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Abstract: Silver birch, a widely distributed deciduous tree native to Europe, is valued for its wood applications in construction, furniture making, and paper production. In Lithuania, silver birch ranks as the third most common forest tree species, comprising 22% of forested areas, and is an important species for tree breeding due to its potential and adaptability. This study was focused on assessing the mechanical properties of wood (sample and log hardness, wood density, dynamic modulus of elasticity (MOEdyn), static modulus of elasticity (MOE) and bending strength (MOR)) in silver birch (Betula pendula L. Roth.) trees from different half-sibling families. Two experimental plantations of the progenies of Lithuanian populations (half-sib families) of silver birch from different regions were analyzed. From these plantations, two genetic families were selected to represent the hardest and the softest wood based on wood hardness values; two genetic families represented non-plastic and plastic genetic family, determined by the Shukla ecovalence coefficient. The study findings revealed significant variability in various wood properties among different genetic families, although the static modulus of elasticity did not exhibit significant differences between the chosen genetic families. All measured wood properties decreased from the bottom to the top of the model trees. Wood hardness displayed a moderately negative correlation with wood density and weak correlations with MOE and MOR. Given the weak correlations between wood hardness and other wood mechanical properties, it is suggested that the MOEdyn would be a more suitable trait for genetic studies.

Keywords: silver birch; wood hardness; half-sib families; modulus of elasticity; wood density

1. Introduction

Silver birch (Betula pendula Roth) is a deciduous tree species native to Europe and parts of Asia. It is widely distributed and valued for its wood, which has various applications in construction, furniture making, paper production, and more. Understanding the mechanical properties of silver birch wood is essential for optimizing its utilization in different industries.

Silver birch is the third most spread forest tree species in Lithuania. Birch stands comprise 22 % of the area occupied by forest [1]. Silver birch is the most common and perspective tree species for tree breeding in Lithuania [2]. From 2006 in Lithuanian field trial test for genetic half-sib families wood properties evaluation, the wood hardness was added as a trait measured by Pilodyn 6J Forest device. Earlier studies selected Pilodyn device for non-destructive testing and get good negative correlation with basic wood density [3]. Even though wood hardness is used as a trait for genetic studies the main parameters used for measuring wood quality in the industry are wood density, modulus of elasticity and bending strength [4,5]. Wood density is an important indicator of wood quality and is closely related to its mechanical properties [6,7]. The density of silver birch wood ranged from approximately 550 to 650 kg/m³ [8]. The elastic modulus, also known as modulus of

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elasticity, reflects the stiffness of wood and its ability to withstand deformation under load. that the previous studies showed that the elastic modulus of silver birch wood was in a range of 10 to 15 GPa [8,9].

Overall, silver birch exhibits remarkable ecological plasticity and can adapt to diverse environmental conditions. Genetic studies have revealed evidence of local adaptation in silver birch populations, with certain genotypes displaying superior performance in specific habitats [10,11]. Understanding the genetic basis of local tree species adaptation is crucial for conservation efforts and forest management practices, particularly under the climate change situation. Several studies were focused specifically on wood quality parameters of conifer species and the influence of forest management on wood density, modulus of elasticity and stiffness [12-15]. As emphasized in the European Green Course and the EU Forest Strategy for 2030, it is appropriate to pay more attention to other tree species and their wood parameters, especially in the context of climate change [16,17].

This study aimed to evaluate the mechanical wood properties of silver birch (Betula pendula Roth) trees of different half-sib families.

2. Materials and Methods

The study objects were selected in the experimental plantations of the progenies of Lithuanian populations (half-sib families) of silver birch from different regions of origin (Table 1). All selected plantations were established in 1999.

Table 1. Description of experimental plantations of the progenies of birch populations in Lithuania.

No.	Plantation	Area, ha	North latitude	East longitude	Altitude, m	Region of provenance	Climate Continental index	/ Forest site type*	Number of population / families
1	Šiauliai, Lukšiai	1.4	55°58′	23°09′	120	1	Intermediate /27	Nb	24 / 111
2	Kaunas, Dubrava	1.5	54°55′	23°27′	75	2	Intermediate /27	Ld	24 / 109

Nb: mineral low-fertility soil of normal moisture regime; Ld: temporary overmoistured mineral very fertile soil according to the Lithuanian classification of forest site types [18].

Each of the 24 populations in the experimental plantations were represented by 5 progeny families, for a total of 101 families. The experimental design included 6 blocks, and trees of each family were grown in one row of 10 trees located randomly within the block. Tree seedlings were planted in rows every 2.0-2.3 m, leaving a distance of 1.5 m between seedlings in the rows by strips using a mill (in Dubrava plantation) or using a soil plough (in Šiauliai plantation).

All standing trees in the experimental plantations were measured wood hardness with a Pilodyn 6J device (Table 2). Wood hardness was taken as the representative traits for wood quality in tree genetic plasticity studies. Phenotypic plasticity was evaluated by the Shukla [19] method and by calculating the ecovalences of the families and their statistical significance.

