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VARIATION IN STRUCTURE AND SELECTED PROPERTIES OF FINNISH BIRCH WOOD: IV. FIBRE AND VESSEL LENGTH IN BRANCHES, STEMS, AND ROOTS

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SELOSTE:

SUOMALAISEN KOIVUPUUN RAKENTEEN JA ERÄIDEN OMINAISUUKSIEN VAIHTELU IV. KUITUJEN JA PUTKILOSOLUJEN PITUUS OKSISSA, RUNGOSSA JA JUURISSA

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Length variation of fibres and vessels was studied in the branches, stems and roots of *Betula pendula* and *B. pubescens*. Both fibres and vessels were significantly shorter in the branches and roots than in the stems. Root fibres were longer than branch fibres. There was a clear increase in cell length from the pith to the surface in each tree part, and a decrease in the branches and stems from the base to the tip. In the roots there was a small increase. The cell lengths were similar in the upper and lower radii of the branches and roots. No large differences were found between the species, although the cells were longer in *Betula pubescens* than in *B. pendula*.

INTRODUCTION

Fibre length has been a subject of vigorous research since SANIO's work (1872) because it is one of the most important wood quality indicators. The relevant literature has been reviewed by various authors (BISSET 1949, SPURR and HYVÄRINEN 1954, DINWOODIE 1961, TAYLOR 1968, JAIN and SETH 1979).

Only a few investigations have been carried out to determine the relative length of the cells in the branches and roots compared with those in the trunk. As the present trend is to harvest whole trees and to make use of formerly non-merchantable tops and roots, there is a need to know the cell length variation in these parts of the tree in order to assess the wood quality differences.

STAUFFER (1892) initiated studies on the cell length of birch species and found that cells were shorter in the heartwood than in the outer sapwood. Similarly, they were shorter in the crown than at the base of the trunk. His results have been supported by many other authors (WALLDÉN 1934, RUNQVIST and THUNELL 1945, KUJALA 1946, BHAT 1980). Further, WALLDÉN's (1934) results revealed that fibre length increased initially up to 3 meters from the ground level and then decreased towards the top. It has been observed, too, that the variation between sampling heights is small compared with the variation from the pith to the surface (KUJALA 1946, BHAT 1980).

According to OLLINMAA (1955, 1958) there is no large difference between the fibre length of normal and tension wood in birch, although tension wood fibres are a little longer both in the trunk and in the branches. It has also been established that the within ring variation of cell length (between early and late wood) is not very great (OLLINMAA 1958, SÜSS 1967).

The effect of growth rate on cell length is not clear. However, in a previous study a negative correlation was found between fibre length and ring width (BHAT 1980).

Of the two common birch species, the fibres are a little longer in *Betula pubescens* than in *B. pendula* (RUNQVIST and THUNELL 1945, KUJALA 1946, OLLINMAA 1955, BRUUN and SLUNGAARD 1959).

The purpose of this study was to determine the length of the fibres and vessels and their variation in the branches and roots compared with that in the stems of *Betula pendula* Roth and *B. pubescens* Ehrh.

The material was collected by Bhat with the assistance of A. Wäänänen. The laboratory work was performed by Leena Kunnari. Kärkkäinen computed the results and Bhat wrote the first version of the manuscript which was then revised by both authors. L. A. Keyworth corrected the English text. Aune Rytkönen and Raija Siekkinen typed the manuscript.

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MATERIAL AND METHODS

Six birch trees, four representing *Betula pendula* and two *B. pubescens* were selected in a natural stand near the Forestry Field Station, University of Helsinki, Hyytiälä (61°51'N, 24°16'E). The trees were straight and dominants or co-dominants with no visible disease or damage. The breast height age of the trees ranged from 65 to 95 years. Other data are given in Table 1.

The trees were cut and cross sectional disks were removed from the trunks at breast height and in the crown region. The location in the crown was chosen in such a way that from the same height level a branch was also sampled. However, the exact point was shifted about 30 cm above the point of insertion of the branch into the stem in order to avoid any abnormality.

