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Hybrid aspen clone wood mechanical properties

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Abstract. The hybrid aspen is believed to be a suitable alternative to the European aspen for raw material supply, but information on its wood properties and their variations among clones is lacking. Nevertheless, its fast growth is associated with a decrease of wood density and mechanical strength. The aim of the study was to assess wood mechanical properties of the hybrid aspen clones and their relationship with growth traits. The tree height and diameter at breast height (DBH), basic wood density, compressive strength, modulus of rupture (MOR), and modulus of elasticity (MOE) were measured for three sample trees from 22 hybrid aspen clones and one common aspen clone. Significant (all $P < 0.001$) differences of assessed wood properties and growth traits were found among the hybrid aspen clones. At the clone mean level, compressive strength ranged from 26.6 ± 1.3 to 36.7 ± 0.8 N mm^{-2} and MOR and MOE were from 57.9 to 74.5 N mm^{-2} and from 7338.5 to 9734.6 N mm^{-2}, respectively. The mean wood density was 383 ± 3.1 kg cm^{-2}. It correlated significantly ($P < 0.001$) with MOR ($r = 0.66$), MOE ($r = 0.63$), and compressive strength ($r = 0.71$) at the individual tree level. All mechanical properties of the wood showed non-significant (all $P > 0.05$) correlation with growth traits. Therefore, selection of fast-growing clones will not interfere with the mechanical quality of wood. However, the suitability for structural applications should be cautiously tested due to the clonal variations.

Key words: *P. tremula* × *P. tremuloides*, basic wood density, bending strength, compressive strength.

INTRODUCTION

European aspen (*Populus tremula*) wood is used for high quality niche products as well as bulk or pulp and paper production, while its logging residues are suitable for bioenergy (Junkkonen & Heräjärvi, 2007; Bjurhager et al., 2008). The proportion of the available assortments (providing most of the financial income) is reduced, mainly due to wood discoloration, heart rot, and browsing (Borrega et al., 2009; Myking et al., 2011; Zeps et al., 2016). The hybrid *P. tremula* × *P. tremuloides* has similar or superior growth in comparison to other tree species or hybrids (Jansons, 2013, 2014a) as well as to its parental species (Yu et al., 2001), allowing the reduction of the rotation period to ca. 20 years (Rytter & Stener, 2005) in order to continuously select clones able to produce the highest increment in particular climatic conditions (Jansons et al., 2014b; Šēnhofa et al., 2016) and to further increase the increment with fertilisation (Bardule et al., 2013). Due to the fast growth and relatively short rotation in comparison to native species, the hybrid aspen has been increasingly planted in northern Europe (Tullus et al., 2012). It has similar wood properties to the European aspen (Junkkonen & Heräjärvi, 2007); therefore, it might be used as a suitable alternative to raw material supply. A number of mechanical properties are genetically determined (Zobel & Buijtenen, 2012), but rapid growth is associated with decreased wood density, which might limit wood processing possibilities. However, this relationship notably differs between species (Zhang, 1995) and might also differ between hybrid aspen clones. Therefore, the aim of the study was to assess (1) the mechanical properties of the wood of the hybrid aspen clones and (2) their relationship with growth traits.

MATERIALS AND METHODS

The study site is located in the central part of Latvia, near Iecava (56°60′ N, 24°15′ E), established with the initial density of 2500 trees ha^{-1}. At the age of 12 years, tree height and diameter at breast height (DBH) were measured for 22 hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) clones and one European aspen (*P. tremula* L.) clone, each represented by three to 49 trees. Afterwards, three sample trees (ramets) from each clone were cut. The sample trees were randomly selected from three diameter groups: close to the average, smallest diameter quartile, and largest diameter quartile of the particular clone. From each sample tree, the stem section was cut from the height of 1.3–3.3 m. These sections were dried to 10.6 ± 0.06% moisture content. Afterwards, from each section, samples of a precise size of the clear wood (without defects) were cut. For compressive strength, the size of the cut sample was 20 × 20 × 30 mm. For bending strength, represented by the modulus of rupture (MOR) and modulus of elasticity (MOE), the size of the sample was 20 × 20 mm transversely and 360 mm longitudinally. In total, 275 samples from 23 clones and 94 samples from eight clones were measured for compressive and bending strength, respectively. Each clone was represented by 10–15 wood samples for compressive strength and 10–15 wood samples for MOR and MOE. The parallel-to-grain compressive strength was measured according to standard DIN 52185, and the parallel-to-grain bending strength was measured according to standard DIN 52186. For each sample, basic wood density and moisture content were measured.

