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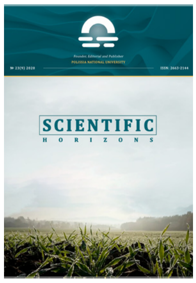

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COMPARATIVE ASSESSMENT OF SOME PHYSICAL AND MECHANICAL PROPERTIES OF WOOD OF DIFFERENT SCOTS PINE CLIMATYPES

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Abstract. For a more efficient and rational use in the production of Scots pine wood of various geographical origin, it is necessary to know its physical and mechanical properties. The purpose of this study was to determine the physical and mechanical properties of wood of 17 climatic ecotypes of Scots pine and to carry out a comparative analysis of the indicators obtained for the studied climatypes separately and when they are grouped into subspecies in accordance with the classification of L.F. Pravdin. The range of the geographical origin of the places of seed procurement is from 47 to 62° north latitude and from 22 to 85° east longitude. The modern density universal testing machine MTS INSIGHT 100 was used for research. As a result of the research, it was found that the density of wood in an absolutely dry state varies from 370 kg/m^3 (Kursk climatype) to 524 kg/m^3 (Volgograd climatype), and at 12% humidity – from 397 kg/m^3 (Kursk climatype) to 550 kg/m^3 (Volgograd climatype). The index of the strength of wood of the studied climatypes for compression along the fibres was from 32 MPa (Kursk climatype) to 54 MPa (Volgograd climatype), and for static bending – from 55 to 92 MPa for the Vologda and Ulyanovsk climatypes, respectively. Distribution of Scots pine climatypes into subspecies in accordance with the classification of L.F. Pravdin and the obtained data on the physical and mechanical properties of wood have a certain pattern. The maximum density of wood at 12% moisture is typical for the European Scots pine subspecies is 497±8 kg/m^3, the minimum value of this indicator for the Siberian Scots pine subspecies is 423±30 kg/m^3. An intermediate position is occupied by the subspecies of Lapland pine and Forest-steppe pine with values of 483±16 and 464±12 kg/m^3, respectively. The strength index of wood in the studied subspecies for compression along the fibres ranged from 47±1 MPa (European subspecies) to 33±4 MPa (Siberian subspecies), in the Lapland pine subspecies – 44±2 MPa and somewhat lower in the Forest-steppe pine subspecies – 42±2 MPa. The maximum value of the static bending strength of wood is typical for the European pine subspecies – 78±4 MPa, and the minimum – for the Siberian pine subspecies – 61±14 MPa. This indicator turned out to be equal in subspecies of forest-steppe and Lapland pine and amounted to 72±4 MPa. The practical value of the work lies in identifying the existing differences and variability among climatypes according to the studied physical and mechanical properties of wood and selecting the most promising of them for further breeding purposes

Keywords: wood density, wood strength, static bending, variability

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INTRODUCTION

One of the most important indicators of the quality of Scots pine wood is its density and strength, which must be taken into account both in forest reproduction and in industrial use [1-4]. Density affects not only the physical, but also the mechanical properties of wood [5]. The density of wood is the most objective and universal indicator of its quality. In most cases, there is a clearly expressed direct correlation between the density and strength of wood. The higher the density, the higher the strength, and the degree of correlation reaches 0.8-0.9 [6].

Many scientists in their works note the existing significant differences among climatypes in survival rate [7], preservation [8], growth [9; 10], resistance to pests and diseases [11; 12], productivity [13], as well as in the composition of chlorophyll, the structure of needles [14; 15], the composition of essential oils, fruiting and other characteristics [16-18]. In this regard, there is interest in possible differences in the quality of wood in different climatypes, which are determined by indicators of physical and mechanical properties. Unique in this regard, experimental model objects are geographic plantations created by seed offspring of the most characteristic populations of different ecotypes (climatypes) in order to test them in new conditions. They serve as an object for studying the geographical variability of the hereditary properties of forest species. The first geographical plantations of Scots pine were established in Belarus in 1959 on an area of 8.7 hectares by V.G. Mishnev and E.D. Mantsevich. They consisted of 65 geographic variants with a geographic range of 48-62° north altitude and 22-111° east longitude. The detail history of the objects is described in the paper [19]. At present, the area of plantations is 6 hectares, the number of surviving variants is 44. These plantings served as the object of the research. To assess the physical and mechanical properties of wood, 17 climatypes were selected from the variants of the origin of the places of harvesting seeds in the range of 47-62° north latitude and 22-85° east longitude. The indicated geographical coordinates of the places of seed procurement are quite consistent with the classification of Scots pine into subspecies according to L.F. Pravdin [20].

