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BASIC DENSITY OF SPRUCE WOOD, WOOD WITH BARK, AND BARK OF BRANCHES IN LOCATIONS IN THE CZECH REPUBLIC

Vladimír Gryc, Petr Horáček, Jarmila Šlezingerová, Hanuš Vavrčík
Mendel University in Brno, Faculty of Forestry and Wood Technology
Brno, Czech Republic

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ABSTRACT

The aim of the research was to find out the basic density of branch wood with bark, branch wood and bark of Norway spruce (*Picea abies* (L.) Karst.) from different testing areas in the Czech Republic. The average basic density was 515 $kg.m^{-3}$ for branch wood with bark, 576 $kg.m^{-3}$ for branch wood and 364 $kg.m^{-3}$ for bark. No statistically significant differences in mean values of basic density of branch wood with bark and branch wood were found between testing areas. Mean value of stem basic density on the same testing areas was 430 $kg.m^{-3}$. Basic density of stem is about 146 $kg.m^{-3}$ lower than basic density of branch wood. Basic density of stem has higher variability between testing areas than basic density of branch wood.

KEYWORDS: Branchwood, branchbark, basic density, spruce.

INTRODUCTION

The amount of wood of adequate quality for industry is continually decreasing. Therefore, it is necessary to use it more efficiently. Besides stem-wood also branch wood with bark, could be interesting for many purposes, like chemical and semi-chemical processing (ground wood, pulp, chips, production of agglomerated materials) and also for energy.

One of the most important properties of wood is its density. For potential industrial utilization of branches we need to know their density as well (for purchase and sale of the material) is the basic density of wood, or of branch wood.

In wood technology there exist several definitions of density. Basic density is expressed as the weight of dry material (wood, wood and bark, bark) at moisture content (MC) of 0 % per maximum volume (moisture ≥ fibre saturation point) (Panshin and Zeeuw 1980).

Density value for whole branches represents the average of densities of compression wood, opposite wood and normal side wood in the branch (Timell 1986). Hartig (1896) indicates for *Picea* *abies* and *Pinus sylvestris* that the specific gravity of both lower and upper branch wood decreases toward the branch top. Very similar results were founded other researches (Hakkila 1969, 1971, Chmelař 1992). Hakkila (1971) reported, that large branches tended to have a higher density than smaller one.

The compression wood is created on the lower part of bent stems and branches. On the microscopic level, compression wood is expressed by the modified structure of tracheids. Tracheids of the normal wood are of tetragonal or hexagonal form on their cross section whereas tracheids of compression wood are of circular form. Thus, there are intercellular spaces between particular tracheids. Also the cell wall structure is modified in compression wood. The cell wall shows a thickened secondary cell wall, S3 layer is missing and a fibril structure demonstrates the marked deviation of fibrils from a vertical axis (Nečesaný 1955, 1956, Timell 1986, Gryc and Horáček 2007).

The aim of this paper is to study the variability of basic density of wood with bark, branch wood and branch bark of spruce (*Picea abies* (L). Karst.) from various forest sites in Czech Republic.

MATERIAL AND METHODS

Ten different forest sites all over the Czech Republic were chosen to collect the material (Tab. 1). It was selected 6 trees at each location and from each of them took 1 branch from the central crown whorl. One core was taken at breast height (1.3 m above ground) from the each of the sampling trees. Such sampling design would allow us to obtain the results with 95 % probability and 4–5 % accuracy for the locations in question as previously shown by Chmelař (1992).

Tab. 1: Basic data on Norway spruce trees from ten locations in Czech Republic; Forest type – Czech typological system consists of horizontal and vertical divisions of zones; 4 zone of beech, 5 – zone of beech with fir, 6 – zone of beech with spruce, B – rich in nutrients (nutrient-rich), F – rich in nutrients (nutrient-medium), M – acid (nutrient-poor), K – acid (acidic), O – gleyic (nutrient-medium)

Location	Forest type	Age	Average tree height (m)	Average diameter at breast height (cm)
1	4B1	92	26	31.5
2	5M1	107	24	28.4
3	5K1	104	28	34.4
4	5B1	92	27	36.7
5	5F1	82	33	38.8
6	5O1	92	27	32.7
7	6M3	103	26	33.2
8	6K2	89	28	32.5
9	6F1	97	20	36.0
10	6O1	93	30	36.0

The sampled branches were then cut into 1 cm discs at each 25 cm, starting at the branch basis. The discs were used define the basic density of the wood and the bark separately, and the wood with bark. The basic density (ρ_k) was calculated using the formula:

$$\rho_k = \frac{m_0}{V_{max}}$$

where: m_0 is the weight of the material at MC = 0 % (kg),
V_{max} is the maximum volume of material (MC ≥ fibre saturation point) (m^3).