The Shapiro-Wilk test was used to assess the normality of the data. The one-way analysis of variance was used to assess differences of basic wood density, compressive strength, MOR, MOE, tree height, and DBH among the clones. Pearson's correlation was used to assess the relationship between the measured parameters among the clones. All tests were performed at $\alpha = 0.05$. All calculations were done in R 3.0.2. (R Core Team, 2013).

RESULTS AND DISCUSSION

The suitability of wood for certain types of production depends on its mechanical properties, namely wood density and bending and compressive strength (Bjurhager et al., 2008; Groover et al., 2010). In our study, the basic density of clones was from 337 ± 14 to 432 ± 16 kg m^{-3} (Table 1), which is considered relatively low in comparison to other species in the region (Rytter et al., 2013). Our results are in range of previously reported values for European and hybrid aspens. The latter tend to have lower basic density, while noticeable variations between studies occur. For instance, Bjurhager et al. (2008) found wood density to be 211 and 284 kg m^{-3} for hybrid and European aspens, respectively; Heräjärvi & Junkkonen (2006) reported densities of 376 and 363 kg m^{-3}. Similarly, Hart et al. (2013) found higher wood densities for intraspecific crossings between *P. tremula* clones (436.2 kg m^{-3}) in comparison to hybrid aspens (413.3 kg m^{-3}). Density variation ($P < 0.001$) was found among the clones, also confirmed by other studies (Zhang et al., 2003; Pliura et al., 2007).

Table 1. Mean values and confidence intervals of measured mechanical properties and growth traits of clones

Clone	Basic density, kg m^{-3}	Compressive strength, N mm^{-2}	MOR, N mm^{-2}	MOE, N mm-^{2}	Height, m	DBH, cm
34	432 ± 16.4	35.8 ± 1.40			15.6 ± 0.41	12.8 ± 0.73
26	422 ± 10.8	34.1 ± 0.93			13.9 ± 1.82	12.6 ± 2.41
36	422 ± 16.0	35.3 ± 2.04			15.4 ± 0.54	10.8 ± 0.59
4	420 ± 7.1	36.6 ± 2.24	74.5 ± 3.27	9735 ± 469.4	17.4 ± 0.48	13.8 ± 0.80
9	412 ± 10.0	36.7 ± 0.79			17.2 ± 0.33	13.4 ± 0.62
20	398 ± 8.6	34.8 ± 1.52			16.1 ± 0.49	13.7 ± 0.82
22	394 ± 6.1	34.2 ± 0.61	70.5 ± 5.08	8532 ± 584.8	16.0 ± 0.57	13.5 ± 0.94
15	394 ± 12.2	32.5 ± 2.30			16.2 ± 0.62	12.7 ± 1.00
19	393 ± 8.5	34.2 ± 0.93	67.0 ± 4.03	8242 ± 351.0	16.7 ± 0.53	13.4 ± 0.74
24	391 ± 6.3	34.8 ± 0.66			14.4 ± 0.66	11.6 ± 1.11
27	387 ± 9.8	30.9 ± 1.18	66.7 ± 1.80	8586 ± 273.5		
6	386 ± 8.7	31.5 ± 1.38			16.1 ± 0.27	12.1 ± 0.66
16	385 ± 9.4	33.7 ± 0.96			16.5 ± 0.31	13.9 ± 1.01
21	373 ± 8.0	33.0 ± 1.17			14.0 ± 1.12	10.6 ± 2.90
10	373 ± 4.4	32.4 ± 1.07	66.7 ± 2.77	7660 ± 245.0	16.7 ± 0.51	14.2 ± 0.87
12	373 ± 12.9	32.0 ± 1.11			14.0 ± 0.68	12.5 ± 0.91
25	372 ± 4.7	32.4 ± 1.01	64.2 ± 2.65	8045 ± 362.9	15.4 ± 0.67	12.5 ± 1.37
EA	371 ± 6.9	30.3 ± 1.10			14.7 ± 0.62	11.2 ± 1.01
3	366 ± 7.8	29.0 ± 0.49			15.7 ± 0.55	12.1 ± 0.80
41	362 ± 5.0	32.2 ± 0.98	64.1 ± 2.63	8068 ± 175.5		
28	353 ± 17.6	28.5 ± 1.78			14.2 ± 0.78	11.2 ± 0.69
30	341 ± 5.1	29.7 ± 1.16	57.9 ± 1.95	7338 ± 534.4	16.0 ± 0.45	14.0 ± 0.71
2	337 ± 14.2	26.6 ± 1.31			15.1 ± 0.4	14.1 ± 1.11
EA	371 ± 6.9	30.3 ± 1.10			14.7 ± 0.62	11.2 ± 1.01
mean	383 ± 3.1	32.6 ± 0.39	66.2 ± 1.38	8262 ± 193.4	15.7 ± 0.20	12.7 ± 0.15