The purpose of the research is to determine the physical (density of wood in an absolutely dry state, density of wood at 12% moisture) and mechanical (strength of wood for compression along the fibres and for static bending) properties of wood of various climatic ecotypes of Scots pine and conducting a comparative analysis of the obtained indicators. The novelty of the research lies in the fact that for the first time in Belarus the physical and mechanical properties of Scots pine wood of various origins at ripening age were determined in the range of geographical origin of seed harvesting places from 47 to 62° north latitude and from 22 to 85° east longitude.

MATERIALS AND METHODS

The geographical culture of Scots pine under study is located in the Negorelsky forestry of the Negorelsky training and experimental forestry enterprise, which is a branch of the Belarusian State Technological University and is geographically located in the Dzerzhinsky district of the Minsk region of the Republic of Belarus (50 km from Minsk). The age of Scots pine climatypes growing in geographical cultures at the time of the study is 60 years.

To assess the physical and mechanical properties of wood 17 climatypes were selected from the variants of the origin of the places of harvesting seeds in the range of 47-62 north latitude and 22-85 east longitude. The choice of climatypes for carrying out research with such a range of geographical coordinates of the places of harvesting seeds is due to the fact that the indicated parent stands are quite consistent with the classification of Scots pine into subspecies according to L.F. Pravdin [20]. Of the 5 subspecies of Scots pine (Lapland, European, Siberian, Steppe and Hooked) the studied climatypes were subdivided as follows: the subspecies Lapland (61-62° NL) included the Arkhangelsk and Leningrad climatypes, the European subspecies included 2 varieties – Western European (53-59°NL and 22-40°EL) with Vologda, Estonian, Latvian, Vitebsk and Minsk climatypes and Eastern European (54 NL and 48-58°EL) that includes the Ulyanovsk and Bashkir climatypes. The Siberian subspecies (57 NL and 85°EL) includes the Tomsk climatype. Also, due to the lack of representation of climatypes of the Steppe pine subspecies (Kustanai, Akmola, Pavlodar, Kokchetav and Semipalatinsk climatypes of Kazakhstan died at the early stages of growth), a subspecies of the Forest-steppe pine was conditionally distinguished (47-51°NL and 27-42°EL) with Belgorod, Kursk, Volgograd, Khmelnytsky, Poltava and Rostov climatypes. A subspecies such as hooked pine, isolated by L.F. Pravdin and growing in the Crimea and the Caucasus was not initially represented in geographical cultures. Thus, for a more logical analysis of the physical and mechanical properties of wood, the studied climatypes of Scots pine are distributed in accordance with the classification of L.F. Pravdin with minor changes.

To study the properties of wood in the model trees of each of the studied climatypes, was taken trunk sections 60 cm long at the same height – 6.5 m, after which samples were made from them to study the physical and mechanical properties of wood. The studied the following properties of wood: density of wood in an absolutely dry state and at 12% moisture content, strength of wood for compression along the grain and for static bending. The study of these properties was carried out in accordance with generally accepted methods: ISO 16483.0-78 Wood. Sampling methods and general requirements for physical and mechanical tests [21]; ISO 16483.1-84 Wood. Density determination method [22]; ISO 16483.3-84 Wood. Method for determining the ultimate strength in static bending [23]; ISO 16483.7-71 Wood. Moisture determination method [24]; ISO 16483.10-73 Wood. Method for determining the ultimate strength in compression along the fibres [25].