Table 1. Properties of the investigation material.
Taulukko 1. Tutkimusaineiston ominaisuuksia.

Species *Puulaji*	Tree No. *Puun n:o*	Tree height m *Puun pituus m*	DBH cm (inside bark) *Kuoreton rinnankorkeus-läpimitta cm*	Trunk diameter at crown sampling point (inside bark) cm *Kuoreton läpimitta latvuskiekon kohdalla cm*	Distance from ground to crown sampling point m *Etäisyys maasta latvuskiekkoon m*	Branch length m *Oksan pituus m*
B.pendula *Rauduskoivu*	1	16,0	20,5	14,7	12,0	3,0
	2	24,0	23,4	10,9	16,0	3,0
	3	24,0	21,1	10,0	16,0	3,0
	4	23,0	21,5	11,8	18,0	3,5
B.pubescens *Hieskoivu*	1	17,0	14,7	8,2	12,0	3,0
	2	18,0	17,9	9,9	12,0	2,5

Transverse disks were cut from the branches at 25 %, 50 % and 75 % of the branch lengths in addition to the basal disks removed at 15 cm above the point of insertion in the stems. Thus, two stem disks and four branch disks were available for the study from each tree. In addition, one lateral root of one of the trees of each species was excavated and three cross sectional disks were obtained from the different positions at 0,5 m intervals from the base.

About 15° wedges were removed from the upper and lower radii of the branch and root disks in addition to the wedges obtained from the random radius of each of the stem disk. A fresh smooth surface was prepared on the end plane of the wedge to make the growth rings distinctly visible for counting purpose. The samples used for cell length measurement were obtained from the lst, 5th 10th, 15th and subsequent intervals of 5 rings from the pith outwards. These sampled growth rings were isolated along the radial plane and the entire ring width was used for macerating the wood elements. The macerating mixture was made up of equal quantities of 30 % hydrogen peroxide and acetic acid. The sample slices were treated in the mixture for 24 hours at 90–100°C. The separated fibres and vessels were mixed thoroughly and randomly selected for length measurements by projecting the images in a projection microscope. Fifty fibres and 30 vessels were measured from each growth ring. A total of 19 750 fibres and 11 400 vessels were measured in the study.

Both unweighted and weighted averages of the cell lengths were computed. The weights represented the torus area of a disk corresponding to the measured growth ring. However, the variation in the width of growth rings was eliminated and a constant value was used.

RESULTS AND DISCUSSION

The results in Table 2 indicate that the fibres and vessels were significantly shorter in the branches than in the stems. This finding agrees with the results of many authors in different tree species. Similarly, the fibres were shorter in the roots than in the stems. The same has been noted in some other species, too, (FEGEL 1941, GLEATON and SAYDAH 1956), although other species, again, have been reported to produce longer cells in the roots (BAILEY and FAULL 1934, FEGEL 1941, VURDU and BENSEND 1979).

An interesting feature is the increase in cell length in the roots from the base to the tip. The same trend has been reported for spruce (ESKILSSON 1972) and some pine species (POLLER et al. 1973). This trend may be one explanation for the differing results on the cell length relations between the stem and the roots. In contrast, in the branches and in the stem the cell length decreased from the base to the top, as found in numerous other studies.

The differences between the species were small. However, except in the branches the cells of *B. pubescens* were longer than those of *B. pendula*. This finding is supported by other birch studies (RUNQVIST and THUNELL 1945, KUJALA 1946, OLLINMAA 1955, BRUUN and SLUNGAARD 1959).

Figures 1–3 show that there was a striking increase in fibre length from the pith outwards, although the rate of increase in the roots was not as great as in the stems and branches. The smaller rate of increase in fibre length was also observed in black alder roots compared with the stem and branches (VURDU and BENSEND 1979). Even the vessel length increased in the same direction except in the roots (Figs. 4–6).

