RIGA TECHNICAL UNIVERSITY
Faculty of Material Science and Applied Chemistry
Institute of Polymer Materials

Gunars Pavlovics

RESEARCH OF CHARACTERISTICS OF LATVIAN INNOVATIVE FURNITURE PRODUCTION AND BUILDING MATERIAL OF WILD CHERRY (*PRUNUS AVIUM* L.) WOOD

Summary of the Doctoral Thesis

Riga 2011

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Doctoral student of Chemical Technology studies programme

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Riga 2011

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DECLARATION

I hereby confirm that I have developed this doctoral thesis, which is submitted for consideration at Riga Technical University for acquisition of a doctoral degree. The doctoral thesis has not been submitted to any other university acquisition for a scientific degree.

Gunārs Pavlovičs…………………………….(Signature)

Date: ………………………

The doctoral thesis has been written in Latvian and contains introduction, review of literature (4 chapters), methodical part (5 chapters), experimental part (5 chapters), comparative part (2 chapters), conclusions and the bibliography.
The thesis contains 72 images, 22 tables and bibliography, which includes 127 literary sources.

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G.Pavlovičs

Riga, 20.06.2011.

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TABLE OF SYMBOLS

R	butt end
¼	one fourth of a tree height
½	one half of a tree height
¾	three thirds of a tree height
Ra	radial direction
Tg	tangential direction
Aks	axial direction
V	volume, cm^3
ρ_o	absolute dry wood density kg/m^3 at moisture W=0 %
$\rho_{sv.c.}$	green wood density, kg/m^3
ρ_{12}	wood density kg/m^3 at standard moisture 12 %
α	wood swelling, %
β	wood shrinkage, %
W	wood moisture, %
$W_{\bar{u}}$	wood water-absorbing capacity, %
τ_{12}	shearing strength at moisture 12 %
K_α	swelling coefficient, %/%
K_β	shrinkage coefficient, %/%

ESSENCE AND TOPICALITY OF THE PROBLEM

Owing to early maturation of the wild cherry (*Prunus avium* L.), as well as to the decorative characteristics of its wood (figuratively it can be called Latvian mahogany) and relatively high physical and mechanical properties, it has recently been recognised as a promising and valuable species in Western European countries [1].

The trees of all wild cherry species grow very strong, with round or roundish crown. Branches form an angle of 45^0 or greater, wild cherry stems often suffer from frost, because the bark is fairly thin [2, 3].

Currently there is no sufficient information about the structure of wood of the wild cherry growing in Latvia, as well as its physical and mechanical properties. Therefore, it is important to study the advantages and shortcomings of Latvian wild cherry wood in comparison with other species and cherry wood grown in other countries. Such information could stimulate wider usage of wild cherry wood.

Due to the fact that the demand for wild cherry wood is growing in the international market and in Latvia they started growing wild cherries in plantations for wood production, some studies have been performed in order to explore the characteristics of the wood of the wild cherry growing in Latvia. In this thesis wild cherry trees from different Latvian groves have been studied. The research covers the cherry trees 19 to 20.5 m high, breast high (1.3 m) diameter of 27.0 to 32.0 cm, 31 to 43 years old. The research has been carried out for the samples from four heights of the stem (butt end, ¼, ½, ¾), in direction from heartwood to bark. Studies of different characteristics of wild cherry wood have been performed, such as morphological, physical, mechanical, technological, optical, thermophysical and chemical. The received results allow to assume that the wood of wild cherry grown in Latvia should be competitive in the international market.

Topicality of the subject

Owing to the great potential of Latvian forests (percentage of forest land exceeds 50%), timber products, wood and the products of wood processing is one of the major export products in Latvia. The future of usage of wood materials depends on traditions, fashion trends, price and availability of resources.

Wild cherry, which in Europe is a relatively widespread tree species and a popular wood material with wide colour range, has also aroused interest among Latvian society. However, there is no information about characteristic properties of the wood of wild cherry growing in Latvia. The results of this thesis will compensate for the deficit of such information.

The objective of the doctoral thesis

To carry out focused research of the wood of wild cherry (*Prunus avium* L.) growing in Latvia and its characteristics (morphological, physical, mechanical, thermophysical and chemical), summarise the results, and compare them with other widespread tree species.

The following tasks have been set to achieve the objective:

- on the basis of literature and standards to develop working methods enabling to secure quantitative characteristics of the wood as source material;
- to experimentally determine morphological, physical, mechanical, thermophysical and chemical characteristics;
- to determine changes in wood properties in longitudinal and transverse sections of the stem;
- to process, interpret and assess the achieved results;
- to determine the spheres of usage.

Theses for defence:

- Determining of morphological characteristics (annual ring width, latewood content in annual ring, porosity of earlywood and latewood) of the wood of wild cherry (*Prunus avium* L.) growing in Latvia;
- Determining of physical characteristics of wild cherry wood along the stem length and in transverse direction from the heartwood to bark (density, green wood moisture content, moisture-absorbing capacity, water-absorbing capacity, wood swelling and shrinkage in the main transverse anisotropy directions in wood, swelling and shrinkage coefficients, optical properties of natural solid wood, UV resistance of optical properties, weather resistance of optical properties and their changes as affected by moisture, optical properties depending on the main transverse anisotropy directions in wood;

- Determining of mechanical characteristics of wild cherry wood along the stem length and in transverse direction from the heartwood to bark (ultimate compression strength, tensile strength, bending strength, shearing strength, detrusion strength, modulus of elasticity, Brinell hardness, resistance to shock, resistance to abrasion, resistance to nail and wood screw withdrawal);
- Chemical characteristics of wild cherry wood (content of cellulose, hemicellulose, holocellulose and lignin, content of extractive substances and ashes both in wood and bark);
- Combustion heat of wild cherry wood in the central and the peripheral parts of the stem and in the bark;
- Resistance to abrasion of the wild cherry wood surface for different finishing varnishes (based on pentaphtol, water and white spirit, *UT 123* polyurethane varnish, *SYNTEKO* primer varnish*)*;
- Dependence of relaxation rate of hogged wild cherry wood pressing on granulometric composition in comparison with relaxation characteristics of other wood species.