The number of measured trees per family per test was calculated to determine the average number of trees per genetic family. The adjusted sum of mean squares of a feature was calculated for each family using the SAS procedure MEANS. The total sum of mean squares was calculated as well. The Shukla ecovalence coefficient was calculated according to the following equation (1).

$$shukla = (n\_fam * (n\_fam - 1) * ss - sss)/((n\_site - 1) * (n\_fam - 1) * (n\_fam - 2)), \quad (1)$$

here, n_fam – number of families, ss - the sum of mean squares of the trait, sss - the total sum of mean squares of the trait, and n_site - number of tests.

For the evaluation of wood mechanical properties, four representative half-sib families were selected by wood hardness trait of standing trees. The genetic families with not less than 30 remaining standing trees were selected. The ANOVA Duncan multiple range test was used for all selected families to ensure the significant differences between the genetic families with the hardest and softest wood. Two genetic families were selected following such principles: (1) one family with the lowest

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mean values of wood hardness represented the hardest wood, and one family with the highest wood hardness values to represented the softest wood; (2) one family was chosen to represent the non-plastic genetic family and one family represented the plastic genetic family, calculated by the Shukla ecovalence coefficient (Table 2).

Table 2. Distribution of silver birch genetic families by wood hardness measured by Pilodyn 6J. Different letters mean the significant difference between parameters by ANOVA Duncan multiple ranges at a significant level p<0.05.

Family No.	Mean of Pilodyn	Std. Dev	Std. Error	Duncan multiple range test	Family No.	Mean of Pilodyn	Std. Dev.	Std. Error	Duncan multiple range test
52-172	22.44	1.54	0.24	T	**60-76**	23.29	1.34	0.21	LFKNJQIRHOPGM
52-169	22.49	1.44	0.18	ST	**15-132**	23.31	1.12	0.15	LFKNJQIRHOPGM
20-125	22.50	1.34	0.17	ST	**49-74**	23.35	1.57	0.17	LFKNJQIEHOPGM
45-99	22.56	1.11	0.18	SRT	**18-50**	23.39	1.45	0.21	LFKNJQIEHOPGM
01-113	22.57	1.30	0.23	SRT	**52-171**	23.39	1.11	0.15	LFKNJQIRHOPGM
20-128	22.70	1.74	0.24	SQRT	**49-72**	23.40	1.31	0.22	LFKNJQIEHOPGM
52-173	22.77	1.58	0.25	SQRPT	**45-98**	23.41	1.52	0.26	LFKNJQIEHOPGM
16-162	22.79	1.57	0.24	SQRPT	**54-83**	23.43	1.13	0.15	LFKNJQIRHOPGM
54-84	22.80	1.26	0.20	SQROPT	**51-86**	23.45	1.18	0.13	LFKNJQIEHOPGM
47-92	22.85	1.63	0.24	SNQROPT	**37-56**	23.47	1.51	0.20	LFKNJDIEHOPGM
40-118	22.94	1.34	0.19	SNQROPTM	**47-91**	23.53	1.61	0.27	LFKNJDIEHOPGM
34-63	22.96	1.60	0.22	SNQROPTM	**43-65**	23.56	1.16	0.20	LFKNJDIEHOGM
34-59	23.00	1.08	0.17	LSNQROPTM	**18-21**	23.57	1.81	0.25	LFKNJDIEHGM
49-71	23.00	1.43	0.21	LSNQROPTM	**43-PL**	23.60	1.71	0.29	LFKNJDIEHCGM
54-81	23.00	1.29	0.21	LSNQROPTM	**51-89**	23.66	1.37	0.20	LFKBJDIEHCGM
S-43	23.00	1.20	0.19	LSNQROPTM	**20-124**	23.74	1.34	0.20	LFKBJDIEHCG
45-100	23.03	1.17	0.20	LSKNQROPTM	**40-119**	23.75	1.58	0.23	LFKBJDIEHCG
49-73	23.04	1.64	0.22	LSKNQROPTM	**37-54**	23.76	0.99	0.13	LFKBJDIEHCG
01-111	23.07	1.46	0.26	LSKNQROPTM	**18-48**	23.76	1.20	0.17	LFKBJDIEHCG
40-120	23.09	1.51	0.26	LSKNQROPTM	**43-64**	23.79	1.62	0.22	FKBJDIEHCG
43-68	23.09	1.14	0.17	LSKNQROPTM	**37-55**	23.88	1.14	0.17	FBJDIEHCG
60-75	23.12	1.43	0.22	LSKNJQROPTM	**51-87**	23.89	1.37	0.17	FBJDIEHCG
19-142	23.12	1.63	0.25	LSKNJQROPTM	**S-39**	23.90	0.98	0.17	FBDIEHCG
47-93	23.14	1.35	0.22	LSKNJQIROPTM	**43-BSM**	23.91	1.53	0.27	FBDIEHCG
49-69	23.14	1.45	0.24	LSKNJQIROPTM	**51-90**	23.95	1.23	0.16	FBDEHCG
43-66	23.15	1.33	0.21	LSKNJQIROPTM	**39-155**	24.00	0.97	0.16	FBDECG
60-77	23.17	1.37	0.16	LSKNJQIROPTM	**37-57**	24.04	1.08	0.14	FBDEC
33-175	23.17	1.27	0.18	LSKNJQIROPTM	**18-47**	24.06	1.10	0.19	BDEC
34-60	23.21	1.28	0.18	LSKNJQIRHOPM	**37-53**	24.08	1.68	0.27	BDEC
38-143	23.23	1.38	0.24	LSKNJQIRHOPM	**66-150**	24.09	1.17	0.19	BDEC
01-112	23.23	1.41	0.18	LSKNJQIRHOPM	**60-78**	24.21	1.36	0.21	BDAC
16-130	23.25	1.26	0.16	LSKNJQIRHOPGM	**47-94**	24.21	1.56	0.23	BDAC
16-163	23.27	1.50	0.18	LKNJQIRHOPGM	**39-154**	24.32	1.06	0.18	BAC
16-161	23.27	1.41	0.17	LKNJQIRHOPGM	**34-58**	24.36	1.38	0.20	BA
51-88	23.29	1.51	0.20	LFKNJQIRHOPGM	**60-79**	24.78	1.08	0.16	A
18-52	23.29	1.82	0.32	LFKNJQIEHOPGM					

