Effect of the position in a stem on the length of tracheids in spruce (*Picea abies* [L.] Karst.) with the occurrence of reaction wood

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ABSTRACT: The paper was aimed at the determination of variability of tracheid dimensions in spruce wood in relation to the position in a spruce stem. Significant changes in dimensions were found in early-wood and late-wood tracheids along the stem length and radius. There were statistically significant differences (variability along the radius) between particular annual rings. The height of 22 m showed statistically significant differences as compared with other heights (variability along the height). Differences between the length of early-wood and late-wood tracheids were not corroborated in zones CW, OW and SWL. Only in the SWP zone, statistically significant differences were found. Data sets (early-wood and late-wood tracheids) from the CW zone showed statistically significant differences as compared with other zones. On the basis of the results obtained, 3D models were created (for CW, OW, SWL and SWP zones; models for an early-wood and late-wood tracheid) describing changes in tracheid dimensions in spruce in relation to the position in a stem. In the models, the length of tracheids decreases with the height of a stem and on the other hand, with an increasing distance from the stem pith the length of tracheids increases. The importance of the paper consists in the enlargement of findings on the structure of spruce wood. In addition to this, the paper can contribute to the partial explanation of the different behaviour of physical and mechanical properties of wood in particular parts of the spruce stem.

Keywords: spruce; tracheid; length of tracheids; compression wood

Norway spruce (*Picea abies* [L.] Karst.) ranks among the most important commercial species in the Czech Republic. In 2002, its area proportion amounted to 53.8% of the total area of Bohemian and Moravian forests (Report on the Condition of Forests and Forestry of the Czech Republic in 2002). For the explanation of wood properties and for the needs of technological processing of wood it is necessary to deal not only with macroscopic but also microscopic structure of wood (e.g. the length of tracheids in paper industry, fibreboards).

The structure of softwood is formed by only two types of anatomic elements: tracheids and parenchymal cells (Wagenführ 1999). Tracheids are the main structural element of wood and their percentage in wood ranges between 90 and 94% (Plomion et. al. 2001; Sisko, Pfäffli 1995; Panshin, Zeeuw 1980; Matovič, Gandelová 1980; Balabán 1955; Kollman 1951; Trendelenburg 1939). The remaining percentage in wood is formed by parenchymal cells which participate in the structure of pith rays, axial wood parenchyma and resin canals. Within particular annual rings, it is possible to observe two types of tracheids, viz. early-wood and late-wood tracheids. Early-wood tracheids are formed at the beginning of the growing season. They have thin cell walls with a wide lumen and numerous bordered pits. Early-wood tracheids fulfil a conduc-

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tive function in wood. On the other hand, late-wood tracheids formed by cambium at the end of the growing season have thick cell walls and small lumen. Late-wood tracheids have a mechanical function in wood (Wagenführ 1989, 1999). The length of tracheids in wood is considerably variable changing both within particular annual rings and along the stem radius and height. Within an annual ring, it has been found that late-wood tracheids are longer than early-wood tracheids (Wagenführ 1989; Götsche, Kühn 1988; Panshin, Zeeuw 1980; Shelbourne, Ritchie 1968; Škripeň, Riasová 1958; Trendelenburg 1939). Along the stem radius, the length of tracheids increases from the stem pith to the stem girth. The main increase in the tracheid length was observed between the pith and the 30th annual ring of a tree; in the following years tracheids show a small increase or the tracheid length stagnation was found (Gryc, Horáček 2003; Sarén et. al. 2001; Yang, Hazenberg 1994; Kučera, Bosshard 1989; Seth, Agrawal 1984; Knigge, Wenzel 1982). Shorter dimensions of tracheids in the region of the stem pith are explained by the juvenile structure of wood (juvenile cambium).

The tracheid length along the stem height is not so unambiguous. Sanio (1873) found that the length of tracheids increased from the stem base reaching its maximum and then the tracheid length gradually decreased towards the tree crown. Gryc and Horáček (2003) reported that the tracheid length gradually decreased with the increasing stem height. On the other hand, Chu (1972) found that in longleaf pine (*Pinus palustris*) the length of tracheids increased from the base to the stem top.

Owing to unfavourable growth factors during the tree growth, reaction wood occurs. Wind, snow load, asymmetrical structure of the tree crown or growth on unstable steep slopes (Schweingruber 1993; Timell 1986; Douda 1948) rank among basic impacts contributing to the creation of reaction wood.