Wood samples on the site of Scots pine geographical plantations were harvested in February 2020 (Fig. 1a), the determination of the physical and mechanical properties of wood was carried out in May 2020. During the research, a universal testing machine MTS INSIGHT 100 was used (Fig. 1b).

a) b)

***Figure 1**. Taking of samples of Scots pine cuts of various origins in geographical cultures (a) to determine the physical and mechanical properties of wood using a universal testing machine MTS INSIGHT 100 (b)*

The use of a universal testing machine of this brand MTS INSIGHT 100 in such studies allows obtaining results with a sufficiently high accuracy, which served as the main criterion for choosing this equipment. The assessment of the reliability of the differences in the results obtained was carried out using the MS Excel software. To confirm or refute the hypothesis about attributing the studied indicators of the physical and mechanical properties of wood to the same set of average data, we calculated such a parametric criterion as the Student's t-test or the difference t-test. In this case, it allows finding the probability that both averages belong or not to the same population. Recalculation of indicators for standard humidity for samples with humidity at the time of testing was carried out according to the generally accepted formula [22; 26].

RESULTS AND DISCUSSION

Statistical processing of indicators for calculating the density of wood in an absolutely dry state is presented in Table 1.

***Table 1**. Statistics of density of wood in an absolutely dry state*

Indicator	Density of wood by climatypes in an absolutely dry state, kg/m^3																
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$\bar{X}$	369.65	480.53	457.21	492.08	524.09	475.19	502.58	478.32	398.50	469.63	472.52	431.48	460.59	442.49	396.98	389.26	423.47
$S_{\bar{X}}$	3.25	5.27	17.77	6.76	9.15	5.36	3.04	7.24	12.88	13.48	6.32	4.65	8.69	11.81	4.68	3.64	2.64

Table 1, Continued

Indicator	Density of wood by climatypes in an absolutely dry state, kg/m^3																
	Kr-1	**Vt-4**	**Bl-5**	**Es-8**	**Vg-9**	**Lt-10**	**Bt-11**	**Gr-15**	**T-23**	**Ul-41**	**Rs-47**	**M-48**	**Ar-52**	**L-53**	**Pl-55**	**Vl-57**	**Kh-58**
S	19.25	27.87	47.01	23.43	47.52	19.33	14.26	27.09	40.72	52.19	27.55	14.71	27.47	35.42	19.29	14.11	9.88
Min	338.65	443.46	400.91	452.34	434.43	455.00	476.75	445.80	349.20	392.00	436.19	408.43	438.36	380.50	369.85	376.17	406.98
Max	429.39	557.60	525.78	528.40	623.81	526.13	543.65	543.34	455.40	541.62	531.03	448.09	511.18	488.34	433.71	417.33	436.19
$t_{05}S_{\bar{X}}$	6.61	10.81	43.47	14.89	18.80	11.68	6.32	15.64	29.13	28.90	13.28	10.52	19.65	27.22	9.92	7.81	5.70
P, %	0.88	1.10	3.89	1.37	1.75	1.13	0.61	1.51	3.23	2.87	1.34	1.08	1.89	2.67	1.18	0.94	0.62
V, %	5.21	5.80	10.28	4.76	9.07	4.07	2.84	5.66	10.22	11.11	5.83	3.41	5.96	8.00	4.86	3.62	2.33

Note (names of climatypes)*: Kr-1 – Kursk, Vt-4 – Vitebsk, Bl-5 – Belgorod, Es-8 – Estonian, Vg-9 – Volgograd, Lt-10 – Latvian, Bt-11 – Buriat, Gr-15 – Grodno, T-23 – Tomsk, Ul-41 – Ulyanovsk, Rs-47 – Rostov, M-48 – Minsk, Ar-52 – Arkhangelsk, L-53 – Leningrad, Pl-55 – Poltava, Vl-57 – Vologda, Kh-58 – Kharkov*