In the stem the fibres and vessels were very short in the rings near the pith. Their length increased rapidly up to 40–45 rings (years) from the pith and then more slowly until they reached a maximum at the age of 75–80 years (Fig. 2). This pattern of cell length increase in birch species obeys Sanio's laws (BAILEY and SHEPHARD 1915). The time when the maximum length is reached appears to vary with the species and possibly with the growth rate.

No statistically significant difference was found in the length of fibres and vessels between the upper and lower radii of the

Table 2. Weighted average values of cell length.
Taulukko 2. Solujen pituuksien painotetut keskiarvot.

Tree part *Puun osa*	Location *Sijainti*	B.pendula *Rauduskoivu*		B.pubescens *Hieskoivu*	
		Fibre length, mm *Kuidun pituus, mm*	Vessel length, mm *Putkilosolun pituus, mm*	Fibre length, mm *Kuidun pituus, mm*	Vessel length, mm *Putkilosolun pituus, mm*
Branch *Oksa*	Base – *Tyvi*	0,88	0,45	0,89	0,41
	25 % length *pituus*	0,84	0,45	0,81	0,40
	50 % length *pituus*	0,82	0,40	0,77	0,36
	75 % length *pituus*	0,72	0,40	0,72	0,30
	Average *Keskiarvo*	0,81	0,42	0,79	0,36
Stem *Runko*	Breast height *Rinnankorkeus*	1,20	0,60	1,24	0,64
	Crown *Latvus*	1,08	0,55	1,19	0,62
	Average *Keskiarvo*	1,14	0,58	1,21	0,63
Root *Juuri*	0,5 m length from base *0,5 m tyveltä*	0,97	0,40	1,10	0,46
	1,0 m from base *1,0 m tyveltä*	0,99	0,45	1,14	0,51
	1,5 m from base *1,5 m tyveltä*	1,05	0,20	1,18	0,48
	Average *Keskiarvo*	1,00	0,35	1,14	0,48

branches and roots.

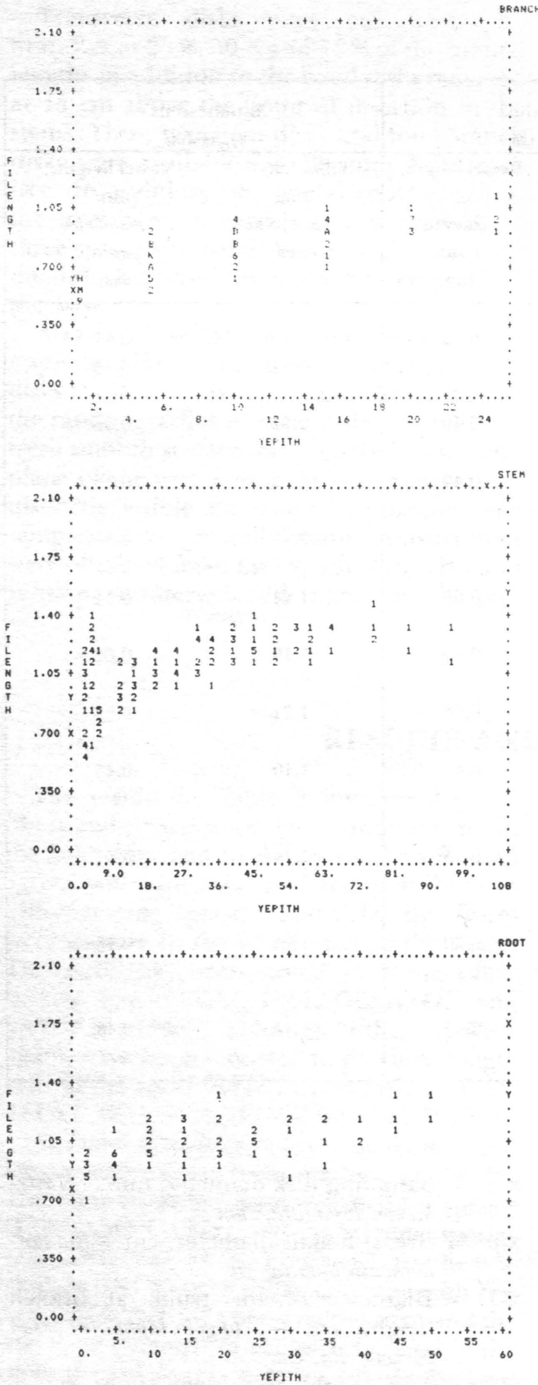
Stepwise regression analysis was used to predict the fibre and vessel length. The following independent variables were used.