In some gymnosperms, reaction wood occurs the wood being called compression wood (Timell 1986). The compression wood is formed on the lower part of bent stems and branches (Wagenführ 1999; Timell 1986; Kolman 1951; Trendelenburg 1939). The majority of authors defines compression wood as a point which shows dark reddish colour as compared with neighbouring wood and annual rings are substantially wider than in normal wood. Reaction wood is often accompanied by eccentrically situated pith (Trendelenburg 1939; Kollman 1951; Butterfield, Meylan 1980; Timell 1986; Schweingruber 1993; Wagenführ 1999; Seeling 1999).

In the region of the microscopic structure of wood, modification of tracheids occurs in particular whereas parenchymal cells are not changed (Timell 1986). Tracheids of the reaction wood are of orbiculate shape (the origin of intercellular spaces) and have thick cell walls where S_3 layer is missing while S_2 layer shows marked reinforcement and lamella-type structure (Timell 1986; Casperson 1962; Knigge 1958; Trendelenburg 1932). Tracheids of the reaction wood are shorter as compared with tracheids of normal late wood (Timell 1986; Seth, Jain 1977; Shelbourne, Ritchie 1968; Onaka 1949).

The paper is focussed on the region of the microscopic structure of wood dealing with the description of the most important anatomical element in softwood, i.e. tracheids in a stem with the occurrence of reaction wood. The objective of the paper was to create models describing variability of the length of early-wood and late-wood tracheids in relation to the position in the tree stem. Another objective was to determine if there was a statistically important difference in the length between early-wood and late-wood tracheids or a statistically significant difference in the length between particular zones.

MATERIAL AND METHODS

In the Křtiny Training Forest Enterprise Masaryk Forest, Forest District Habrůvka, one sample spruce

Fig. 1. Position of the selected tree in a stand (selected tree is marked by an arrow)

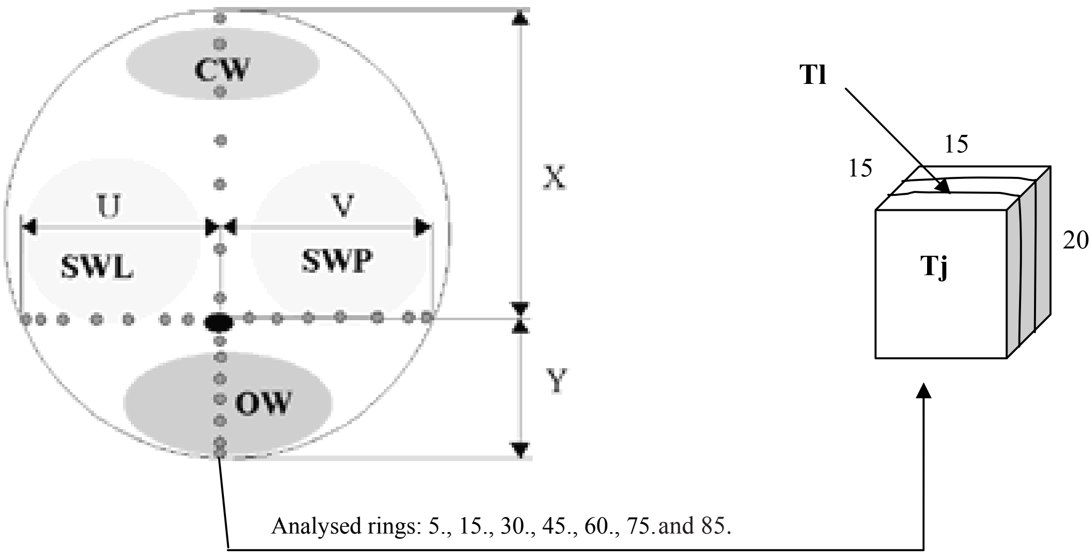

Fig. 2. Sampling points on a log, dimensions of the sample (mm)
X, Y, U, V – directions of measurement, CW – compression wood zone, OW – opposite zone, SWL and SWP – lateral wood zones, ooo – examined annual rings, Tj – tangential area of early wood, Tl – places of taking the tangential area of late wood

tree (*Picea abies*) with the supposed occurrence of reaction wood was selected (Fig. 1). The axis of the tree was diverted from the direction of the Earth gravity. The selected tree was about 110 years old. The total length of the tree was 33 m.