EA – European aspen.

The MOR and MOE represent the bending strength and stiffness of wood, respectively. The MOR and MOE varied from 57.9 to 74.5 N mm^{-2} and from 7338.5 to 9734.6 N mm^{-2} (Table 1). Our results are somewhat higher than the mean values reported by Peters et al. (2002) for 11 hybrid poplar clones: 52.3 and 5680 N mm^{-2}, respectively. Results similar for MOR (53 to 62 N mm^{-2}) but lower for MOE (5314 to 6732 N mm^{-2}) were observed by De Boever et al. (2007) for *P. trichocarpa* × *P. deltoides* clones. Yet, significant (both $P < 0.001$) differences for both parameters among the clones were found in our study, also noted between other *Populus* hybrids and their clones (Carlson & Berger, 1998; Peters et al., 2002; De Boever et al., 2007). Like the other mechanical traits, the compressive strength showed significant differences between clones ($P < 0.001$) and was from 26.6 ± 1.3 to 36.7 ± 0.8 N mm^{-2}.

Wood density correlated significantly (all $P < 0.001$) with other mechanical properties at the individual tree level; the correlation coefficients were 0.66, 0.63, and 0.71 for MOR, MOE, and compressive strength, respectively. Similarly, a strong relation between density and MOR and MOE was found at the clone level (De Boever et al., 2007). A strong ($r = 0.84$, $P < 0.001$) correlation between MOE and MOR was found, as observed for other diffuse porous hardwoods (Heräjärvi, 2004).

The DBH and height showed significant (both $P < 0.001$) differences between clones and was from 10.6 ± 2.9 to 14.2 ± 0.9 cm and from 13.9 ± 1.8 to 17.4 ± 0.5 m, respectively. None of the clones showed noticeable superiority of DBH, while few clones (e.g., Clone 36) had significantly lower DBH than the mean of the rest of the clones. The height variation was more pronounced — several clones (e.g., Clones 12 and 24) were significantly lower, but Clone 4 and Clone 9 significantly exceeded most of the other clones. However, no significant relation between growth (DBH and height) and mechanical parameters was found at the clone mean level (Table 2). This is consistent with other findings that indicate a non-significant relationship between wood density and DBH or height for hybrid aspen (Ilstedt & Gullberg, 1993), *Populus xiaohei* (Jiang et al., 2007), and several other *Populus spp*. hybrids (Zhang et al., 2003). No clear relation between growth rate and wood density has been found for other diffuse porous hardwoods (Zhang, 1995) and, in specific cases, also for clones of softwoods (Jansons et al., 2016). In contrast, other studies reported negative significant relations between density and growth traits for *Populus* × *euramericana* clones (Hernández et al., 1998) as well as for several other *Populus spp*. clones (Pliura et al., 2007).

Table 2. Pearson's correlation coefficients and their *p*-value for the wood properties and growth traits at the clone mean level

Growth traits	Basic density		Compressive strength		MOR		MOE	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*
DBH	-0.05	0.39	0.08	0.72	0.02	0.97	-0.09	0.87
H	0.26	0.26	0.37	0.10	0.62	0.19	0.60	0.21

CONCLUSIONS

Significant (all $P < 0.001$) differences of assessed wood properties (basic density, compressive strength, MOR, and MOE) and growth traits (tree height and DBH) were found among the hybrid aspen clones. All mechanical properties of wood significantly intercorrelated (all $P < 0.001$) and showed non-significant (all $P > 0.05$) correlation with growth traits. Therefore, the results suggest that selection of fast-growing clones will not interfere with the mechanical quality of the wood. However, the suitability for structural applications should be cautiously tested due to clonal variations.

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