It can be seen from the data presented that the average density of different climatypes is in the range of 370-524 kg/m^3, i.e., the magnitude of the variation exceeds 150 kg/m^3. Based on the literature data [27], which are averaged indicators calculated from highly variable values, the density of pine wood in an absolutely dry state is about 480 kg/m^3. The variability of the indicator under consideration, which is characterised by the coefficient of variation (V), can be considered insignificant, since in most cases it does not exceed 10%. The relative error does not exceed 5%. Statistical processing of the data showed that in many cases the confidence intervals ($t_{05}S_{\bar{X}}$) of one population (climatype) overlap to some extent with those of another population. It was found that the density of wood of the Vitebsk (Vt-4) and Grodno (Gr-15) climatypes is within the same population, and the average sample of the Minsk (M-48) climatype significantly differs from the average of the climatypes Vt-4 and Gr-15. The average sample of the Belgorod climatype (Bl–5) does not significantly differ from the average of ten other studied climatypes. The average wood density of the Volgograd climatype (Bg-9) significantly differs from all other climatypes. The Kursk (Kr-1) and Buryat (Bt-11) climatypes do not significantly differ from the Tomsk (T-23) and Estonian (Es-8) climatypes. On average, the compared indices of the density of one climatype did not significantly differ from the analogous indices of any five other climatypes.

Since the density of wood directly depends on moisture content, it is generally accepted in wood science to carry out a comparative assessment of the properties of wood at a standard moisture content of 12%. The value of this density is difficult to obtain directly from experience, since it is very difficult to bring wood to a moisture content of exactly 12%. Therefore, the density of wood at 12% moisture content is calculated by the appropriate formulas, depending on the moisture content of the wood at the time of testing [22]. The average density of pine wood at this moisture content corresponds to 505 kg/m^3 according to [26, 27]. According to some literature data [25], the density value from the indicated average value can fluctuate up or down, that is, from 350 to 650 kg/m^3. The average density of pine wood by climatypes varies within 397-550 kg/m^3. As for the values of statistical indicators, there is a similar situation with the previous calculations indicated in Table 1. This is explained by the fact that the values of the density indicators of wood at 12% moisture were found by recalculating similar indicators at moisture at the time of testing (Table 2) [22].

Table 2*. Statistics of wood density at 12% moisture*

Indicator	Density of wood by climatypes at 12% humidity, kg/m^3																
	Kr-1	**Vt-4**	**Bl-5**	**Es-8**	**Vg-9**	**Lt-10**	**Bt-11**	**Gr-15**	**T-23**	**Ul-41**	**Rs-47**	**M-48**	**Ar-52**	**L-53**	**Pl-55**	**Vl-57**	**Kh-58**
$\bar{X}$	396.50	509.14	488.60	521.07	550.39	502.53	530.01	509.47	423.22	496.59	498.82	459.06	489.96	474.38	423.56	415.21	452.17

Table 2, Continued

Indicator	Density of wood by climatypes at 12% humidity, kg/m^3																
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$S_{\bar{X}}$	3.47	5.35	17.80	7.46	9.38	5.13	3.13	7.84	13.13	13.76	6.49	4.46	9.08	11.97	4.98	4.05	2.95
S	20.52	28.30	47.09	25.83	48.76	18.51	14.66	29.35	41.51	53.28	28.30	14.12	28.73	35.90	20.55	15.68	11.03
Min	364.04	470.65	431.13	478.86	458.65	482.90	505.24	474.29	371.49	409.32	465.54	437.84	467.12	414.30	396.26	396.94	434.74
Max	461.13	589.19	557.33	561.23	654.61	551.34	573.89	580.04	480.70	569.05	559.76	472.05	543.21	521.03	461.36	444.11	466.67
$t_{05}S_{\bar{X}}$	7.05	10.97	43.56	16.41	19.29	11.19	6.50	16.94	29.70	29.50	13.64	10.10	20.55	27.59	10.56	8.68	6.37
P, %	0.87	1.05	3.64	1.43	1.70	1.02	0.59	1.54	3.10	2.77	1.30	0.97	1.85	2.52	1.18	0.97	0.65
V, %	5.18	5.56	9.64	4.96	8.86	3.68	2.77	5.76	9.81	10.73	5.67	3.07	5.86	7.57	4.85	3.78	2.44