The wood volume was established using the Olesen's method (Olesen 1971). The samples were laid in beakers with water until their maximum dimensions were reached. Then they were dried with filter paper, bark was separated from the branch and using the Olesen's method, and the volumes of the wood and of the bark were determined separately. Afterwards, the samples were dried in oven at the temperature of 103 ± 2 °C until their MC reached 0 %. The weight was measured by using an analytic balance, again for the wood and the bark separately. Finally the obtained results were processed with standard statistic methods.

RESULTS AND DISCUSSION

Basic density of wood with bark

The average basic density of wood with bark was 514.69 kg.m^{-3} (coefficient of variation 14.67 %), the values ranging between 496 and 542 kg.m^{-3} in specific locations (Tab. 2).

Tab. 3 shows the significance of arithmetic means differences between particular locations which are in most cases insignificant. Based on this we can conclude that the location does not affect the basic density of spruce branch wood with bark.

Tab. 2: Basic density of Norway spruce branch wood with bark from ten locations in Czech Republic (μ – mean, SD – standard deviation, CV – coefficient of variation)

Location (forest type)	Number of branches	Number of samples	Basic density		
			μ (kg.m^{-3})	SD (kg.m^{-3})	CV (%)
1 (4B1)	6	53	517.45	11.88	16.71
2 (5M1)	6	65	506.46	11.03	17.56
3 (5K1)	6	69	510.88	8.90	14.47
4 (5B1)	6	66	527.11	9.97	15.37
5 (5F1)	6	70	510.64	8.87	14.54
6 (5O1)	6	59	495.95	8.52	13.20
7 (6M3)	6	58	541.49	8.32	11.70
8 (6K2)	6	62	513.21	9.51	14.59
9 (6F1)	6	64	512.70	8.45	13.18
10 (6O1)	6	58	512.78	9.40	13.96

Tab. 3: Significance of differences in arithmetic means of basic density for spruce branch wood with bark in ten locations of the Czech Republic (statistical differences: (-) insignificant, (+) significant, (++) highly significant

	1 (4B1)	2 (5M1)	3 (5K1)	4 (5B1)	5 (5F1)	6 (5O1)	7 (6M3)	8 (6K2)	9 (6F1)	10 (6O1)
1 (4B1)		-	-	-	-	-	-	-	-	-
2 (5M1)			-	-	-	-	-	-	-	-
3 (5K1)				-	-	-	+	-	-	-
4 (5B1)					-	+	-	-	-	-
5 (5F1)						-	+	-	-	-
6 (5O1)							++	-	-	-
7 (6M3)								+	+	+
8 (6K2)									-	-
9 (6F1)										-
10 (6O1)										

Basic density of branch wood

Average values of the basic density of branch wood for individual locations including other statistic quantities are presented in Tab. 4. The average basic density of branch wood was 576 kg.m^{-3} (ranging from 570 to 593 kg.m^{-3}). Generally spoken, we can state that the differences of arithmetic means of the basic density of spruce branch wood between particular locations are statistically insignificant (Tab. 5). It means that the influence of the location on this property is not visible. The values of the coefficient of variation for individual sets are as follows: for the sets expressed by the arithmetic mean for individual branches the values range between 6.3 and 22.9 % (mostly 10–15 %), for individual locations 12.8–19.5 % and for the entire set of the Czech Republic it is 15.1 %.

Tab. 4: Descriptive statistics of basic density of spruce branch wood in ten locations in the Czech Republic (μ – mean, SD – standard deviation, CV – coefficient of variation)

Location (forest type)	Number of branches	Number of samples	Basic density		
			μ (kg.m^{-3})	SD (kg.m^{-3})	CV (%)
1 (4B1)	6	53	564.26	15.18	19.58
2 (5M1)	6	65	584.43	11.57	15.96
3 (5K1)	6	69	577.49	10.51	15.12
4 (5B1)	6	66	592.67	11.83	16.22
5 (5F1)	6	70	567.13	9.78	14.44
6 (5O1)	6	59	572.73	10.09	13.54
7 (6M3)	6	58	588.89	10.49	13.57
8 (6K2)	6	62	562.96	10.87	15.20
9 (6F1)	6	64	570.94	9.11	12.77
10 (6O1)	6	58	572.64	10.62	14.13