Eight discs 100 mm thick were taken from the tree stem from the base to the tree top at a height of 6, 8, 10, 12, 15, 18, 20 and 22 m. In each of the discs, the direction of measurement was marked, viz. reaction wood zone (X), opposite zone (Y) and two lateral zones (U and V) (Fig. 2).

To determine variability of the tracheid length in relation to the position in a stem, samples of wood were taken in respective zones (CW, OW, SWL and SWP), the 5th, 15th, 30th, 45th, 60th, 75th and 85th annual rings (counted from cambium) and heights (6, 8, 10, 12, 15, 18, 20 and 22 m). Dimensions of the wood samples were 15 (height) × 15 (width) × 20 (length) mm (Fig. 2).

To make permanent microscopic preparations it was necessary to put samples into a mixture of water and glycerol and to boil them under a reflux condenser. After softening, samples were fixed in a microtome (Leica SM2000R) and two tangential cuts were done within an annual ring. One tangential cut was from the region of early wood and the second from the region of late wood. Tangential cuts were 18–20 µm thick. The cuts were dyed (safranine), dewatered (alcohol series; Wagenführ 1999) and installed between slide and cover glass by means of Canadian balsam.

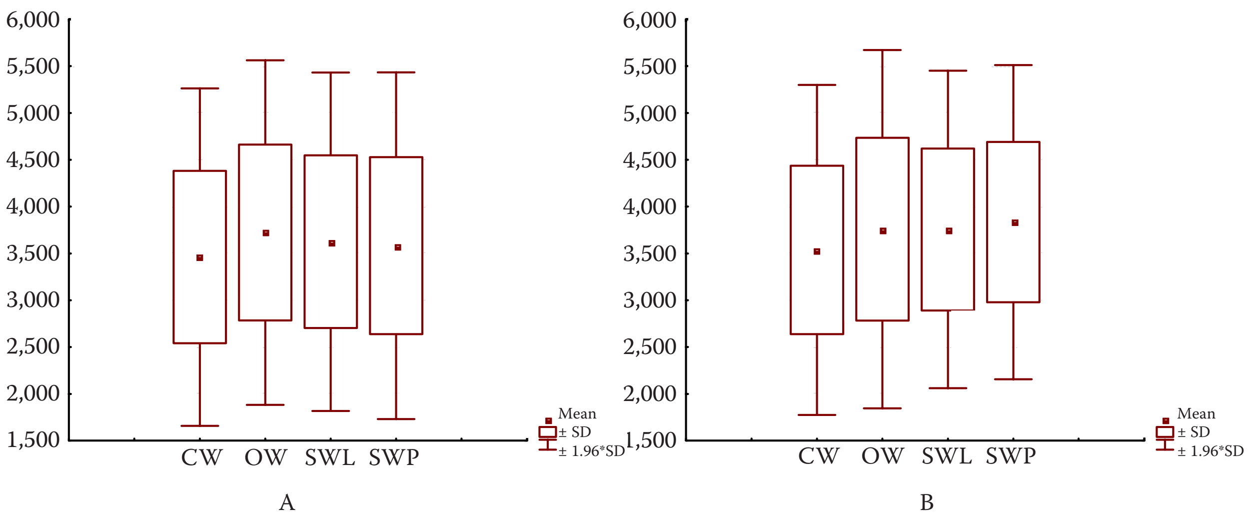

Fig. 3. Box diagram – mean length of tracheids for particular zones (all data were used)
A – early-wood tracheid, B – late-wood tracheid

Table 1. Descriptive statistics of the length of early-wood (J) and late-wood (L) tracheids for particular zones and heights