As is known, the mechanical properties of wood are closely related to density, which characterises its ability to resist the action of external mechanical forces. These properties of wood are highly dependent on its moisture content; therefore, the evaluation and comparison of the results of mechanical tests are carried out at a standard 12% moisture content.

Statistical processing of the calculation data for the compressive strength of wood along the fibre at 12% moisture content is presented in Table 3.

***Table 3**. Statistics of the compressive strength of wood along the fibre at 12% moisture*

Indicator	Compressive strength of wood in terms of climatypes along the fibre at 12% moisture content, MPa																
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$\bar{X}$	31.84	48.80	40.48	48.93	53.63	47.49	49.84	46.26	33.35	46.47	48.47	42.03	47.41	40.61	36.43	38.71	42.46
$S_{\bar{X}}$	0.39	0.65	3.16	0.99	1.23	0.73	0.86	0.75	1.71	2.01	0.84	0.64	1.19	0.89	0.68	0.69	0.56
S	2.33	3.45	8.35	3.44	6.37	2.63	4.04	2.81	5.41	7.79	3.66	2.03	3.75	2.66	2.82	2.68	2.10
Min	26.97	42.77	28.79	43.30	42.51	43.31	39.27	43.16	27.02	34.25	43.34	38.70	43.44	35.39	32.48	35.98	38.97
Max	36.59	58.96	52.53	55.14	64.55	51.92	54.03	50.72	42.61	58.11	54.66	44.77	54.69	42.83	41.67	43.80	46.69
$t_{05}S_{\bar{X}}$	0.80	1.34	7.72	2.18	2.52	1.59	1.79	1.63	3.87	4.32	1.77	1.45	2.68	2.04	1.45	1.49	1.21
P, %	1.24	1.33	7.80	2.03	2.29	1.54	1.73	1.63	5.13	4.33	1.73	1.53	2.50	2.18	1.88	1.79	1.32
V, %	7.32	7.06	20.63	7.02	11.89	5.54	8.11	6.08	16.23	16.77	7.56	4.84	7.91	6.54	7.73	6.94	4.94

It should be noted that the compressive strength of wood along the fibres is the most characteristic of the mechanical properties of wood and the most important in practical terms. According to some literature data [6], this indicator can vary from 27 to 63 MPa, with an average value of 46 MPa. The obtained average strength indicators of the tested samples of all climatypes were in the range of 32-54 MPa. Analysing the statistical indicators of calculating the compressive strength of wood along the fibres, it is easy to see that they have a certain similarity with those of calculating the density of wood. For example, the strength of wood of the Belgorod climatype (Bl-5) does not reliably differ from ten others and the Latvian one (Lt-10) from seven others.

But at the same time, there are certain differences. For example, wood of the Buryat climatype (Bt-11) does not have significant differences in strength from five other climatypes, while in terms of wood density it does not differ significantly only from the Estonian climatype (Es-8). The strength indicators of the Belarusian climatypes turned out to be significantly different (the values of the density indicators of wood at 12% humidity were found by recalculating similar indicators at humidity at the time of testing).

The test results and statistical processing of the data for calculating the static bending strength of wood at 12% moisture content are presented in Table 4. Since the variability of the strength of wood in many variants turned out to be significant ($V>10\%$), and the value of the relative error in six cases exceeded 5%, a comparative analysis of the strength indicators of wood for static bending within climatypes was not carried out (Table 4).