The genetic family 52-172 was identified as the family with the hardest wood, and the family 60-79 - with the softest wood (Table 2). Genetic family 51-88 was selected as representative of the non-plastic family , and family 49-69 – as representative of the plastic genetic family. According to the mentioned parameters, three model trees were selected per each genetic family in the experimental plot. The selected trees were cut and transported to the laboratory. Altogether, 24 trees were cut, 12 were sampled in Kaunas and 12 in Šiauliai experimental areas. The model tree stems were sorted into 3-meter logs across the length of the stem. Three to four representative sections were taken from each tree stem for wood mechanical properties determination. In the laboratory, 3-meter logs were divided into 1-meter sections, as shown in Figure 1.

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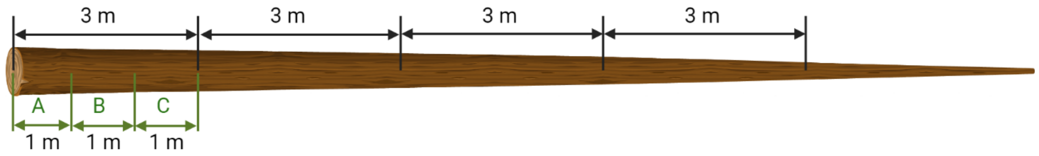


Figure 1. Model tree sampling.

For each 1-meter section, the wood hardness was measured with a Pilodyn 6J device at three points (Figure 2).

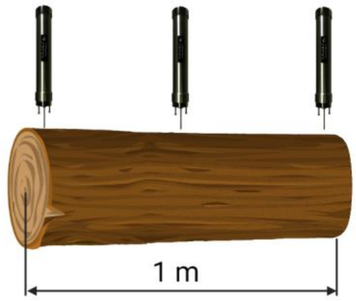
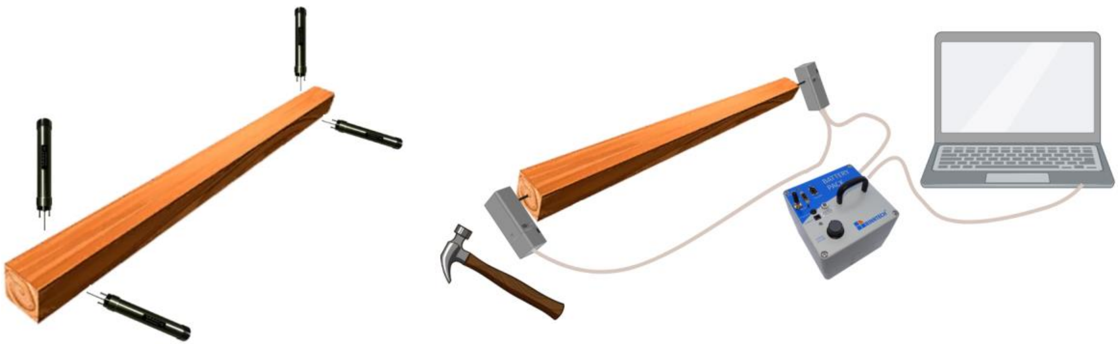


Figure 2. Scheme for wood hardness measurement places on log samples.

Wood samples of 50×50×1000 mm were cut from the logs. Altogether, 520 wood samples were prepared. For wood samples, wood hardness at four points, dynamic modulus of elasticity (MOEdyn), static modulus of elasticity (MOE) and bending strength (MOR) were measured.. The wood hardness and MOEdyn test schemes are shown in Figure 3.