Scientific novelty of the thesis

The results of the research allow to determine the characteristics of the wood of wild cherry growing in Latvia and its main morphological, chemical and thermotechnical characteristic properties, to forecast its exploitation conditions, and to recommend possible spheres of its usage.

Practical importance of the thesis

The results of the thesis, confirming that certain mechanical and physical characteristics of wild cherry wood are equal in the central and the peripheral parts of the stem, give good reason for using this material for production of exclusive furniture, for internal decoration, production of parquet boards and wood block flooring, as well as for manufacturing of different goods and souvenirs. Owing to brilliant decorative properties of the wood, it can be used for exclusive interior decoration (automobiles, yachts, etc.).

Approbation of results of the thesis

The main scientific achievements and results of the doctoral thesis were presented and received positive assessment at the XXI International Scientific Conference. 17 printed works on the subject of the dissertation have been published.

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SUMMARY OF THE DOCTORAL THESIS

Introduction presents substantiation of the topicality of the doctoral thesis, formulation of the objectives and tasks, and the conceptual issues of the doctoral thesis.

First chapter is a literature review, presenting general characteristics of wind cherry species, xylology, as well as decorative properties and usage of this wood.

Second chapter is a methodological part, describing the methods, facilities and standards used in the experimental part, as well as preparation of source material samples.

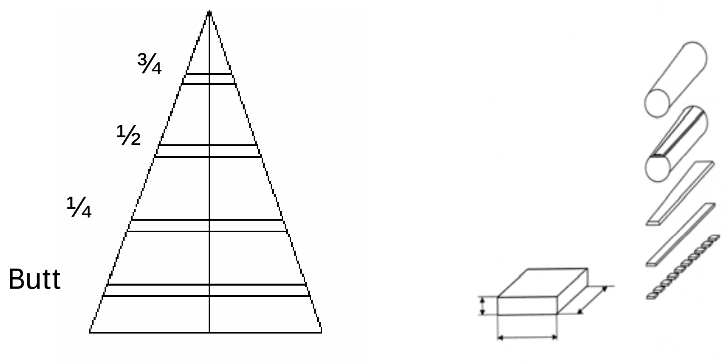


Fig. 1. Schematic location of samples in the stem

Third chapter is an experimental part, presenting assessment of the results of certain morphological, physical, mechanical, thermophysical and chemical characteristics. The results are mutually compared in both, stem heights and transverse sections of the wood.

Fourth chapter, basing upon the previous chapter, summarises the obtained information and compares the results with other deciduous and coniferous species.

Conclusions present formulation of the achieved results of the thesis and main judgements.

Bibliography contains the list of the literary sources referred to in the thesis, on the basis whereof the research directions have been determined and the received results have been compared.

RESULTS OF THE THESIS AND THEIR ASSESSMENT

The experimental part contains a detailed assessment of characteristics of wild cherry wood structure (annual rings and cell cavities), physical characteristic properties, such as density, shrinkage, swelling, water- and moisture-absorbing capacity. In their turn, mechanical characteristics are more precisely determined in shearing, compression, tension, bending and detrusion modes, as well as resistance to nail and wood screw withdrawal, hardness and resistance to shock. For potential use of this comparatively exclusive material, both, thermophysical (combustion heat, content of ashes, relaxation rate of hogged wood) and chemical characteristics have been determined.

Wild cherry is a tree of the future, which already today successfully grows in self-seeded woodland and plantations.

Morphological characteristics

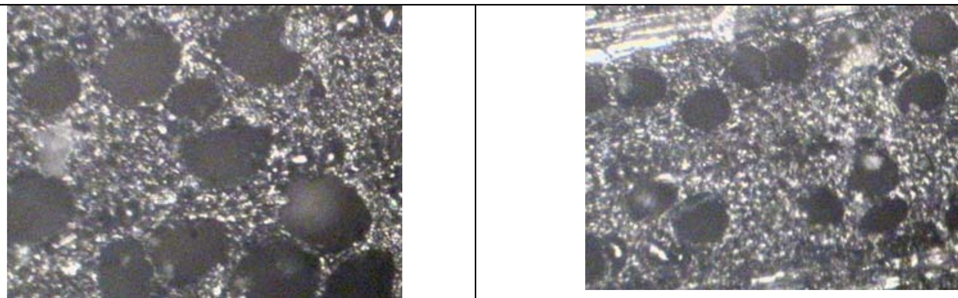
Wood structure is natural veins of wood in tangential and radial directions created by annual rings and anatomic elements. Main anatomic elements that create the structure of wood of deciduous trees are annual rings, large vessels, medullary rays, parenchyma and fibres. Anatomic parameters have been studied in reflected light with the help of *MTKF-1* microscope and *JVC TK-C721EG* colour video camera using *IMAGE-PRO EXPRESS* image analysis software. Width of annual rings of wood of wild cherry and other tree species is shown in Table 1.