***Table 4**. Statistics of the bending strength of wood at 12% moisture content*

Indicator	Static bending strength of wood by climatypes, MPa																
	Kr-1	Vt-4	Bl-5	Es-8	Vg-9	Lt-10	Bt-11	Gr-15	T-23	Ul-41	Rs-47	M-48	Ar-52	L-53	Pl-55	Vl-57	Kh-58
$\bar{X}$	59.36	90.25	73.83	87.42	89.21	76.20	71.19	80.34	60.84	92.44	86.46	73.35	76.59	68.11	63.15	54.85	60.04
$S_{\bar{X}}$	4.47	1.66	4.76	1.05	2.57	1.31	6.35	4.79	5.20	3.99	1.17	1.80	1.97	2.35	1.68	4.09	5.84
S	9.99	3.72	11.66	2.36	5.74	2.92	14.20	10.71	11.62	8.91	2.34	4.03	4.40	5.25	3.75	9.15	13.05
Min	47.95	83.90	63.30	85.25	80.35	71.72	46.54	71.83	50.72	86.08	83.52	68.86	71.71	61.74	59.31	40.18	39.71
Max	75.09	93.75	89.98	90.31	94.71	79.19	82.98	98.19	75.26	107.53	88.61	77.61	82.90	75.40	68.84	64.93	68.98
$t_{05}S_{\bar{X}}$	12.41	4.62	12.24	2.92	7.13	3.63	17.63	13.30	14.43	11.07	3.72	5.00	5.47	6.51	4.66	11.36	16.20
P, %	7.53	1.84	6.45	1.21	2.88	1.72	8.92	5.96	8.54	4.31	1.35	2.46	2.57	3.44	2.66	7.46	9.72
V, %	16.83	4.12	15.80	2.69	6.43	3.84	19.95	13.33	19.10	9.64	2.70	5.49	5.75	7.70	5.95	16.68	21.73

The obtained indicators of the physical and mechanical properties of wood of various climatypes of Scots pine, grouped in accordance with the classification of L.F. Pravdin into subspecies, have a certain pattern. The maximum density of wood at 12% moisture is typical for the European Scots pine subspecies is 497±8 kg/m^3, the minimum value of this indicator for the Siberian Scots pine subspecies is 423±30 kg/m^3. An intermediate position is occupied by the subspecies of Lapland pine and Forest-steppe pine with values of 483±16 and 464±12 kg/m^3, respectively. The strength index of wood in the studied subspecies for compression along the fibres ranged from 47±1 MPa (European subspecies) to 33±4 MPa (Siberian subspecies), in the Lapland pine subspecies – 44±2 MPa and somewhat lower in the Forest-steppe pine subspecies – 42±2 MPa. The maximum value of the static bending strength of wood is typical for the European pine subspecies – 78±4 MPa, and the minimum – for the Siberian pine subspecies – 61±14 MPa. This indicator turned out to be equal in subspecies of forest-steppe and Lapland pine and amounted to 72±4 MPa (Table 5).

***Table 5**. Indicators of physical and mechanical properties of Scots pine wood by subspecies*

Name of the climatype and subspecies (varieties) of Scots pine	Geographic coordinates, °		Indicator		
	North latitude	East Longitude	ρ_{12}, kg/m^3	σ_{cs}, MPa	σ_{bs}, MPa
Scots pine Lapland subspecies					
Leningrad	61	34	474±28	41±2	68±6
Arkhangelsk	62	43	490±21	47±3	77±5
By Lapland subspecies	61-62	34-43	483±16	44±2	72±5