(**A**) (**B**)

Figure 3. Wood hardness test scheme for wood samples (A) and wood propagation speed measurement by ARBOTOM 3D (B).

The wood hardness for wood samples was performed with a Pildoyn 6J device. The MOEdyn was measured by multiplying wood density and sound propagation speed according to the equation (2). The sound propagation speed was measured by ARBOTOM 3D acoustic tomography.

$$MOEdyn=V^2\rho; \quad (2),$$

here: *MOEdyn* - dynamic modulus of elasticity (N mm^{-2}); ρ – wood density (kg m^{-3}); V – wave propagation speed (m s^{-1}).

In the laboratory, all wood samples were tested with a Bending Testing Machine 500 kN (FORM+TEST Seidner&Co. GmbH). The tests were done following the methodology given in Standard EN 408:2006 [20]. The samples were tested in a four-point bending test. The MOE and MOR were evaluated and calculated at 12% moisture content according to Standard EN: 384:2016 [21]. The static modulus of elasticity was calculated according to equation (3).

$$MOE \quad \frac{l^3(F_2-F_1)}{bh^3(w_2-w_1)}\left[\left(\frac{3a}{4l}\right)-\left(\frac{a}{l}\right)^3\right]; \quad (3),$$

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here: *F1-F2* – is an increment of load on the straight-line portion of the load deformation curve, 0,2 F_{max} (F_2) ir 0,4 F_{max} (F_1), N; *ω2-ω1* – is the increment of deformation corresponding to *F2-F1*, mm; *l* - span, mm; *a* - distance between a loading position and the nearest support, mm; *b* - width of cross section, mm; *h* - depth of cross section, mm.

A random wood sample was cut from each broken specimen to determine the wood density. The wood density was determined using equation (4).

$$\rho_w = \frac{m_w}{a_w b_w l_w}\ ; \qquad (4),$$

here: ρ_w – wood density, kg m^{-3}; m_w – mass of the sample, kg; a_w, b_w – cross-section dimensions of the sample, m; l_w – length of the sample, m.

To determine wood density, the samples were cut near the breakage point immediately after the bending test. The moisture content was determined by the oven-dry method according to Standard EN: 13183-1:2002 [22]. The wood density was calculated using the mass/volume ratio according to the equation (5). The values at 12% moisture content were calculated according to Standard EN 384:2016 [21].

$$W = \frac{m - m_0}{m_0} * 100\%; \ (5),$$

here: *W* – moisture content, %; *m* – wet sample mass, g; m_0 – dry sample mass, g.

The statistical analysis of ANOVA and correlations were performed with SAS 9.4. statistical program.

3. Results

The main values of the tree diameter at breast height (DBH), tree height, log hardness, sample hardness, wood moisture, wood density, dynamic modulus of elasticity (MOEdyn), static modulus of elasticity (MOE) and bending strength (MOR) of silver birch of different genetic families are summarized in Table 3. Mean tree DBH of model trees varied in a range from 16.2 cm in the birch genetic family representing the soft-wood to 18.5 cm in the non-plastic genetic family. The mean height of model trees ranged from 17.0 m to 20.0 m, the tree with the largest height of 22.3 m was found in the genetic family with hard wood and the lowest height tree of 14.5 m was found in the non-plastic genetic family. The mean log hardness values between genetic families varied slightly from 17.0 mm to 18.7 mm.

Table 3. Summary of the descriptive statistics of the main parameters by different genetic families.

Parameter	Units	Mean	Std Dev	Std Error	Minimum	Maximum	Probability
				Hard			
Tree DBH	cm	18.20	2.10	0.16	12.90	20.70	
Tree Height	m	20.04	1.94	0.15	15.10	22.30	
Log hardness	mm	18.61	1.26	0.10	15.67	21.67	
Sample hardness	mm	10.15	1.26	0.10	7.00	14.25	
Moisture	%	9.68	1.22	0.09	7.32	1952	<0.0001
Density	Kg/m³	545	37.04	2.81	487	661	
MOEdyn	N/mm²	12489	1773.58	134.45	7637	17267	
MOR	N/mm²	52.71	9.83	0.75	22.14	81.96	
MOE	N/mm²	11386	2239.75	169.79	4608	17571	
				Non-Plastic			
Tree DBH	cm	18.50	1.87	0.17	14.50	20.75	
Tree Height	m	18.13	1.69	0.15	14.50	20.20	
Log hardness	mm	17.65	1.38	0.13	15.33	21.00	<0.0001
Sample hardness	mm	10.07	1.71	0.16	7.00	15.25	
Moisture	%	9.83	1.11	0.10	8.09	13.15	