Table 1

Comparison of number of annual rings per centimetre for different deciduous trees

Parameter	**Wild cherry**	**Grey alder**	**Black alder**	**Birch**
Number of annual rings per 1 cm	3.0	5.3 [4]	5.8 [5]	5.5 [5]

Each annual ring consists of two parts – external, or latewood, which grows at the end of summer and internal, or earlywood, which grows in spring. Earlywood and latewood of deciduous trees (including wild cherry) do not differ much in colour, the difference is in density of wood. Earlywood is more porous and, therefore, its density is lower, i.e., the vessels are much larger than in latewood. In turn, density of latewood is greater and mechanical characteristics are better. The differences between earlywood and latewood are shown in Fig. 2.



Earlywood of the butt end | Latewood of the butt end

Fig. 2. Photographs of wild cherry wood vessels

Physical characteristics of wild cherry and other most popular tree species growing in Latvia are shown in Table 2, whence it follows that wild cherry wood is characterised by higher density values, which, in turn, affects mechanical characteristics of the wood. Wood density also affects its water-absorbing capacity, shrinkage and swelling.

Table 2

Comparison of physical characteristics of wood for different tree species

Parameter		Wild cherry	Grey alder [6]	Black alder [6]	Birch [5]	Spruce [7]
Density ρ_0, kg/m³		628	444	520	620	502
Density ρ_{12}, kg/m³		657	476	552	640	532
Water-absorbing capacity W_{max}, %		112	184	157	119	164
Moisture-absorbing capacity $W_{\bar{u}}$, %		21	19	19	-	21
Shrinkage, % /shrinkage coefficient K_β,%/%	Tg	10.7/0.37	10.5/0.35	9.1/0.30	9.40/0.31	8.5/0.28
	Ra	5.1/0.17	4.8/0.16	4.8/0.15	8.2/0.27	3.6/0.12
	V	15.0/0.5	14.5 /0.48	13.3/0.44	16.0/0.53	12.4/0.41
Swelling, % /swelling coefficient K_α,%/%	Tg	12.0/0.4	11.19/0.38	10.3/0.33	10.2/0.34	7.9/0.26
	Ra	5.35/0.18	5.17/0.17	4.8/0.16	8.7/0.29	3.8/0.13
	V	17.6/0.59	17.7/0.59	16.17/0.54	19.5/0.65	11.3/0.38

(Symbols: Tg - tangential direction; Ra - radial direction; V - volume)

Wood density is also affected by the width of annual rings – the greater the width of latewood in annual rings, the greater the density of the wood. Tree species with greater density absorb water more slowly.

Wood shrinkage depends on species, density, as well as on potential content of latewood in annual rings.

Mechanical characteristics

The thesis contains the results of research of wild cherry wood shearing strength – see Table 3.

Table 3

Wild cherry wood ultimate shearing strength

Stem part	Shear τ_{12}, MPa			
	Radial direction		Tangential direction	
	Central part	Outer part	Central part	Outer part
R	43.8	44.8	45.6	47.9
¼	38.8	37.9	43.7	44.2
½	39.2	41.2	41.8	37.2
¾	-	39.6	-	44.6
Average value	41.3	40.4	42.2	44.6

Shearing strength in radial direction is the lowest at ¼ stem height. It correlates with research of wood anatomy, where exactly at ¼ stem height the width of annual rings is the largest. Different tendency is observed in tangential direction – shearing strength in both, the central and the outer parts from the butt end to ½ stem height decreases, but at ¾ stem height it increases again. Shearing strength in radial and tangential direction gradually decreases from the butt end to the top of the tree.

Ultimate tensile strength of wild cherry wood is the highest at the stem butt end and at ¼ stem height (Fig. 3) and decreases towards the top of the tree. As opposed to the indices of compression resistance, the ultimate tensile strength in the central part is about 8.5 ÷ 26.6 % lower than in the outer part. This regularity is characteristic of all trees.

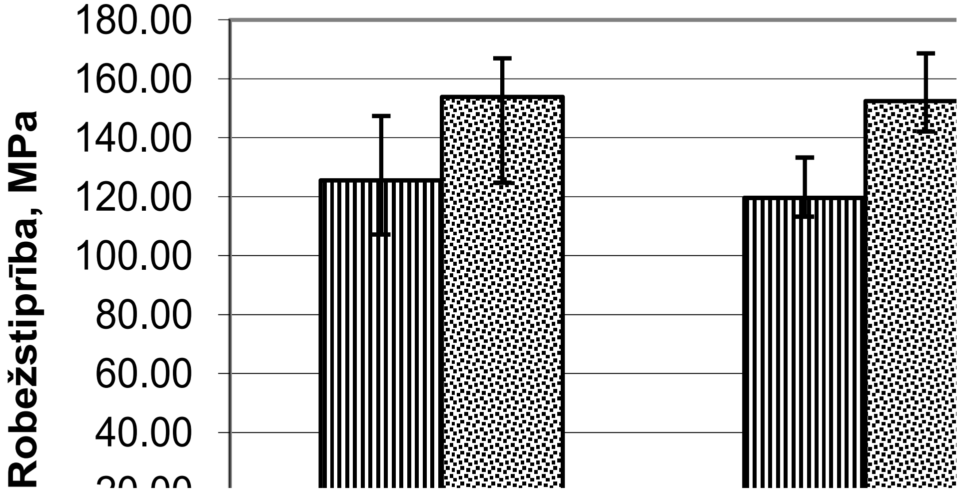


Fig. 3. Ultimate tensile strength of wild cherry wood

Ultimate compression resistance (see Fig. 4) has a slight tendency to decrease towards the top, however, it is not considerable. It is typical that ultimate compression strength in the central part is a little higher or equal to that in the outer part, which is not characteristic for other tree species. Although ultimate compression strength depends on both, wood density and height point on the stem, the chart below demonstrates that compression resistance of wild cherry wood does not change from the bottom to the top of the tree.