Height (m)	Statistical variable	CW		OW		SWL		SWP	
		J	L	J	L	J	L	J	L
	Mean (μm)	2,926.38	2,840.99	3,415.70	3,171.88	3,152.32	3,200.53	3,219.99	3,455.95
	Median (μm)	2,826.13	2,961.76	3,543.29	3,225.24	3,232.01	3,340.80	3,195.99	3,515.60
22	Variance (μm^2)	621,929.75	536,065.61	867,747.65	763,453.59	635,819.18	878,476.92	438,357.17	385,141.61
	Standard deviation (μm)	788.63	732.17	931.53	873.76	797.38	937.27	662.09	620.60
	Coefficient of variation (%)	26.95	25.77	27.27	27.55	25.30	29.28	20.56	17.96
	Mean (μm)	3,401.15	3,484.08	3,561.45	3,668.45	3,581.56	3,776.61	3,448.30	3,710.01
	Median (μm)	3,413.00	3,426.69	3,527.86	3,665.37	3,633.67	3,899.73	3,533.92	3,831.39
20	Variance (μm^2)	562,466.20	532,588.47	499,245.93	468,357.47	346,769.23	438,735.30	686,350.69	635,191.36
	Standard deviation (μm)	749.98	729.79	706.57	684.37	588.87	662.37	828.46	796.99
	Coefficient of variation (%)	22.05	20.95	19.84	18.66	16.44	17.54	24.03	21.48
	Mean (μm)	3,488.33	3,728.85	4,020.92	3,671.52	3,566.07	3,629.25	3,456.28	3,929.91
	Median (μm)	3,464.65	3,934.44	4,110.21	3,877.12	3,660.58	3,814.43	3,554.19	3,941.04
18	Variance (μm^2)	740,753.72	758,773.94	705,722.95	1,241,331.98	705,604.63	855,260.26	638,244.61	479,372.89
	Standard deviation (μm)	860.67	871.08	840.07	1,114.15	840.00	924.80	798.90	692.37
	Coefficient of variation (%)	24.67	23.36	20.89	30.35	23.56	25.48	23.11	17.62
	Mean (μm)	3,650.01	3,808.25	3,759.46	3,957.62	3,754.33	3,866.50	3,672.76	3,864.60
	Median (μm)	3,541.95	3,893.61	3,773.75	4,011.80	3,693.78	3,947.71	3,735.04	3,913.92
15	Variance (μm^2)	460,472.69	463,471.42	686,100.80	662,139.34	553,740.83	442,951.86	837,571.77	607,644.80
	Standard deviation (μm)	678.58	680.79	828.31	813.72	744.14	665.55	915.19	779.52
	Coefficient of variation (%)	18.59	17.88	22.03	20.56	19.82	17.21	24.92	20.17
	Mean (μm)	3,846.48	3,858.74	3,827.25	4,028.70	3,882.41	3,828.30	3,804.01	3,901.00
	Median (μm)	4,032.26	3,859.89	3,782.85	4,037.11	3,840.02	3,835.85	3,821.89	3,879.91
12	Variance (μm^2)	585,236.74	509,128.35	792,313.86	840,381.25	875,569.79	663,482.89	893,143.31	705,415.29
	Standard deviation (μm)	765.01	713.53	890.12	916.72	935.72	814.54	945.06	839.89
	Coefficient of variation (%)	19.89	18.49	23.26	22.75	24.10	21.28	24.84	21.53
	Mean (μm)	3,558.79	3,595.34	3,632.37	3,748.04	3,904.96	4,032.40	3,555.78	3,696.51
	Median (μm)	3,757.93	3,759.68	3,854.28	3,996.19	3,984.85	4,143.87	3,804.59	4,035.19
10	Variance (μm^2)	1,007,599.08	940,490.17	1,173,335.72	1,143,314.44	585,935.34	506,728.90	1,202,696.02	1,128,858.27
	Standard deviation (μm)	1,003.79	969.79	1,083.21	1,069.26	765.46	711.85	1,096.67	1,062.48
	Coefficient of variation (%)	28.21	26.97	29.82	28.53	19.60	17.65	30.84	28.74

Table 1 to be continued

	Mean (µm)	3,197.04	3,341.60	3,899.66	3,904.06	3,806.05	3,952.33	3,761.38	4,055.01
	Median (µm)	3,311.90	3,518.46	4,048.89	4,153.88	4,011.74	3,967.37	3,771.59	4,152.79
8	Variance (µm²)	1,221,859.67	1,077,881.85	776,285.63	800,857.96	917,396.73	707,092.68	759,698.84	589,644.16
	Standard deviation (µm)	1,105.38	1,038.21	881.07	894.91	957.81	840.89	871.61	767.88
	Coefficient of variation (%)	34.58	31.07	22.59	22.92	25.17	21.28	23.17	18.94
	Mean (µm)	3,593.70	3,677.90	3,670.57	3,843.40	3,376.50	3,462.84	3,542.83	3,863.31
	Median (µm)	3,748.94	3,784.88	3,803.64	4,104.32	3,588.62	3,611.53	3,872.35	4,045.99
6	Variance (µm²)	790,802.59	709,242.71	1,156,591.93	1,090,608.29	1,364,787.60	1,429,373.07	1,279,436.02	944,496.47
	Standard deviation (µm)	889.27	842.17	1,075.45	1,044.32	1,168.24	1,195.56	1,131.12	971.85
	Coefficient of variation (%)	24.75	22.90	29.30	27.17	34.60	34.53	31.93	25.16

After hardening the permanent preparation, tangential cuts were taken by means of a digital camera in the University Biometrical Laboratory. The photographs were evaluated using the Lucia program. In each of the tangential cuts, lengths of 20 early-wood and 20 late-wood tracheids were measured. The values obtained were statistically processed by means of Statistica 6.0 program (descriptive statistics ANOVA) and Table Curve 3D 4.0 (tracheid variability in relation to the position in a stem).