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Density	Kg/m³	568	52.45	4.81	470	712	
MOEdyn	N/mm²	12028	1967.27	180.34	8213	18316	
MOR	N/mm²	51.00	10.85	0.99	15.26	78.43	
MOE	N/mm²	10916	2493.07	228.54	3428	16777	
Plastic							
Tree DBH	cm	17.48	2.85	0.26	14.85	22.35	
Tree Height	m	18.67	1.44	0.13	16.20	20.10	
Log hardness	mm	17.52	1.16	0.11	14.67	20.33	
Sample hardness	mm	9.61	1.26	0.11	6.75	15.50	
Moisture	%	9.36	0.74	0.07	7.60	11.02	<0.0001
Density	Kg/m³	578	39.99	3.64	513	705	
MOEdyn	N/mm²	12776	1923.60	174.87	8221	18616	
MOR	N/mm²	54.67	9.71	0.88	30.34	76.12	
MOE	N/mm²	11255	2318.79	210.80	5742	17166	
Soft							
Tree DBH	cm	16.16	2.02	0.20	13.30	18.55	
Tree Height	m	17.04	0.94	0.09	15.50	18.20	
Log hardness	mm	17.00	1.01	0.10	14.00	19.00	
Sample hardness	mm	9.94	1.38	0.14	6.75	14.00	
Moisture	%	9.49	0.95	0.09	7.45	12.75	<0.0001
Density	Kg/m³	571	44.32	4.33	499	704	
MOEdyn	N/mm²	12423	1776.47	173.37	7351	16267	
MOR	N/mm²	54.34	9.61	0.94	30.69	73.17	
MOE	N/mm²	11222	2209.71	215.65	4406	16961	

The variation of the sample hardness, wood density, MOEdyn, MOE, and MOR in relation to the genetic families is given in Table 3 and Figure 4. The highest sample hardness value was found in the plastic genetic family (15.5 mm), and the lowest value of sample hardness was found in the genetic family with the soft-wood (14.0 mm). The mean values of wood hardness in the samples were similar for all genetic families and varied from 9.6 mm to 10.2 mm. The mean moisture content of the samples was 9.6 %. The mean wood density ranged between 545 to 578 kg/m³. The differences between mean MOEdyn in the studied genetic families varied in a narrow range from 12028 N/mm² (for non-plastic family) to 12776 N/mm² (for plastic family). The highest mean values of MOR were found for the plastic family, and the lowest mean values – for the non-plastic family with 6.7% difference between the genetic families. The mean MOE ranged from 10916 N/mm² to 11386 N/mm² between the genetic families.