Variables – *Muuttujat:*

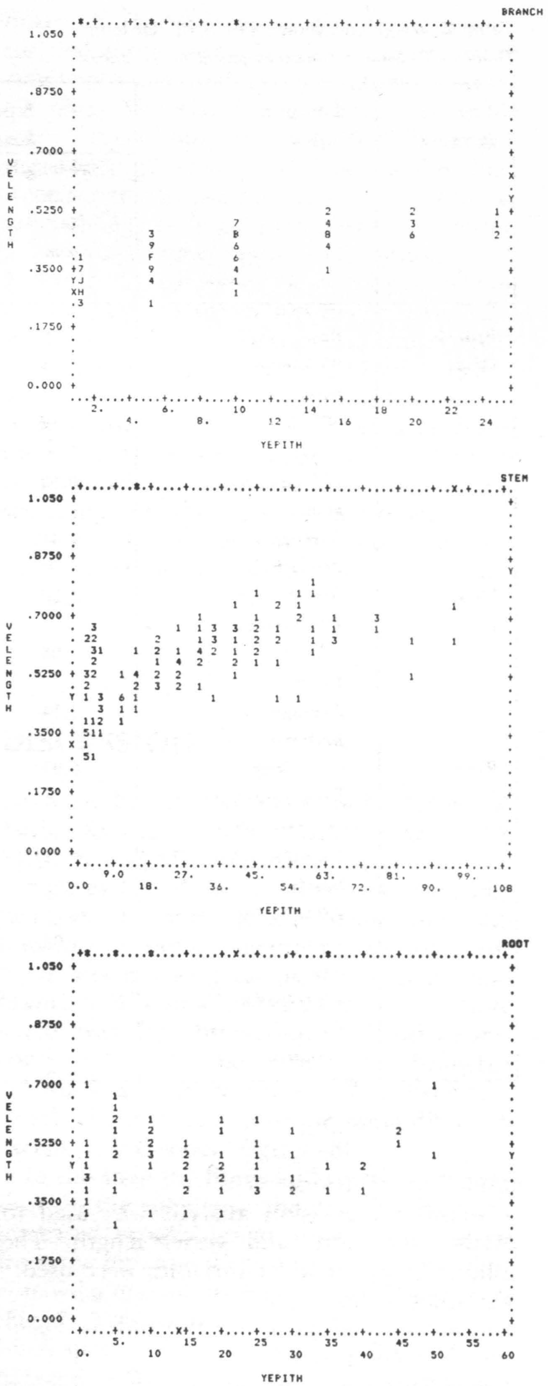
x(1) = Years (rings) from the pith – *Vuosilustoja ytimestä*
x(2) = Distance from the pith, mm – *Etäisyys ytimestä, mm*
x(3) = Sampling height, m – *Näytteenottokorkeus, m*
x(4) = Distance in the branch from the branch base, m – *Etäisyys oksassa oksan tyveltä, m*
x(5) = Sampling disk diameter, mm – *Näytekiekon läpimitta, mm*
x(6) = Breast height diameter, cm – *Rinnankorkeusläpimitta, cm*
x(7) = Diameter of the trunk at branch height, cm – *Rungon läpimitta oksan korkeudella, cm*
x(8) = Tree height, m – *Puun pituus, m*
x(9) = Branch length, m – *Oksan pituus, m*

Quadratic and simple interaction terms (type x(1)x(2)) were also used.