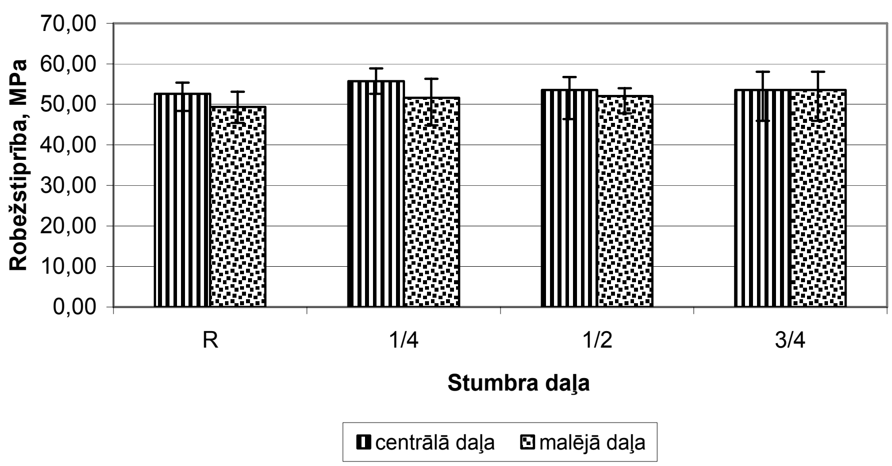


Fig 4. Ultimate compression strength of wild cherry wood in direction of fibres along the stem

Ultimate bending strength of wild cherry wood in the outer and the central part (see Fig. 5) is practically equal from the butt end to ½ stem height, at ¾ stem height it decreases by 9 % in the central part and by 4 % in the outer part.

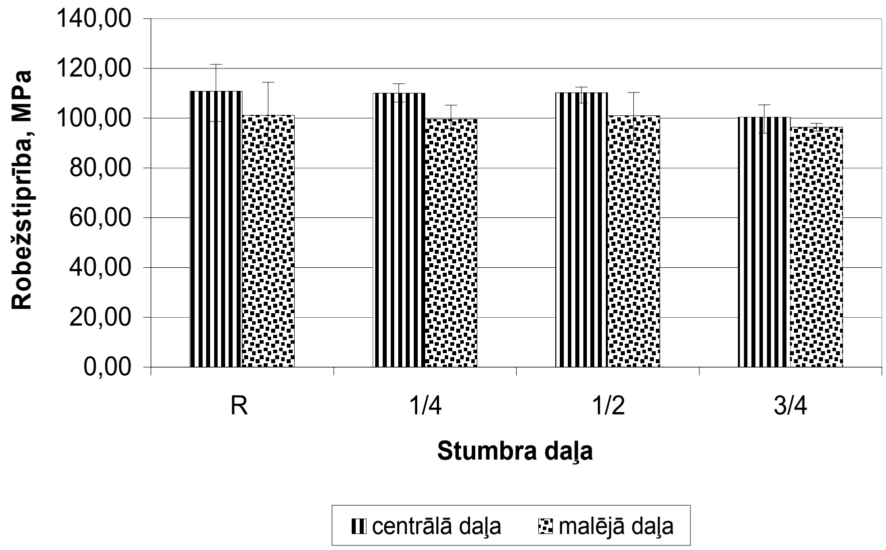


Fig 5. Ultimate static bending strength of wild cherry wood

Ultimate static bending, tensile and compression strength on average is comparable with ash-tree strength (the difference is 3.7÷12.2 %) – Fig. 6. According to the comparative chart, by strength wild cherry wood belongs to the category of ash-tree and birch.

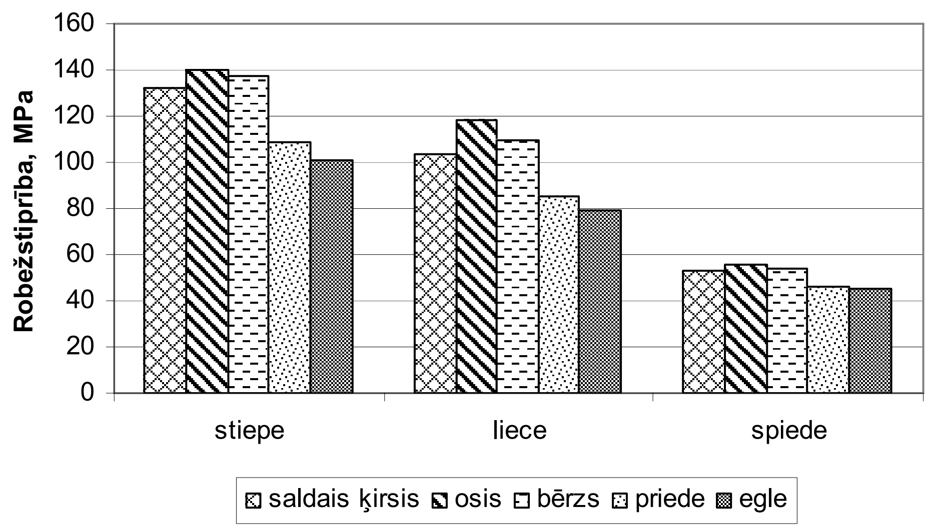


Fig. 6. Comparison of ultimate tensile, bending and compression strength of different tree species