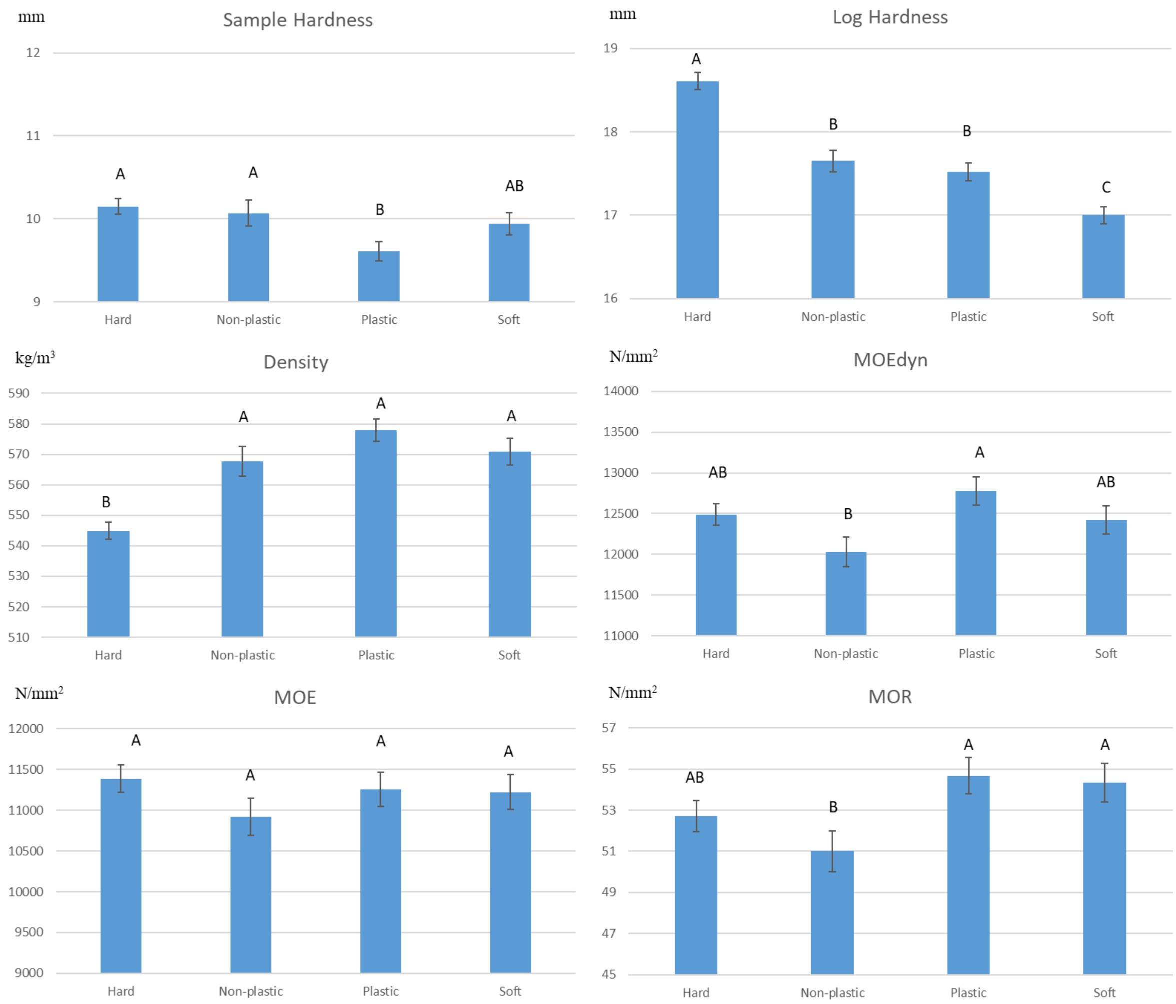

Figure 4. The main birch wood parameters - sample and log hardness, wood density, dynamic modulus of elasticity (MOEdyn), static modulus of elasticity (MOE) and bending strength (MOR) – in different genetic families. Different capital letters above the columns show significant differences between the wood from selected genetic families by ANOVA Duncan multiple range test at significant level p<0.05.

The significantly lowest mean sample hardness was found for the plastic genetic family compared to other genetic families (Figure 4). For the log hardness, the genetic families representing the soft-wood and hard-wood significant differedby 9%. The lowest mean wood density was found for the genetic family representing the hard-wood and this value significantly differed from other genetic families. The MOEdyn significantly differed between the plastic and non-plastic genetic families. The MOE was similar in all studied genetic families and the MOR in the non-plastic genetic family was significantly lower than in other genetic families (Figure 4).

The wood mechanical properties of different tree stem sections are shown in Figure 5. Analysis of the hardness of the wood sample revealed that there was a large difference between the stem sections: the hardest wood samples were in the Ist stem section. This parameter decreased significantly from the stem bottom to the top, and the diffeence between the stem sections I and IV was about 18%. The log hardness showed significant difference between the stem sections I-III and IV. The highest mean wood density was found in the stem bottom section. There were no significant differences in wood density between other stem sections. The highest mean MEOdyn was found the II stem section. The MOE and MOR showed a decreased trend from section I to section IV, which was 11% for MOE and 13% for MOR.