Table 5, Continued

Name of the climatype and subspecies (varieties) of Scots pine	Geographic coordinates, °		Indicator		
	North latitude	East Longitude	ρ_{12}, kg/m³	σ_{cs}, MPa	σ_{bs}, MPa
			Scots pine Western European variety		
Vologda	59	40	415±9	39±1	55±11
Estonian	58	27	521±16	49±2	87±3
Latvian	57	22	503±11	47±2	76±4
Vitebsk	55	29	509±11	49±1	90±5
Minsk	54	27	459±10	42±1	73±5
Grodno	53	24	509±17	46±2	80±13
By Western European variety	53-59	22-40	489±9	46±1	77±5
			Scots pine Eastern European variety		
Ulyanovsk	54	48	497±30	46±4	92±11
Bashkir	54	58	530±7	50±2	71±19
By Eastern European variety	54	48-58	516±13	48±2	82±11
By forest subspecies	53-59	22-58	497±8	47±1	78±4
			Scots pine forest-steppe subspecies		
Belgorodsky	51	38	489±44	40±8	74±12
Kursk	51	34	397±7	32±1	59±12
Volgograd	51	42	550±19	54±3	89±7
Khmelnitsky	50	27	452±6	42±1	60±16
Poltava	49	33	424±11	36±1	63±5
Rostov	47	40	499±14	48±2	86±4
By forest-steppe subspecies	47-51	27-42	464±12	42±2	72±5
			Scots pine Siberian subspecies		
Tomsk	57	85	423±30	33±4	61±14
By Siberian subspecies	57	85	423±30	33±4	61±14

Note: *ρ_{12} is the density of wood at 12% moisture content, σ_{cs} is the compressive strength of wood along the grain, σ_{bs} is the static bending strength of wood*

From the data presented, it can be seen that in some cases the averages of the studied indicators for subspecies overlap with confidence intervals, that is, they admit the hypothesis that the obtained averages relate to the same population. To test this hypothesis, a parametric test – Student's *t*-test (difference *t*-test) was calculated, which allows finding the probability that both means obtained relate to the same population. If this probability p is below the significance level (p <0.05), then it is considered that the samples belong to two different populations (Table 6).

Table 6. *Values of actual t-criteria of differences among the subspecies of Scots pine in terms of density and strength of wood*

Scots pine subspecies	The actual value of the probability p by indicators for the subspecies			
	Lapland	Forest	Forest-steppe	Siberian
		Density of wood at 12% moisture (ρ_{12})		
Lapland	–	0.098	0.055	0.001
Forest	0.098	–	0.000	0.000
Forest-steppe	0.055	0.000	–	0.015
Siberian	0.001	0.000	0.015	–
		Compressive strength of wood along the fibre (σ_{cs})		
Lapland	–	0.050	0.101	0.000
Forest	0.050	–	0.000	0.000
Forest-steppe	0.101	0.000	–	0.000
Siberian	0.000	0.000	0.000	–

Table 6, Continued

Scots pine subspecies	The actual value of the probability p by indicators for the subspecies			
	Lapland	Forest	Forest-steppe	Siberian
Static bending strength of wood (σ_{bs})				
Lapland	–	0.055	0.821	0.091
Forest	0.055	–	0.058	0.024
Forest-steppe	0.821	0.058	–	0.113
Siberian	0.091	0.024	0.113	–

This parametric test (Student's *t*-test) allows finding the probability that both means relate to the same population. If this probability p is below the significance level (p<0.05), then it is generally accepted that the samples belong to two different populations.

Analysing the obtained average values of the density of pine wood by subspecies, it should be noted that this indicator for the Lapland pine subspecies does not statistically differ from the analogous indicators of pines of the forest and forest-steppe subspecies (t_{fact}=0.098 and 0.055, respectively). A similar situation is observed when comparing the compressive strength of wood along the fibres (t_{fact}=0.050 and 0.101, respectively). As for the strength of wood for static bending, no significant differences were also found among pine subspecies, despite the greatest difference between the Lapland and forest-steppe (t_{fact}=0.821) and forest-steppe and Siberian (t_{fact}=0.113) pines.