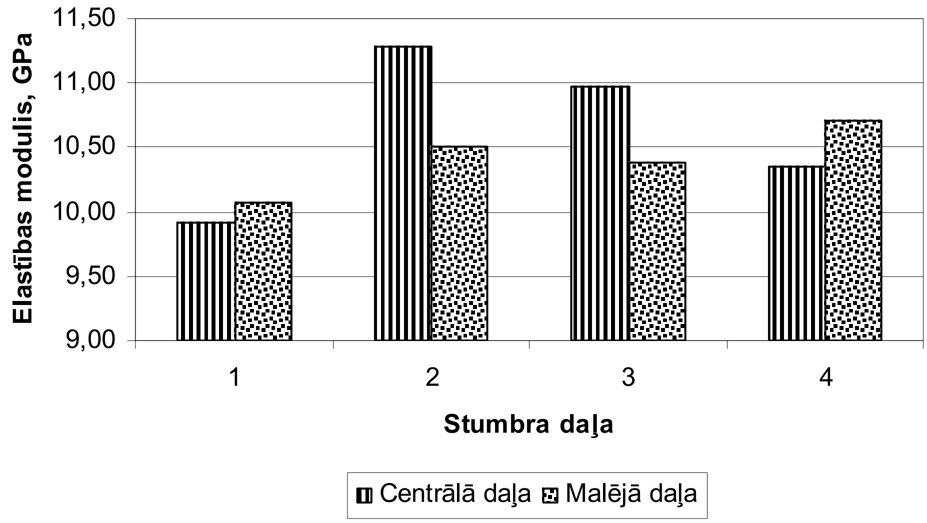


Fig. 7. Modulus of elasticity in bending of wild cherry wood at different stem heights

Modulus of elasticity of wood is affected by location of a sample in the stem – the lowest modulus of elasticity (see Fig. 7) is at the butt end of the stem, while the highest value is at $^1/_4$ stem height, i.e., modulus of elasticity in the central part exceeds 11 GPa.

Ultimate detrusion strength of wild cherry wood in tangential direction is the same to strength at the butt end, as well as ¼ and ½ stem height and is equal to 16 MPa – Fig. 8.

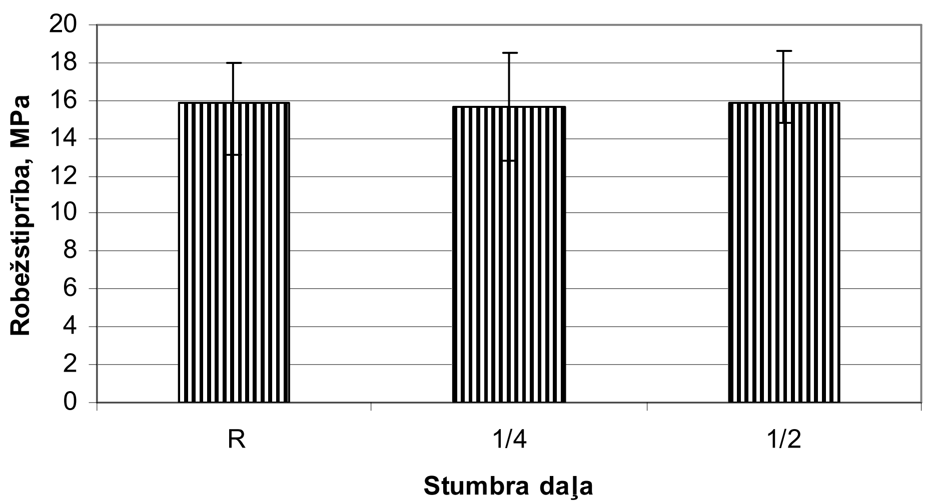


Fig. 8. Ultimate detrusion strength of wild cherry wood in tangential direction

Out of comparable tree species (Fig. 9) ultimate detrusion strength of wild cherry wood in tangential direction is the highest. For example, it exceeds the nearest ash-tree wood samples by 23 %. It can be concluded that this parameter of the wood of wild cherry growing in Latvia is approximately the same and does not fall behind – the difference is about 1.8 %.

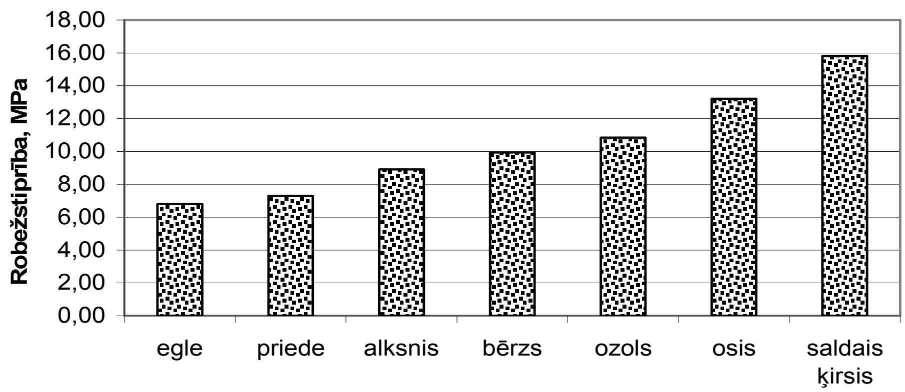


Fig. 9. Parameters of ultimate detrusion strength of wild cherry wood and other species [8] in tangential direction

Wild cherry wood hardness in axial direction is by 32 % greater that birch wood hardness, but in radial and tangential directions birch wood hardness is a little greater than wild cherry wood hardness – Fig. 10.