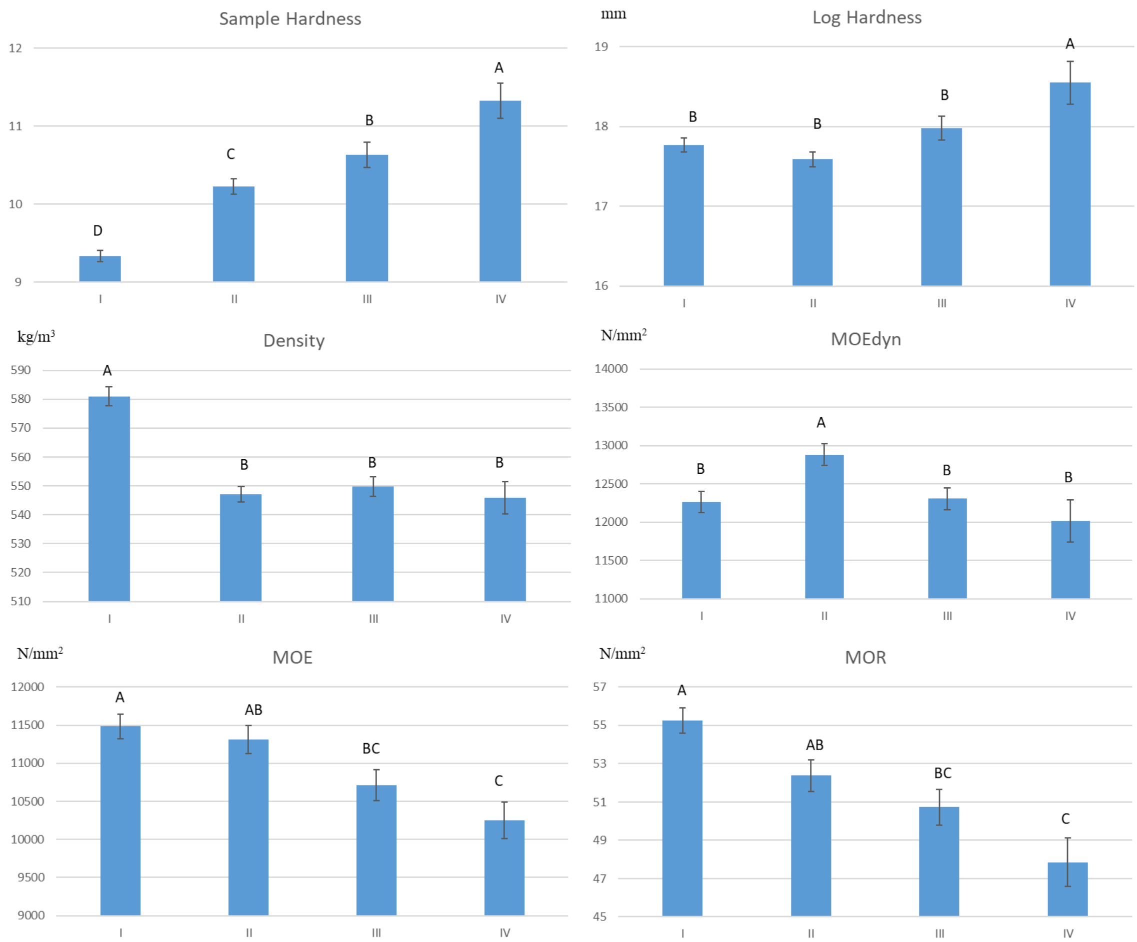

Figure 5. The differences in the main birch wood parameters - sample and log hardness, wood density, dynamic modulus of elasticity (MOEdyn), static modulus of elasticity (MOE) and bending strength (MOR) – in different stem sections (obtained from the tree bottom to the tree top). Different capital letters above the columns show significant differences between different stem sections by ANOVA Duncan multiple range test at significant level $p<0.05$.

To compare the relations between tree and wood parameters, the Pearson correlations were analysed (Table 4).

Table 4. The relationship between main wood parameters and the tree parameters by Pearson correlations. Bold values mean statistically significant correlations.

Parameter	Tree DBH*	Tree Height	Log hardness	Sample hardness	Wood Density	MOEdyn	MOR	MOE
Tree DBH		-0.07273	**0.35531**	**-0.15055**	**0.12787**	0.00703	-0.07027	-0.01384
p <0,05		0.0979	**<.0001**	**0.0006**	**0.0035**	0.8731	0.1098	0.7531
Tree Height	-0.07273		-0.03773	0.06689	**-0.33369**	0.08393	-0.03367	**0.09071**
p <0,05	0.0979		0.391	0.1281	**<.0001**	0.056	0.444	**0.0388**
Log hardness	**0.35531**	-0.03773		**0.25161**	**-0.17284**	**-0.20031**	**-0.08731**	**-0.10048**
p <0,05	**<.0001**	0.391		**<.0001**	**<.0001**	**<.0001**	**0.0468**	**0.0221**
Sample hardness	**-0.15055**	0.06689	**0.25161**		**-0.6701**	**-0.25045**	**-0.20996**	**-0.17597**
p <0,05	**0.0006**	0.1281	**<.0001**		**<.0001**	**<.0001**	**<.0001**	**<.0001**
Wood Density	**0.12787**	**-0.33369**	**-0.17284**	**-0.6701**		**0.19008**	**0.18013**	**0.09168**
p <0,05	**0.0035**	**<.0001**	**<.0001**	**<.0001**		**<.0001**	**<.0001**	**0.0368**
MOEdyn	0.00703	0.08393	**-0.20031**	**-0.25045**	**0.19008**		**0.40588**	**0.4848**
p <0,05	0.8731	0.056	**<.0001**	**<.0001**	**<.0001**		**<.0001**	**<.0001**
MOR	-0.07027	-0.03367	**-0.08731**	**-0.20996**	**0.18013**	**0.40588**		**0.86457**
p <0,05	0.1098	0.444	**0.0468**	**<.0001**	**<.0001**	**<.0001**		**<.0001**
MOE	-0.01384	**0.09071**	**-0.10048**	**-0.17597**	**0.09168**	**0.4848**	**0.86457**	

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p <0,05	0.7531	**0.0388**	**0.0221**	**<.0001**		**0.0368**	**<.0001**	**<.0001**	

*DBH – tree diameter at breast height / 1.3 m above ground level; MOEdyn - dynamic modulus of elasticity, MOE - static modulus of elasticity and MOR - bending strength.

The strongest correlation was found between the MOE and MOR parameters (r=0.86) (Table 4). Wood density significantly correlated with all selected parameters. The MOEdyn correlated with the MOE (r=0.48) and the MOR (r=0.41). The sample hardness strongly correlated with the wood density (r=-0.67). The Tree DBH correlated with the log hardness (r=0.36) and the sample hardness (r=-0.15). However, the wood density had weak correlations with MOEdyn (r=0.19), MOE (r=0.18) and MOR (r=0.09). Most of the evaluated parameters showed low or moderate correlations.