CONCLUSIONS

Thus, summing up the results of the study performed to identify differences in the physical and mechanical properties of pine wood (density at 12% moisture content, compressive strength along the fibres, strength in static bending) of 17 different climatypes, it should be noted that in most cases the statistical significance of differences between wood of different climatypes was not found. The similar situation can be traced when comparing the studied properties of wood of various subspecies of pine, identified by L.F. Pravdin. This is due to the fact that wood, which is of plant origin, has a fairly high variability of its properties. This natural feature of wood is determined by its age, growing conditions, hereditary characteristics and other factors that manifest themselves in the process of tree growth. Moreover, it should be noted that most researchers point to a significant variability of wood properties within the breed. The nature of the variability of indicators of some properties of wood can be judged by such a statistical indicator as the coefficient of variation (variability). The smallest variability within the species is characteristic of wood density indicators and is 2.8-10.2%. For the strength in compression along the fibres, the variability varies from 4.8% to 20.6%, for the strength in static bending it is 2.7-21.7%. Ultimately, it can be assumed that an infinitely large number of sample tests are probably required to achieve an acceptable level of confidence in the difference between the studied parameters.

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ПОРІВНЯЛЬНА ОЦІНКА ДЕЯКИХ ФІЗИКО-МЕХАНІЧНИХ ВЛАСТИВОСТЕЙ ДЕРЕВИНИ РІЗНИХ КЛІМАТИПІВ СОСНИ ЗВИЧАЙНОЇ

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Анотація. Для більш ефективного і раціонального використання у виробництві деревини сосни звичайної різного географічного походження необхідно знати її фізико-механічні властивості. Метою дослідження є визначення фізичних (щільність деревини в абсолютно сухому стані, щільність деревини за 12 % вологості) і механічних (міцність деревини за стискання вздовж волокон і на статичний вигин) властивостей деревини 17 кліматичних екотипів сосни звичайної та проведення порівняльного аналізу отриманих показників у досліджуваних походжень окремо і за їх групування у підвиди відповідно до класифікації Л.Ф. Правдіна. Діапазон географічного походження місць заготівлі насіння – від 47 до 62° північної широти і від 22 до 85° східної довготи. Для проведення досліджень була використана сучасна універсальна випробувальна машина MTS INSIGHT 100. В результаті досліджень встановлено, що щільність деревини в абсолютно сухому стані варіює в межах від 370 кг/м^3 (курський кліматип) до 524 кг/м^3 (волгоградський кліматип), а при 12 % вологості – від 397 кг/м^3 (курський кліматип) до 550 кг/м^3 (волгоградський кліматип). Показник міцності деревини досліджуваних кліматипів на стискування вздовж волокон становив від 32 МПа (курський кліматип) до 54

МПа (волгоградський кліматип), а на статичний згин – від 55 до 92 МПа у вологодського і ульяновського кліматипів відповідно. Розподіл кліматипів сосни звичайної на підвиди проведено відповідно до класифікації Л.Ф. Правдіна і отримані дані фізико-механічних властивостей деревини мають певну закономірність. Максимальна щільність деревини при 12 % вологості характерна для підвиду сосни звичайної європейської і становить 497±8 кг/м3, мінімальне значення даного показника у підвиду сосни звичайної сибірської – 423±30 кг/м^3. Проміжне становище займає підвид сосни лапландської і сосни лісостеповій зі значеннями 483±16 і 464±12 кг/м^3 відповідно. Показник міцності деревини у досліджуваних підвидів на стискування вздовж волокон становив від 47±1 МПа (підвид європейська) до 33±4 МПа (підвид сибірська), у підвиду сосни лапландської – 44±2 МПа і трохи нижче у підвиду сосни лісостеповій – 42±2МПа. Максимальне значення показника міцності деревини на статичний згин характерно для підвиду сосни європейської – 78±4 МПа, а мінімальне – у сосни підвиду сибірської – 61±14 МПа. Цей показник виявився однаковим у підвидів сосни лісостепової і лапландської і становив 72±4 МПа. Практична цінність роботи полягає у виявленні наявних відмінностей і мінливості серед кліматипів з досліджуваних фізико-механічних властивостей деревини та проведення відбору найбільш перспективних з них для подальших цілей селекції

Ключові слова: щільність деревини, міцність деревини, статичний згин, мінливість