Tab. 5: Significance of arithmetic means differences in basic density of spruce branch wood in locations in the Czech Republic (- statistically insignificant difference, + statistically significant difference, + + highly statistically significant difference)

	1 (4B1)	2 (5M1)	3 (5K1)	4 (5B1)	5 (5F1)	6 (5O1)	7 (6M3)	8 (6K2)	9 (6F1)	10 (6O1)
1 (4B1)		-	-	-	-	-	-	-	-	-
2 (5M1)			-	-	-	-	-	-	-	-
3 (5K1)				-	-	-	-	-	-	-
4 (5B1)					-	-	-	-	-	-
5 (5F1)						-	-	-	-	-
6 (5O1)							-	-	-	-
7 (6M3)								-	-	-
8 (6K2)									-	-
9 (6F1)										-
10 (6O1)										

Basic density of branch bark

The basic density of branch bark ranged between 335 and 400 kg.m^{-3} (average 364 kg.m^{-3}). The values of the coefficient of variation are as follows: for individual branches it was within 2.2–16.6 %, for individual locations 5.3–15.1 % and for the entire set of the Czech Republic it was 11.6 %. The coefficient of variation for most of the locations was below 11 %. Tab. 6 presents the descriptive statistics for individual locations. In contrast to the basic density of wood with bark and wood, the differences between individual locations in the basic density of branch bark were statistically significant or even highly significant (Tab. 7).

Tab. 6: Descriptive statistics of the basic density of spruce branch bark in locations in the Czech Republic (μ – mean, SD – standard deviation, CV – coefficient of variation)

Location (forest type)	Number of branches	Number of samples	Basic density		
			μ (kg.m^{-3})	SD (kg.m^{-3})	CV (%)
1 (4B1	6	53	399.91	5.70	10.38
2 (5M1)	6	65	336.00	5.07	12.17
3 (5K1)	6	69	350.42	5.36	12.70
4 (5B1)	6	66	366.88	4.71	10.42
5 (5F1)	6	70	360.70	3.44	7.99
6 (5O1)	6	59	334.93	3.09	7.10
7 (6M3)	6	58	384.05	2.68	5.32
8 (6K2)	6	62	395.13	7.59	15.17
9 (6F1)	6	64	368.29	3.00	7.17
10 (6O1)	6	58	357.17	3.16	6.73

Tab. 7: Significance of arithmetic means differences in basic density of spruce branch bark in locations in the Czech Republic (- statistically insignificant difference, + statistically significant difference, + + highly statistically significant difference)

	1 (4B1)	2 (5M1)	3 (5K1)	4 (5B1)	5 (5F1)	6 (5O1)	7 (6M3)	8 (6K2)	9 (6F1)	10 (6O1)
1 (4B1)		++	++	++	++	++	+	-	++	++
2 (5M1)			-	++	++	-	++	++	++	++
3 (5K1)				+	-	+	++	++	++	-
4 (5B1)					-	++	++	++	-	-
5 (5F1)						++	++	++	-	-
6 (5O1)							++	++	++	++
7 (6M3)								-	++	++
8 (6K2)									++	++
9 (6F1)										+
10 (6O1)										

Mass and volumetric portion of branch bark

Descriptive statistics of mass portion of bark at moisture content 0 % is presented in Tab. 8. Tab. 9 shows the significance of arithmetic means difference between particular locations. It was found out that in the most cases are differences in arithmetic means in this characteristic statistical insignificant. It means that the locations does not affect the mass portion of spruce branch bark. The values of the coefficient of variation for individual branches ranged between 19.96 and 77.23 %, for individual locations 30.6–52.5 and for entire set of the Czech Republic it was 42.9 %. Value of coefficients of variation for mass proportion were highest from all studying properties.

The results of volumetric portion of branch bark are presented in Tab. 10. The average values of the mass portion of branch bark ranged between 23 and 32 %. It was found out that in the most cases are differences in arithmetic means in this characteristic statistical insignificant (without locality 7) see Tab. 11. The values of the coefficient of variation for this characteristic for individual branches ranged between 15.6 and 57.11 %, for individual locations 25.6–41.8 % and for entire set of the Czech Republic it is 35.2 %.