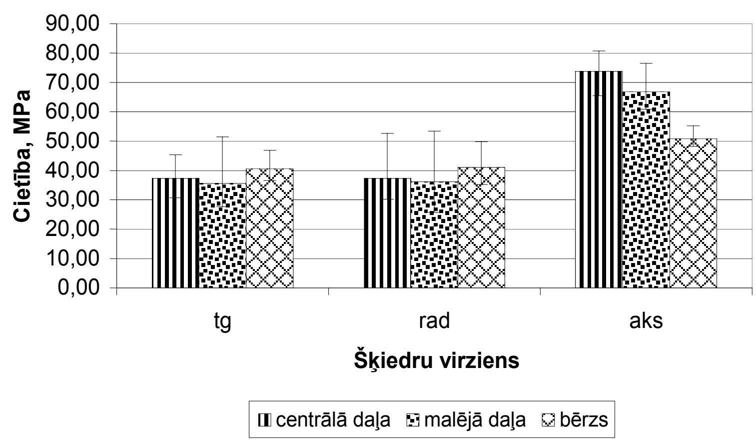


Fig. 10. Parameters of wild cherry and birch wood hardness in the main transverse anisotropy directions in wood

Resistance of wild cherry wood and other species to nail and wood screw withdrawal is shown in Table 4. Wild cherry wood, as well as birch wood in tangential and radial directions have greater nailing resistance than in axial direction. In its turn, resistance of wild cherry wood and birch wood to wood screw withdrawal in axial direction is about 1.5 times lower than in tangential and radial directions.

Table 4

Resistance to nail and wood screw withdrawal

Species	**Resistance to nail and wood screw withdrawal, MPa**					
	Wood screws			**Nails**		
	Direction					
	Rad.	**Tang.**	**Ax.**	**Rad.**	**Tang.**	**Ax.**
Birch	130.16	130.62	101.56	16.40	19.36	9.85
Spruce	126.2	120.5	50.2	89	81	43
Cedar	81.0	104.2	65.9	88	89	58
Larch	236.8	231.1	124.3	127	120	90
Fir	116.2	106.8	66.6	63	65	36
Pine	124.9	126.2	72.8	76	77	50
Wild cherry						
Central part	157.16	155.49	125.84	21.49	21.38	15.15
Outer part	152.00	151.27	131.53	22.53	23.20	14.95

Wood resistance to shock is the amount of work used for crushing a sample, the greater this value, the harder the wood. Wild cherry wood resistance to shock increases from the butt end to ¼ stem height and then decreases to the top of the tree (Fig. 11).

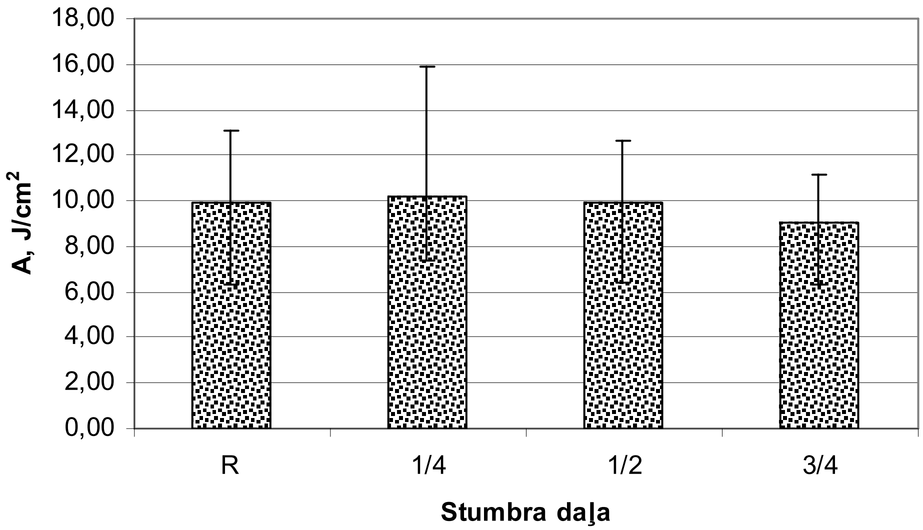


Fig. 11. Parameters of wild cherry wood resistance to shock at different stem heights

By the parameter of resistance to shock wild cherry wood exceeds the respective parameter of deciduous and coniferous trees – Fig. 12.

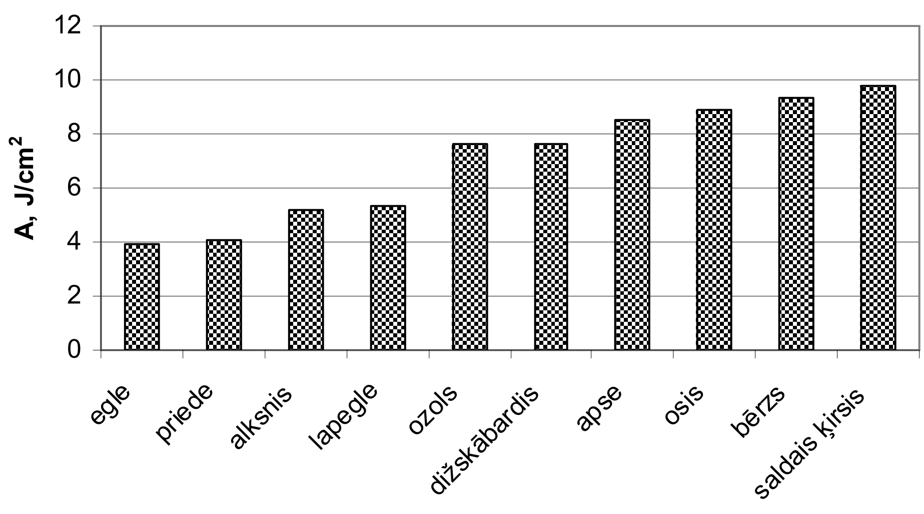


Fig. 12. Comparison of parameters of resistance to shock of wild cherry wood and other species [8]

After hogged wood pressing at pressure of 150 MPa, wild cherry wood has the third best parameter (relaxation rate) after ash-tree and oak wood – Table 5.