The most interesting correlation coefficients for the stem and branches are



Figs. 1–3. Fibre length (FILENGTH) according to the age from the pith (YEPITH) in branches (Fig. 1), stems (Fig. 2), and roots (Fig. 3).
Kuvat 1–3. Kuidun pituus (FILENGTH) ytimestä lasketun iän (YEPITH) mukaan oksissa (kuva 1), rungoissa (kuva 2) ja juurissa (kuva 3).



Figs. 4–6. Vessel length (VELENGTH) according to the age from the pith (YEPITH) in branches (Fig. 4), stems (Fig. 5), and roots (Fig. 6).
Kuvat 4–6. Putkilosolun pituus ytimestä lasketun iän (YEPITH) mukaan oksissa (kuva 4), rungoissa (kuva 5) ja juurissa (kuva 6).

Table 3. Correlation coefficients for the stem and branches. The tree species are together.
Taulukko 3. Rungon ja oksien korrelaatiokertoimet. Puulajit ovat yhdessä.

Independent variable *Selittävä muuttuja*	Dependent variable – *Selitettävä muuttuja*			
	Fibre length *Kuidun pituus*		Vessel length *Putkilosolun pituus*	
	Stems *Rungot*	Branches *Oksat*	Stems *Rungot*	Branches *Oksat*
x_1	.63**	.84**	.65**	.79**
x_2	.72**	.81**	.65**	.75**
x_3	–.28**	–.01	–.18*	.07
x_4	–	–.31**	–	–.23**
x_5	.18*	.36**	.11	.29**
x_6	–.08	.12	–.02	.19*
x_7	–.06	.21**	–.15	.16*
x_8	–.06	–.06	.06	.05
x_9	–	.06	–	.07

* = significant at 5 per cent risk level
merkitsevä 5 % riskitasolla

** = significant at 1 per cent risk level
merkitsevä 1 % riskitasolla

presented in Table 3. The regression equations are presented in Table 4.

The results show that the most important predictors are location variables like distance from the pith or years from the pith. Tree species, too, is significant in many cases. It is interesting to note that even in branches the coefficient for tree species is positive, i.e. the fibres and vessels are longer in *B. pubescens* than in *B. pendula* when other independent variables are included in the equation. As mentioned earlier, the average fibre and vessel lengths in the branches were larger in *B. pendula* than in *B. pubescens* (Table 2).

The relative importance of age from the pith or distance from the pith is not clear. In practice these independent variables can be interchanged in the equations without greater loss of predictive power. Possibly age is more important in the younger trees than the distance (DINWOODIE 1961, ELLIOT 1960).

Table 4. Regression equations for the fibre and vessel length (μm) in stem, branch, and root wood.

Taulukko 4. Regressioyhtälöt runkopuun, oksien ja juurten kuitujen ja putkilosolujen pituuden (μm) ennustamiseksi.