4. Discussion

The study results demonstrated tree genetic effect on wood qualityparameters sample and log hardness, wood density, dynamic modulus of elasticity (MOEdyn), static modulus of elasticity (MOE) and bending strength (MOR). The findings of this study showed that different half-sib families caused various responses on wood quality characteristics of Silver birch trees. Previous studies, for example that conducted in Sweden, also showed high variation in wood hardness - from 8.3 to 24.1 mm - for Silver birch standing trees [23]. This is an even larger variation in wood hardness compared to our study log hardness parameters. These differences may be due to different tree age and specific growing conditions. Another study in Sweden showed similar mean wood hardness parameters to our study (17.4 mm) for standing trees obtained with a Pilodyn instrument for silver birch [24].

There was a wide range of wood density parameters in the genetic progeny test plots, as shown in the Swedish studies, where average wood density values ranged from 408 to 444 kg/m^3. [23,24]. The wood density determined during the genetic studies in Sweden was 21-28% lower than the data from the genetic research in Lithuania. These differencies could be caused by different genetic material of trees and specific growing conditions. Other studies conducted in the 30-year-old Silver birch stands in different regions of Poland showed higher mean wood density values, which were 512 kg/m^3. Mean values of wood density have been found to increase with age, and 70-year-old trees have higher wood density than 30-year-old trees [25].The results obtained in Poland reflect the distribution of wood density between different tree parts found in our study. Previous studies in Wales and Scotland (UK) also showed a significant effect of wood density on silver birch growth rate, with faster growing trees having significantly lower wood density compared to slow growing trees [26]. Relationship between wood hardness and nondestructive wood quality parameter - acoustic velocity - was different in different Swedish studies. Positive relatively weak relationship was found in Jones et al. [23] study with r values of 0.09 and 0.16. Later studies by Jones et al. [24] showed negative correlation between the acoustic velocity and wood hardness (r=-0.18). Our study results showed negative correlation between MOEdyn calculated by acoustic velocity and wood density values with log (r=-0.20) and sample hardness (r=-0.25). Correlation in both Sweden studies showed moderate relationship between the wood hardness and wood density [23,24]. Similar trends were found in our study for Lithuania genetic trials. The relationship between different locations and different stand age in Sweden varied from r=-0.36 to r=-0.62.

Analysing the MOE and MOR parameters for Silver birch in Finland, the MOE was 13620 N/mm^2 and the MOR was 43,9 N/mm^2 for the wood samples with knots. Higher values were found for wood samples without knots, when the MOE was 16530 N/mm^2 and the MOR – 52.7 N/mm^2 [27]. The mentioned study found strong correlation between MOE and MOR for all tested samples (r=0.87). In comparison to Finlad study, our results showed lower mean values for MOE and MOR of Silver birch but similar correlation between these two parameters. The lower MOE and MOR mean values in Lithuania could be caused by young tree age and measured samples from full tree height, because of high variation of wood parameters within tree. From our study results, it is clear that MOE and MOR values decreaced from tree bottom to tree top. The decreace in MOE values was found in the Silver birch stands with different growing rates in Wales and Scotland [26]. This study showed that the mean MOE in slow grown stand was 12668 N/mm^2 and in fast grown stand 8108 N/mm^2.

The wood density - one of the main wood quality parameters - moderately strongly correlated with the MOE (r=0.67) and the MOR (r=0.66) parameters in the Finland study [27]. Erlier study in Sweden show stronger correlations between wood density and MOE (r=0.85) [28]. Other study from China and USA found strong correlation between the wood density and the MOE obtained using SilviScan [29]. The authors found that the relationship between the wood density and MOE was r=0.85 for 10 different hardwood species [29]. Our study showed weak corelation between the wood density with MOE and MOR. The relations between the mentioned parameters could be improved by increasing the number of model trees and more diverse tree age of the samples. The different results of this study may have been due to some limitations, one of which is the limited selection of model trees, as genetic trials are very valuable for genetic selection and genetic studies, and strictly regulated selection of only specific trees were alowed to use for this study. Due to limited selection of the model trees, all tree parts (sections) were taken in this study. Under these conditions, some wood quality parameters may be lower due to a certain proportion of samples from the tree top, which contain larger amount of juvenile wood, which may decrease the wood quality parameters. Different site conditions in the Silver birch genetic trials in Lithuania could also be taken as limitation of this study. Additional research is needed in the future and it is necessary to measure more model trees and more half-sib families in the future after next generation gentic trials for Silver birch would be established in Lithuania.

5. Conclusions

In this investigation, the aim was to assess the wood mechanical properties between half-sib families of Silver birch and to analyze the relationship between the wood hardness parameter and other wood properties. This study has identified high variability of different wood properties between different genetic families, although static modulus of elasticity did not show significant differences between the selected genetic families. All measured wood properties decreased from tree bottom to top of the model trees.

The wood hardness showed moderately negative correlation with wood density, and weak correlations with static modulus of elasticity and bending strength. Due to weak correlations between wood hardness and other wood mechanical properties, it is likely that dynamic modulus of elasticity would be a more appropriate trait for genetic studies. Further efforts are needed to obtain more accurate results by studying a larger number of model trees.

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