Table 5

Density relaxation of granular matter of sawdust of different species (sawdust sifted through sieve with mesh aperture Ø 2.0 mm)

Species	Density change after removal of load, g/cm^3		Density relaxation, %
	1 min	5 min	
Grey alder	0.8607	0.7710	11.5
Birch	0.9289	0.8539	8.78
Black alder	0.9539	0.8784	8.60
Aspen	0.9759	0.8836	10.45
Spruce	0.9781	0.9076	7.78
Pine	0.9967	0.9191	8.46
Ash-tree	0.9982	0.9323	7.06
Wild cherry	1.0086	0.9393	7.38
Oak	1.0304	0.9656	6.71

Wood of these species exceeds coniferous species considered to be classically suitable for granulation – spruce and pine. The greatest relaxation rate has grey alder, followed by aspen, birch and black alder.

Characteristics determining thermophysical parameters

Apart from organic substances the wood also contains mineral substances, which after wood burning turn into ashes. The amount of ashes for one and the same species may vary depending on the part of the tree, its age and growing conditions. There are more ashes in the bark and leaves than in the wood.

Combustion heat and moisture at the moment of testing and the amount of ashes in wild cherry wood and bark are shown in Table 6.

Table 6

Combustion heat, moisture and the amount of ashes in wild cherry wood and bark

Definable parameter	Unit	Testing results		
		Bark	**Outer part**	**Central part**
Moisture, W_{abs}	%	8.33	8.30	8.59
Combustion heat, Q_z	kJ/kg	21787	17154	17570
Amount of ashes, A	%	1.87	0.20	0.23

The outer and the central parts of wild cherry wood and bark were used for determining the combustion heat and the content of ashes. It follows from Table 6 that moisture at the moment of testing ranges from 8.3 to 8.6 %. In comparison of the combustion heat of the central part of wild cherry wood with the outer part, the combustion heat of the central part is higher by 2.4 %. The amount of ashes in the central part is 0.23 %. On the other hand, the combustion heat of the bark is by 24 % higher than the combustion heat of the heartwood, while the content of ashes is 8.7 times greater.

The amount of ashes in the wood with bark, without bark and in the bark is lower in wild cherry wood comparing with willow species. The content of ashes of approximately 0.2 % is indicated for Japanese cherry in literary source [9].

Chemical characteristics

The cellulose produced by Kirchner's method possibly contains hemicellulose admixtures, therefore it demonstrates the highest content of cellulose in wood, but this is classical method of determining of content of cellulose and thus the received result may be regarded as the most accurate. – Fig. 13.

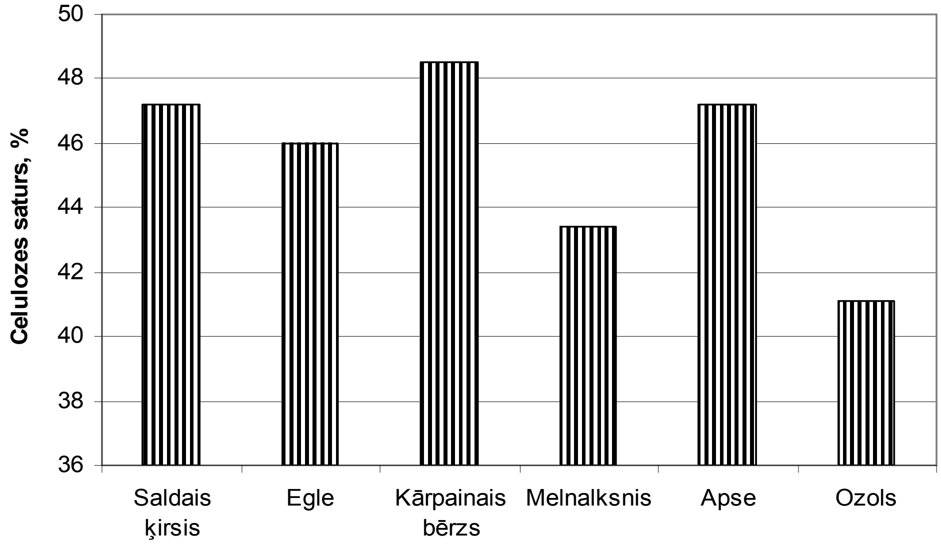


Fig. 13. The content of cellulose received by Kirchner's method for different tree species.

Cellulose, hemicellulose, holocellulose and lignin are main components of wood, making 96% of dry wood mass. Fig 14. The content of lignin in wild cherry wood and spruce wood is similar, while the content of holocellulose is similar in spruce and aspen wood.