RESULTS

Mean values of the early-wood and late-wood tracheid length for particular zones are given in Table 1. Lengths of early-wood and late-wood tracheids for particular zones (all data measured in the respective zones were used) are depicted using a box diagram (Fig. 3). The diagram shows that the length of late-wood tracheids shows a slightly higher mean value than early-wood tracheids. A statistically significant deviation was found only between mean lengths of early-wood and late-wood tracheids in SWP zone.

It was found by means of two-factor ANOVA that there was a statistically significant difference in the mean values of early-wood and late-wood tracheids between particular zones. These significant differences occurred in early-wood tracheids between zones: CW and OW, CW and OW, CW and SWP, CW and SWL and OW and SWP. In the case of late-wood tracheids, differences were found between zones: CW and OW, CW and OW, CW and SWP and CW and SWL (Table 3). Thus, the compression wood zone shows statistically significant differences in the length of tracheids as compared with other zones. Between other zones, statistically significant differences were not corroborated.

Moreover, it was been found that there was a statistically significant effect of the tree height and position along the stem radius on the length of early-wood and late-wood tracheids. Statistically significant differences in the length of early-wood and late-wood tracheids along the stem height were found at a height of 22 m in relation to other heights, viz. in all zones (CW, OW, SWL and SWP). In early-wood tracheids, there were also statistically significant differences in the length of tracheids in the following sets: CW – 8 m, OW – 20 m and OW – 8 m. In late-wood tracheids, other statistically significant deviations were found in the following sets: CW – 8 m and SWL – 6 m. Statistically significant differences were not corroborated between other heights in late-wood and early-wood tracheids.

In the case of variability in the length of tracheids along the stem radius, statistically significant effects were observed between particular annual rings in all zones. Statistically significant effects were not proved in late-wood tracheids between annual rings 5 and 15 (for all zones) and in early-wood tracheids between annual rings 15 and 30 (also for all zones).

Based on the data, 3D models were created (for particular zones: CW, OW, SWL and SWP) describing the length of early-wood and late-wood tracheids in relation to the position along the stem radius and height. In all models (Fig. 4), the length

Table 2. Table of resulting functions and coefficients and coefficients of determination of the sampling and basic set for the length of early-wood and late-wood tracheids in particular zones of a stem

Zone	Tracheid type	Function	Coefficient of determination – set		Coefficients					
			sampling	basis	a	b	c	d	e	f
CW	J	$z = a + bx + cx^2 + dy + ey^2 + fy^3$	0.48	0.48	4,140.32	104.46	–5.73	–48.29	1.07	–0.01
OW	J	$z = a + bx^2 + cx^2 lnx + dx^3 + ey + fy^3$	0.44	0.44	5,537.81	–71.87	33.49	–1.61	–8.89	–0.003
SWL	J	$z = a + bx + cx^2 + dy + ey^2 + fy^3$	0.43	0.43	4,080.39	103.49	–5.60	–27.17	0.60	–0.01
SWP	J	$z = a + bx^2 + cy^3$	0.43	0.43	4,476.03	–2.32	–0.005			
CW	L	$z = a + bx^{1.5} + cx^2 + dx^{2.5} + ey + fy^3$	0.51	0.51	6,100.79	–488.45	214.35	–24.82	–7.46	–0.003
OW	L	$z = a + bx + cy + dx^2 + ey^2 + fxy$	0.44	0.44	3,716.56	118.55	34.45	–5.42	–0.57	–1.46
SWL	L	$z = a + bx + cy + dx^2 + ey^2 + fxy$	0.47	0.46	3,199.86	159.81	39.15	–6.11	–0.62	–1.59
SWP	L	$z = a + bx + cx^2 + dx^3 + ey + fy^2$	0.39	0.38	6,210.17	–437.23	33.80	–0.88	4.86	–0.36

of tracheids was found to increase along the stem radius. This result is fully consistent with results of two-factor ANOVA analysis. The accelerated increment of the length of tracheids in the first thirty years of a tree is typical of all models. In next years, a slow increase in the length of tracheids is shown. Within the last twenty years (a region below cambium), an increment in the length of tracheids is not so marked. This graphical depiction also corresponds to the results of two-factor ANOVA analysis where it was found that between annual rings 5 and 15 or 15 and 30, there were no statistically significant differences and, therefore there are no statistically significant differences in the length between tracheids in these annual rings.

