tremula* L.), lodgepole pine (*Pinus contorta* Douglas ex Loudon), poplar (*Populus balsamifera* L. × *P. laurifolia* Ledeb.) and willow (*Salix viminalis* L.).

Material and Methods

All aspen sample trees were grown naturally in former agricultural and forest lands – in *Aegopodiosa*, *Hylocomiosa* and *Mercurialiosa* a total of 18 trees were cut. Hybrid aspen trees were grown on former agriculture lands in the central part of Latvia. The planting design of this experiment was: block plots for 25 trees (block size 5 × 5 plants), planted by 3 × 3 m in 3 to 5 replications. Seven aspen hybrid clones (Sable *et al.*, 2013b) – eight sample trees for each clone – were selected for this study. Aspen and hybrid aspen were cut at the age of 19–20 years. Willow samples were grown in sandy loam soil, in Olaine parish and were cut at the age of 8 years; diameter at breast height (DBH) of the selected samples was 4.55 ± 0.08 cm, tree height – 9.5 ± 0.10 m. The material of poplar was collected in 14 stands (at the age of 54–65 years), located in the central and western part of Latvia, which were established on fertile drained mineral soil and mineral soil with normal moisture regime (Jansons *et al.*, 2014). Lodgepole pine was represented by 26 sample trees from 3 provenances from Canada; plant production in Latvia was carried out in 1985 on dry, sandy soil (*Myrtillosa* forest type) and trees were cut at the age of 24–25 years.

Wood chemical analyses and kraft cooking were made from the stem wood at the height of 1.0 to 1.3 m.

The content of cellulose (as a weight percent of holocellulose according to TAPPI 203cm-99), Klason lignin (according to TAPPI 222om-98), extractives (according to TAPPI T280pm-99) and ash were determined in wood (according to TAPPI T211om-02).

Pulp fibres were obtained by the kraft cooking method (in a 2-l laboratory digester at 170°C, 57.4 g l^{-1} active alkali as NaOH, sulphidity 29.8 %, and liquor to wood ratio 4.5 l kg^{-1}). Fibre properties (length, width and form) were determined by a "Fiber Tester" (Lorentzen & Wettre, Sweden). Klason lignin in pulp was determined according to TAPPI 222om-98.

The ANOVA procedure was used for the determination of the factor (species) effect on the inspected properties. If the factor was significant ($p < 0.05$), the *Bonferroni test* was used (*post hoc*) to determine, which species differed. The ANOVA pro-

Table 1. Chemical composition of wood of different species (means ± standard deviation).

Species	Cellulose (%)	Klason Lignin (%)	Extractives (%)	Ash (%)
Aspen	52.3 ± 1.7	18.0 ± 1.6	2.7 ± 1.0	0.4 ± 0.0
Aspen hybrid	51.8 ± 1.5	19.3 ± 1.2	2.0 ± 0.6	0.4 ± 0.0
Lodgepole pine	47.6 ± 1.7	28.6 ± 1.3	2.6 ± 0.5	0.29[3]
Poplar	53.7 ± 2.6	23.0 ± 2.5	3.3[2]	1.43[4]
Willow	49.8 ± 2.0	26.8 ± 0.2[1] 21.3[5]	2.0 ± 0.2	0.3[2] 1.5[5]

[1] Ai & Tschirner, 2010
[2] Fengel & Weneger, 2003
[3] Sable *et al.*, 2012a
[4] Sannigrahi *et al.*, 2010
[5] Caslin *et al.*, 2012

cedure was not used for comparing data from other sources, which are marked and reference is given below (Table 1).

Results

Poplar had a significantly ($p < 0.05$) higher content of cellulose among the tested wood species. The content of cellulose of aspen was much higher than that of willow and lodgepole pine (LP), but the difference between aspen and aspen hybrid (AH) as well as between willow and LP was not significant ($p > 0.05$). Differences of lignin content in wood were significant ($p < 0.05$) among all tested species.

The content of extractives in aspen was considerably higher ($p < 0.05$) than in aspen hybrid and willow, but these two did not differ ($p > 0.05$). The result of LP showed a significant ($p < 0.05$) difference in HA. Original experimental data for ash content were only for aspen and HA, and they did not differ.

Kraft pulp yield was measured after the pulping process, and results (Figure 1) were 51.7% for aspen, 50.6% for AH, 40.7 % for LP, 53.9% for poplar and 44.6% for willow. Significant differences ($p < 0.05$) were among all species tested, except those between aspen and its hybrid.

Measurements of residual Klason lignin in pulp showed 1.3% for aspen pulp, 1.5% for AH pulp, 4.1% for LP pulp and 2.2% for poplar pulp, but the result of 3.6% for willow pulp was found in the literature (Ai *et al.*, 2010), because of the lack of the current experiment in the case of this species. A statistical procedure indicated a significant ($p < 0.05$) difference among the residual lignin content in pulp of all tested species.

Table 2 explores measurements of the tested fibre parameters. Considerable differences among species ($p < 0.05$) appeared in fibre length. Aspen and HA fibres were equal, but shorter than pine, poplar and willow fibres. LP fibres were longer than those of other species, except willow. There was no difference between the length of willow and pine fibres and also between poplar and willow fibres.

Fibres of LP were wider ($p < 0.05$) than those of other species; poplar fibre was wider ($p < 0.05$) than all others, except pine fibre, and there were no differences among fibres of aspen, HA and willow.

LP fibres had a lower ($p < 0.05$) shape factor than other species; a significant ($p < 0.05$) difference was also between aspen and its hybrids.

Measurements of the fine content in pulp showed a significant ($p < 0.05$) difference among all tree species.