Tab. 8: Descriptive statistics of the mass portion of spruce branch bark (MC = 0 %) in locations in the Czech Republic (μ – mean, SD – standard deviation, CV – coefficient of variation)

Location (forest type)	Number of branches	Number of samples	Mass portion of branch bark		
			μ (%)	SD (%)	CV (%)
2 (5M1)	6	65	22.02	1.44	52.52
3 (5K1)	6	69	19,87	1.03	43.07
4 (5B1)	6	66	21.42	0.95	35.85
5 (5F1)	6	70	20.34	1.08	44.58
6 (5O1)	6	59	22.64	1.47	49.86
7 (6M3)	6	58	17.14	0.69	30.64
8 (6K2)	6	62	23.68	1.07	35.40
9 (6F1)	6	64	22.28	1.39	49.81
10 (6O1)	6	58	20.42	0.93	34.65

Tab. 9: Significance of arithmetic means differences in mass portion of spruce branch bark (MC = 0 %) in locations in the Czech Republic (- statistically insignificant difference, + statistically significant difference, + + highly statistically significant difference)

	1 (4B1)	2 (5M1)	3 (5K1)	4 (5B1)	5 (5F1)	6 (5O1)	7 (6M3)	8 (6K2)	9 (6F1)	10 (6O1)
1 (4B1)		-	+	-	-	-	+ +	-	-	-
2 (5M1)			-	-	-	-	+ +	-	-	-
3 (5K1)				-	-	-	+	+	-	-
4 (5B1)					-	-	+ +	-	-	-
5 (5F1)						-	+	+	-	-
6 (5O1)							+ +	-	-	-
7 (6M3)								+ +	-	+ +
8 (6K2)									-	+
9 (6F1)										-
10 (6O1)										

Tab. 10: Descriptive statistics of the volume portion of spruce branch bark (MC ≥ fibre saturation point) in locations in the Czech Republic (μ – mean, SD – standard deviation, CV – coefficient of variation)

Location (forest type)	Number of branches	Number of samples	Volume portion of branch bark		
			μ (%)	SD (%)	CV (%)
1 (4B1)	6	53	29.22	1.06	26.39
2 (5M1)	6	65	31.89	1.66	41.85
3 (5K1)	6	69	28.45	1.32	38.54
4 (5B1)	6	66	29.88	1.03	28.06
5 (5F1)	6	70	28.08	1.27	37.79
6 (5O1)	6	59	32.39	1.58	37.46
7 (6M3)	6	58	23.54	0.79	25.63
8 (6K2)	6	62	30.25	1.12	29.16
9 (6F1)	6	64	29.87	1.48	39.52
10 (6O1)	6	58	28.57	1.04	29.71

Tab. 11: Significance of arithmetic means differences in volume portion of spruce branch bark (MC ≥ fibre saturation point) in locations in the Czech Republic (– statistically insignificant difference, + statistically significant difference, + + highly statistically significant difference)

	1 (4B1)	2 (5M1)	3 (5K1)	4 (5B1)	5 (5F1)	6 (5O1)	7 (6M3)	8 (6K2)	9 (6F1)	10 (6O1)
1 (4B1)		-	-	-	-	-	++	-	-	-
2 (5M1)			-	-	-	-	++	-	-	-
3 (5K1)				-	-	-	++	-	-	-
4 (5B1)					-	-	++	-	-	-
5 (5F1)						+	++	-	-	-
6 (5O1)							++	-	-	-
7 (6M3)								++	-	++
8 (6K2)									-	-
9 (6F1)										-
10 (6O1)										

Comparison of basic density of branch and stem wood

The average values of the basic density of stem (at breast height) and branch wood from individual locations are presented in Tab. 12. Presence of compression wood is a reason of heigh basic density of branch wood compared to basic density of stem wood (difference between stem and branch was 146 kg.m^{-3}). The major histological characteristics for compression wood tracheids are on transversal section rounded outline, intracellular spaces and thick wall (Fig. 1).

The average value of the basic density of the stem wood is 430 kg.m^{-3}. The difference in basic density between the maximum (location 1) and the minimum value (location 9) is 105 kg.m^{-3}. As far as the basic density of branch wood is concerned, the differences between individual locations are considerably lower (only 30 kg.m^{-3}). This shows that the variability in basic density of stem wood is higher than that of branch wood.