The models also show changes in the length of tracheids in relation to the tree height. The length of tracheids between the 5^{th} and the 18^{th} metre is nearly constant. A decrease in the length of tracheids occurs between the 18^{th} and the 25^{th} metre. However, here it is also possible to observe the congruence of a model with statistical examinations which have proved that a height of 22 m (both in early-wood and late-wood tracheids) shows statistically different values as compared with other heights.

The models (that are nearly identical) do not indicate any differences between the lengths of early-wood and late-wood tracheids. Differences between particular zones are also minimal (the SWP lateral zone demonstrated the same model as the SWL zone). Functions, equation coefficients and coefficients of determination for particular zones are given in Table 2. Coefficients of determination of sampling sets range between 0.39 and 0.51, i.e. the length of tracheids shows medium correlation dependence in relation to the position along the stem radius and height.

DISCUSSION

The objective of the paper was to determine variability in the length of a tracheid in relation to its position in the tree stem. Studies in the field of the microscopic structure of wood (tracheid length)

Table 3. Results of Tukey's method of the multiple comparison of tracheid length between particular zones

	Zone	CW	OW	SWL	SWP
A	CW		0.0000	0.0000	0.0000
	OW	0.0000		0.7596	0.1332
	SWL	0.0000	0.7596		0.0079
	SWP	0.0000	0.1332	0.0079	
B	CW		0.0000	0.0028	0.0448
	OW	0.0000		0.1841	0.0205
	SWL	0.0028	0.1841		0.8142
	SWP	0.0448	0.0205	0.8142	

A – early-wood tracheid, B – late-wood tracheid ($P < 0.05$ statistically significant difference, $P > 0.05$ statistically insignificant difference)