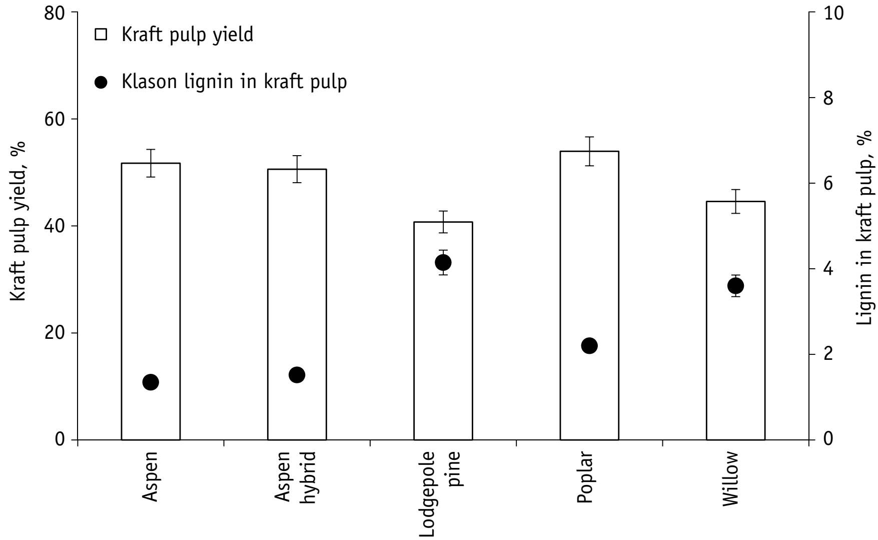

Figure 1. Kraft pulp yield and residual Klason lignin content of wood, used for bioenergy.

Table 2. Dimensional parameters, form and fine content of kraft pulp fibres of different species (± standard deviation).

Species	Fibre length (mm)	Fibre width (μm)	Fibre form factor (%)	Fines in pulp (%)
Aspen	0.8 ± 0.05	21.5 ± 0.7	94.9 ± 0.7	3.4 ± 1.0
Aspen hybrid	0.8 ± 0.08	21.3 ± 1.1	93.9 ± 1.0	4.1 ± 1.0
Lodgepole pine	1.4 ± 0.4	27.7 ± 2.6	91.2 ± 1.0	1.3 ± 0.2
Poplar	1.0 ± 0.07	24.9 ± 1.5	94.3 ± 0.7	5.2 ± 1.1
Willow	1.2 ± 0.08	21.6 ± 0.8	94.4 ± 0.8	20.2 ± 1.2

Discussion and Conclusions

The chemical composition of a tested wood species (Table 1) elucidates the possibilities of its using. Each component separately and the composition as a whole provides an opportunity to increase the marketing value of wood. Cellulose is the source of fibres for the pulp and paper industry; also, modified fibres can be used for textile. Micro- and nano-scale cellulose products have a wide range of applications for innovative composite materials, electronics, pharmaceuticals, *etc*. (Moon *et al*., 2011). Lignin and its derivatives could be an excellent source of industrial specialty and commodity chemicals, displacing the materials currently produced from crude oil and natural gas (Pye, 2006). Wood extractives consist of terpenes, resin acids, and fatty acids (Elder, 2004) – the source for natural chemicals.

Figure 1 gives useful information about the yield of fibres after kraft pulping, and the results are in accordance with the chemical composition of wood. Poplar had the highest content of cellulose and also showed a high yield of kraft pulp. The values for cellulose content in the current study are in accordance with those in the previous investigation (Treimanis *et al*., 2006; Ai & Tschirner, 2010; Zeps *et al*., 2012) or are slightly higher. The differences from other works can be explained as the dependence of pulp yield on the chosen pulping method conditions. Another important factor that indicates the pulp quality is the content of residual lignin. It can affect the production and utilisation of paper and paper products, and can influence both mechanical and optical properties. The highest number in the case of LP is logically connected with the results of the lignin content in wood, because softwood usually has more lignin than hardwood (Fengel & Wegener, 2003). The result of willow, in the case of the lignin content both in wood and in pulp, is closer to softwood characteristics. Based on the quite different information (Ai & Tschirner, 2010; Caslin *et al*., 2012) about the properties of willow wood and fibres, we can conclude about the strong dependence of these properties on external conditions.

Fibres of softwood normally are longer and wider than those of hardwood (Fengel & Wegener, 2003). Our study confirms (Table 2) this well-known fact with the exception of the case of willow. The result of 1.2 ± 0.08 disagrees with other studies (Ai & Tschirner, 2010), where 0.34 mm of the willow fibre length is given. Aspen, AH and poplar fibre length results are in accordance with the studies performed by Ai & Tschirner (2010) and Zeps *et al*. (2012). The claim of the dependence on growing conditions is testified by Treimanis *et al*. (2006), namely, if they are similar, fibre properties diversify insignificantly. Tree age is the main factor that influences fibre length. It is known that the average fibre length itself is not always a good predictor of the product properties, and every parameter must be taken into account. The form factor of fibre provides information about its shape. If it is 100%, the fibre is completely straight. In the pulping process, all natural wood fibres are deformed and the measured numbers are in the interval of 91–94%.

Obvious differences between the fine content in pulp were caused by the variety of species, tree age and diameter. Willow trees were the youngest samples in the current study, with a smaller average diameter; therefore the highest result of the fine content was detected. The presence and variations of fines can change the optical properties of paper products (Pauler, 2012), depending on the requirements for their quality. Different types of wood had different response (degree of delignification) during the kraft cooking, thus the optimization of cooking parameters is needed for each type to obtained fibers of similar/best properties.

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