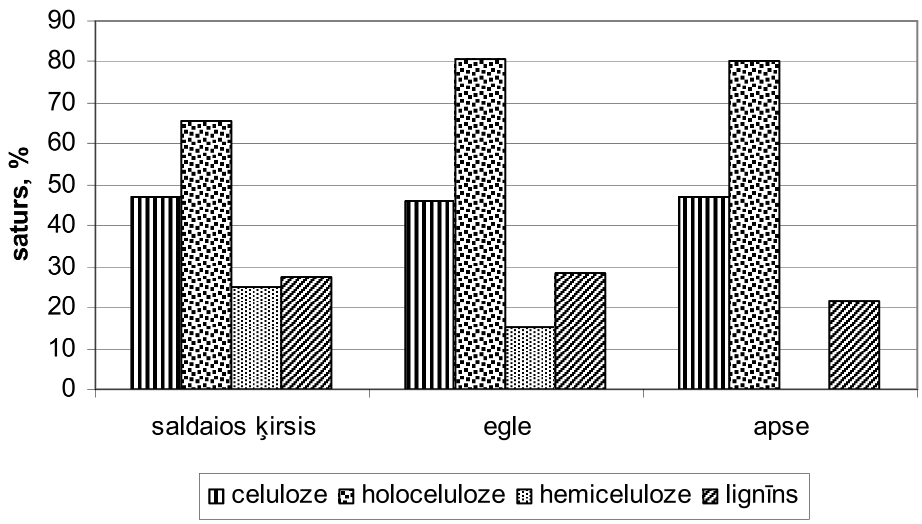


Fig. 14. Content of main wood components (cellulose, hemicellulose, holocellulose and lignin) for different tree species (%)

CONCLUSIONS

Characteristic properties of the wood of wild cherry growing in Latvia described in the thesis is the first detailed assessment of characteristics of wild cherry wood. Recently the popularity of this wood, its high characteristics and economical aspects have contributed to planting of vast plantations with base material grown in Latvia, which, in turn, has been thoroughly selected from the best provenance by Latvian State Forestry Research Institute "Silava".

1. One of the main characteristic properties of the tree growth – width of an annual ring, for a wild cherry tree is 3.3 mm on average.
2. Average transverse section areas of pores in the outer part of the stem for both latewood and earlywood are greater than in the central part of the stem. Average porosity is 59 % and average area of pores is 1510.8 μm^2.
3. Physical characteristics – density, swelling and shrinkage are a little higher in the outer part of the stem than in the central part. It can be concluded that the wood of wild cherry growing in Latvia belongs to the group of wood with medium density and medium hardness with the following characteristics: absolute dry wood density ρ_o = 628 kg/m^3, ρ_{12} = 657 kg/m^3, moisture of green wood W_{svc} = 53 %, volume shrinkage coefficient K_β = 0.50 %/%, shrinkage coefficient in radial direction K_β = 0.17 %/%, shrinkage coefficient in tangential direction K_β = 0.36 %/%, volume swelling coefficient K_α = 0.58 %/%, swelling coefficient in radial direction K_α = 0.18 %/%, swelling coefficient in tangential direction K_α = 0.40 %/%, water-absorbing capacity $W_{\bar{u}}$ = 112.0 %, moisture-absorbing capacity W_m = 21.0 %,
4. It has been stated that mechanical characteristic properties of wild cherry wood between transverse section of the central and the outer peripheral part of the stem have minor differences: ultimate shearing strength in tangential direction τ_{12} = 43,4 MPa, and in radial direction τ_{12} = 40,8 MPa, ultimate tensile strength $\sigma_{st,12}$ = 136,3 MPa, ultimate compression strength σ_{sp12} = 52,5 MPa, ultimate bending strength $\sigma_{l,12}$ = 104,7 MPa, modulus of elasticity 10,5 GPa, ultimate detrusion strength $\sigma_{b,tg12}$ = 15,7 MPa, hardness in axial direction H_B= 70,3 MPa. Resistance of wild cherry wood to wood screw withdrawal in radial, tangential

and axial directions is higher than resistance to wood screw withdrawal of pine, spruce, fir, cedar and birch wood.

5. Parameters of wild cherry wood resistance to shock increase from the butt end to ¼ stem height and then decrease towards the top. It is the highest value as compared to more widely used tree species (e.g. oak, ash-tree, spruce, pine, etc.).
6. The best results of hogged wood (Ø = ≤ 2.0mm) pressing at pressure of 150 MPa (the lowest relaxation of dimensions and, respectively, decrease of density after removal of load) are for the following deciduous species: oak, ash-tree and wild cherry, which exceed coniferous species considered to be classically suitable for granulation – spruce and pine.
7. Combustion heat of wild cherry wood is 17362 kJ/kg, amount of extract substances is 3.95 % and amount of ashes is 0.21 % without bark. In comparison of combustion heat of the central part of wild cherry wood with the outer part, the combustion heat of the central part is higher by 2.4 %. On the other hand, the combustion heat of the bark is by 24 % higher than the combustion heat of the wood without bark, while the content of ashes is 8.7 times greater.
8. The content of cellulose in wild cherry wood is 47.2 %, similar to aspen wood. The content of hemicellulose in wild cherry wood is 24.8 %, the content of holocellulose is 65.5 %, in spruce wood – 80.9 %, and in aspen wood – 80.3 %. The content of lignin in wild cherry wood is high comparing to other deciduous species, where its content ranges from 19 – 28 %. It can be concluded that the content of lignin in wild cherry wood of 27.6 % is close to maximum content of lignin in deciduous wood.
9. It can be concluded from the received results that wild cherry wood can be used for production of furniture, for internal decoration, production of parquet boards and wood block flooring, as well as for manufacturing of different goods and souvenirs. Owing to brilliant decorative properties of the wood, it can be used for exclusive interior decoration (automobiles, yachts, etc.).

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