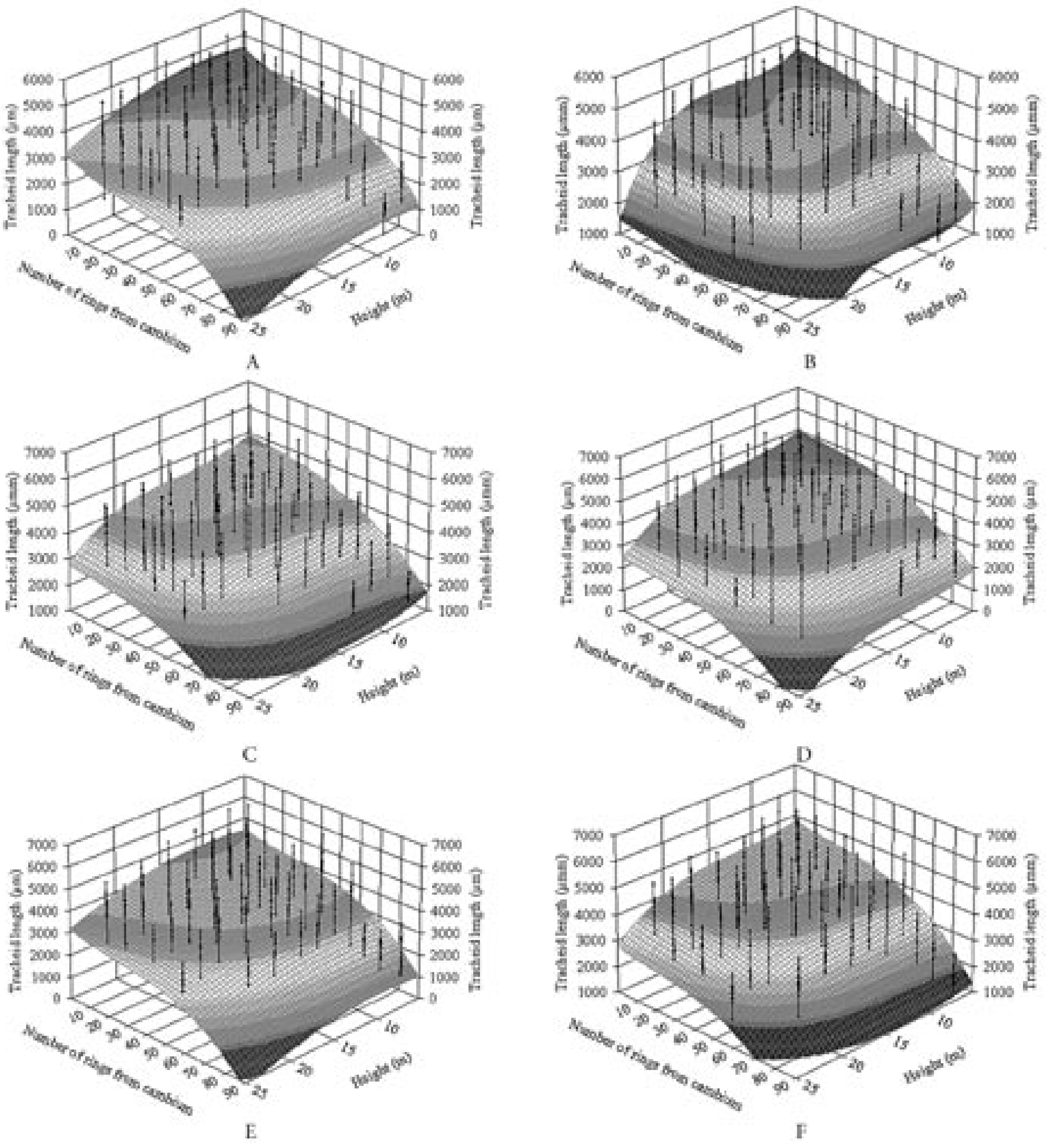

Fig. 4. Tracheid length as related to its position in the tree stem
A – early-wood tracheid CW, B – late-wood tracheid CW, C – early-wood tracheid OW, D – late-wood tracheid OW, E – early-wood tracheid SWL, F – late-wood tracheid SWL

were carried out as early as at the end of the 19th century. The studies have demonstrated that the length of tracheids is considerably variable. The length is affected by the kind of wood, site and climatic conditions, position along the stem radius and height and position in an annual ring (Gryc, Horáček 2003; Sarén et. al. 2001; Sisko, Pfäffli 1995; Yang, Hazenberg 1994; Seth, Agrawal 1984; Panshin, Zeeuw 1980; Škripeň, Riasová 1958; Trendelenburg 1939). The mean length of tracheids of the wood of conifers ranges from 2,500 to 5,000 μm (Sisko, Pfäffli 1995; Wagenführ 1989; Sachsse 1982; Panshin, Zeeuw 1980). The results obtained by our team – 3,593 μm for an early-wood tracheid and 3,714 μm for a late-wood tracheid (all data from the set of early-wood and late-wood tracheids) are in accordance with literature data. Statistical differences in the length between early-wood and late-wood tracheids were found only in SWP zone. In other zones, statistically significant differences between early-wood and late-wood tracheids were not detected. This result is not however consistent with literature data which indicate that the length of a late-wood tracheid is longer than that of an early-wood tracheid (Wagenführ 1989; Götsche, Kühn 1988; Panshin, Zeeuw 1980; Shelbourne, Ritchie 1968; Škripeň, Riasová 1958; Trendelenburg 1939). The results obtained can be interpreted by the modified structure of wood with the occurrence of reaction wood (compression wood).

When comparing particular zones it is possible to see that the length of tracheids in the compression wood zone (CW) as compared with other zones (OW, SWL and SWP) shows lower values. The result is obviously caused by the modification of late-wood or early-wood tracheids occurring in annual rings where the compression wood is well evident. Another potential factor to explain the result is a fact that the length of tracheids is changed even in zones which do not appear as compression wood (annual rings with slightly developed compression wood, so-called moderate compression wood – Timell 1986; Shelbourne, Ritchie 1968).

Moreover, 3D models were prepared describing variability in the length of tracheids in relation to their position in the tree stem. The models are fully consistent with existing results of many authors presenting their results in the form of 2D diagrams. In studying the effect of the stem radius it is evident that the length of a tracheid in annual rings in the proximity of the stem pith shows an intensive increase in length (Sarén et al. 2001; Yang, Hazenberg 1994; Seth, Agrawal 1984). In next years, a gradual increase in the length of tracheids is demonstrated. The trend was found both for early-wood and late-wood tracheids. In the case of the effect of height, the models show a decrease in the length of both early-wood and late-wood tracheids in a zone under the tree crown (height 18–25 m). Thus, it is possible to conclude that the trends correspond to conclusions of Sanio (1873). The length of tracheids in the central part of the stem did not show any marked changes.