Tab. 12: Arithmetic means of basic density of spruce stem and branch wood for ten locations in the Czech Republic

Location (type)	Basic density - (kg.m^{-3})		
	Stem	Branches	Difference
1 (4B1)	476	564	88
2 (5M1)	446	584	138
3 (5K1)	441	577	136
4 (5B1)	428	593	165
5 (5F1)	414	567	153
6 (5O1)	446	573	127
7 (6M3)	422	589	167
8 (6K2)	436	563	127
9 (6F1)	371	573	202
10 (6O1)	419	572	153
Average	**430**	**576**	**146**

The data on density of spruce stem wood, are generally known and can be found in a wide range of literature. Also the variability of wood density and the factors affecting it were examined in many studies (Trendelenburg 1959, Janota and Škripeň 1960, Palovič and Kamenický 1961, Bernhart 1964, Kommert 1987, Petty et al. 1990, Grammel 1990, Zobel and Sprague 1998, Wagenführ 2000, Perstoper et al. 2001, Niemz and Sonderegger 2003, Kärenlampi and Riekkinen 2004, Gryc and Horáček 2007, Přemyslovská et al. 2008). However, the studies on density of spruce branch wood, wood with bark and bark and its distribution within branches are rare. Our results show that the branch wood has a higher basic density than stem wood; the difference between these two densities is 88–218 kg.m^{-3} (average for ten sites in Czech Republic is 146 kg.m^{-3}). Trendelenburg (1959) already stated that the density of dry spruce branch wood can be twice as high as stem wood density and that it can reach up to 900 kg.m^{-3}.

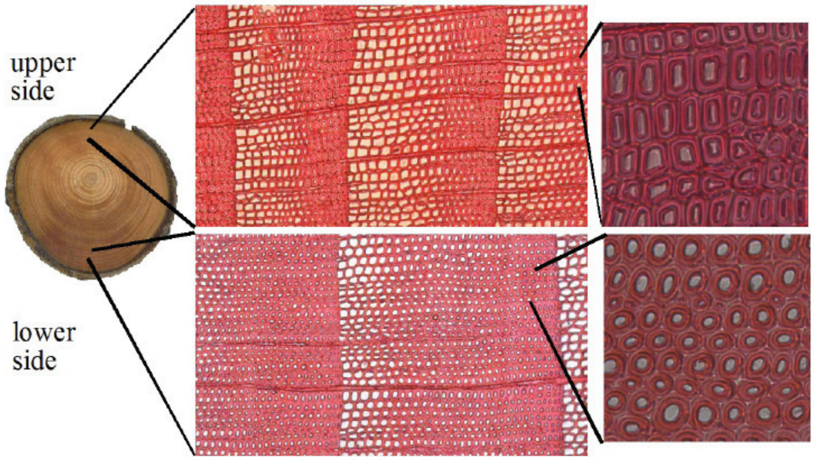

Fig. 1: Macroscopic and microscopic structure of branch wood

Our data approximate these values. The individual values of the basic density of branch wood ranged namely between 330 and 920 kg.m^{-3}, the coefficient of variation for individual partial sets was 8.53–31.4 %. Such significant variability can be explained by the occurrence of compression wood, which is present in various amounts (abundant, moderate, or slight compression wood). The rule is that the basic density of branch wood decreases in the direction from the branch basis to its top; the greatest decrease was found in the first metre of the branch. Then the decrease is minimal.

The data presented in literature indicate that the difference in density of the stem and the branch wood is related to wood species. For some species (or genera) the differences in wood density of stem and branches are small. The density of pine branch wood is only 430–570 kg.m^{-3} (Timell 1986); the density of pine stem is 510 kg.m^{-3} on average (Wagenführ 2000).

Our density values of spruce branch bark 365 kg.m^{-3}, correspond quite well to basic density of spruce stem bark obtained for other regions 342 kg.m^{-3}, south-west Germany, 333 kg.m^{-3}, Switzerland, as presented by Dietz (1975).

CONLUSIONS

No relationship between the basic density of stem and branches was found. There was also found no relationship among locations; the average values of the basic density of branch wood in various locations did not differ considerably. It means that the obtained values of the basic density of wood with bark 515 kg.m^{-3} and the basic density of branch wood 576 kg.m^{-3}, can be used for any location within the Czech Republic.

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Vladimír Gryc
Mendel University in Brno
Faculty of Forestry and Wood Technology
Czech Republic
Corresponding author: gryc@mendelu.cz

Petr Horáček
Mendel University in Brno
Faculty of Forestry and Wood Technology
Czech Republic
E-mail: horacek@mendelu.cz

Jarmila Šlezingerová
Mendel University in Brno
Faculty of Forestry and Wood Technology
Czech Republic
E-mail: slezing@centrum.cz

Hanuš Vavrčík
Mendel University in Brno
Faculty of Forestry and Wood Technology
Czech Republic
E-mail: vavrcik@mendelu.cz