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Vliv polohy ve kmeni na délku tracheid u smrku (*Picea abies* [L.] Karst.) s výskytem reakčního dřeva

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ABSTRAKT: Práce byla zaměřena na zjištění variability rozměrů tracheid dřeva smrku v závislosti na poloze v kmeni. Byly zjištěny významné změny rozměrů jarních a letních tracheid po výšce i poloměru kmene. Mezi jednotlivými letokruhy byly statisticky významné rozdíly (variabilita po poloměru). Výška 22 m vykazovala statisticky významnou odlišnost v porovnání s ostatními výškami (variabilita po výšce). Rozdíly mezi délkou jarní a letní tracheidy nebyly potvrzeny v zónách CW, OW a SWL, pouze u zóny SWP byl zjištěn statisticky významný rozdíl. Soubory dat (jarní a letní tracheida) ze zóny CW vykazovaly statisticky významnou odlišnost v porovnání s ostatními zónami. Na základě naměřených výsledků byly vytvořeny 3D modely (pro zóny CW, OW, SWL, SWP; modely pro jarní a letní tracheidu), které popisují změnu rozměrů tracheid smrku v závislosti na poloze ve kmeni. U modelů vychází pokles délky tracheidy ve vyšších výškach kmene, naproti tomu se zvětšující se vzdáleností od dřeně délka tracheidy stoupá. Význam práce lze spatřovat v rozšíření poznatků o struktuře dřeva smrku. Současně může práce přispět k částečnému vysvětlení odlišného chování fyzikálních a mechanických vlastností dřeva v jednotlivých částech kmene.

Klíčová slova: smrk; tracheida; délka tracheidy; tlakové dřevo

Práce je zaměřena na analýzu délky tracheidy u smrku (*Picea abies* [L.] Karst.) s výskytem reakčního dřeva. Cílem práce bylo vytvořit modely, které by popsaly variabilitu délky jarní a letní tracheidy v závislosti na poloze ve kmeni. Dalším cílem bylo zjistit, zda existuje statisticky významný rozdíl v délce mezi jarní a letní tracheidou, popř. statisticky významný rozdíl v délce tracheid mezi jednotlivými zónami (zóna tlakového dřeva – CW, zóna protilehlá OW, postranní zóny SWL a SWP).

Odběr vzorků byl proveden na ŠLP Masarykův les Křtiny Mendelovy zemědělské a lesnické univerzity v Brně, polesí Habrůvka, kde byl vybrán jeden vzorníkový smrk s předpokladem výskytu reakčního dřeva. Byl vybrán strom, jehož osa kmene byla odchýlena od směru zemské tíže. Pro zjištění variability délky tracheidy v závislosti na umístění ve kmeni byly odebrány vzorky dřeva v příslušných částech kmene. Délka tracheidy byla zjišťována na tangenciálním řezu v jarní (jarní tracheida) a letní části (letní tracheida) letokruhu.

U všech modelů bylo zjištěno, že dochází ke zvětšení délky tracheidy po poloměru kmene. Co je typické pro všechny modely, je zrychlený přírůstek délky tracheidy v prvních třiceti letech stromu. V dalších letech je vykazován pomalý přírůstek délky tracheidy. V posledních dvaceti letech (oblast pod kambiem) není již přírůstek délky tracheidy tak výrazný. Modely také ukazují změnu délky tracheidy s výškou. Délka tracheidy je mezi 5.–18. m téměř konstantní, mezi 18.–25. m se projevuje pokles délky tracheidy.

Při porovnání jednotlivých zón se ukazuje, že délka tracheid v zóně tlakového dřeva (CW) v porovnání s ostatními zónami (OW, SWL a SWP) vykazuje nižší hodnoty. Tento výsledek je zřejmě způsoben modifikací letních, popř. jarních tracheid, které jsou v letokruzích, ve kterých je dobře patrné tlakové dřevo. Druhým možným faktorem pro vysvětlení tohoto výsledku je, že délka tracheid je změněna i v oblastech, které se nejeví jako tlakové dřevo.

Statistickým šetřením byla statisticky významná odchylka zjištěna pouze mezi středními délkami jarní a letní tracheidy u zóny SWP. U ostatních zón rozdíl v délce mezi jarní a letní tracheidou nebyl potvrzen.

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