Tree part *Puun osa*	Dependent variable *Selitettävä tekijä*	Independent variable *Selittävä tekijä*	Coefficient *Kerroin*	t-value *t-arvo*
Stem *Runko*	Fibre length, μm *Kuidun pituus*, μm	Constant – *Vakio*	725	
		Species – *Puulaji* (0=B.pendula-*Rauduskoivu*, 1=B.pubescens- *Hieskoivu*)	80,2	3,8
		Distance from the pith, mm – *Etäisyys ytimestä, mm*	13,0	11,7
		Distance from the pith squared – *Edellisen neliö*	– 0,0793	7,2
		R^2 = 67,8 %		
		F = 103 (3,146)		
		$S_{y.x}$ = 118,0		
	Vessel length, μm *Putkilo-solun* pituus, μm	Constant – *Vakio*	294	
		Species – *Puulaji* (0=B.pendula-*Rauduskoivu*, 1=B.pubescens – *Hieskoivu*)	34,4	2,3
		Rings from the pith – *Vuosilustoja ytimestä*	5,36	4,4
		Distance from the pith, mm – *Etäisyys ytimestä, mm*	5,13	6,4
		Distance from the pith squared – *Edellisen neliö*	– 0,0338	4,5
		Rings from the pith x disk diameter, mm – *Vuosilustoja ytimestä x kiekon läpimitta, mm*	– 0,0208	3,4
		Disk diameter, mm x tree height, m *Kiekon läpimitta, mm x puun pituus, m*	0,0207	2,8
		R^2 = 64,6 %		
		F = 44 (6,143)		
		$S_{y.x}$ = 71,7		
Branch *Oksa*	Fibre length, μm *Kuidun pituus*, μm	Constant – *Vakio*	428	
		Species – *Puulaji (0=B.pendula-Rauduskoivu*, 1=B.pubescens – *Hieskoivu*)	76,1	3,4
		Rings from the pith – *Vuosilustoja ytimestä*	49,4	11,6
		Rings from the pith squared – *Edellisen neliö*	– 1,10	9,9
		Tree height, m, squared – *Puun pituuden, m, neliö*	– 0,571	5,5
		DBH, cm x sampling height, m – *Rinnankorkeusläpimitta, cm x näytteenottokorkeus, m*	0,114	4,5
		Distance in the branch from the branch base, m x rings from the pith – *Etäisyys oksassa oksan tyveltä, m x vuosilustoja ytimestä*	– 0,478	2,0
		R^2 = 85,5 %		
		F = 148 (6,151)		
		$S_{y.x}$ = 60,4		
	Vessel length, μm *Putkilo-solun pituus*, μm	Constant – *Vakio*	333	
		Rings from the pith, squared-*Vuosilustoja ytimestä, neliö*	– 0,551	6,8
		Distance from the pith, mm, squared – *Etäisyys ytimestä, mm, neliö*	0,0670	2,3
		Sampling height, m, squared – *Näytteenottokorkeus, m, neliö*	– 0,103	3,4
		Rings from the pith x branch length, m – *Vuosilustoja ytimestä x oksan pituus, m*	0,616	12,6
		R^2 = 72,8 %		
		F = 102 (4,153)		
		$S_{y.x}$ = 38,6		
Root *Juuri*	Fibre length, μm *Kuidun pituus*, μm	Constant – *Vakio*	933	
		Distance from the pith, mm x distance in the root from the root base, *m – Etäisyys ytimestä, mm x etäisyys juuressa sen tyveltä, m*	0,0361	8,2
		R^2 = 49,1 %		
		F = 67 (1,70)		
		$S_{y.x}$ = 96,4		
	Vessel length, μm *Putkilo-solun pituus*, μm	Constant – *Vakio*	410	
		Distance from the pith, mm, squared – *Etäisyys ytimestä, mm, neliö*	0,0227	3,7
		Distance from the pith, mm, x breast height diameter, cm-*Etäisyys ytimestä, mm, x rinnan-*korkeusläpimitta, cm	– 0,0124	2,7
		Distance in the root from the root base, m x breast height diameter, cm – *Etäisyys juuressa sen tyveltä, m x rinnankorkeus-läpimitta, cm*	0,00541	3,8
		R^2 = 28,3 %		
		F = 9 (3,68)		
		$S_{y.x}$ = 76,3		

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SELOSTE:

SUOMALAISEN KOIVUPUUN RAKENTEEN JA ERÄIDEN OMINAISUUKSIEN VAIHTELU IV. KUITUJEN JA PUTKILOSOLUJEN PITUUS OKSISSA, RUNGOSSA JA JUURISSA

Neljästä raudus- ja kahdesta hieskoivusta otettiin näytteitä kuitujen ja putkilosolujen pituuden selvittämiseksi. Runkonäytteet otettiin kahdelta korkeudelta, oksanäytteet neljältä suhteelliselta etäisyydeltä oksan tyvestä ja juurinäytteet puolen metrin välein. Näin valmistetuista suurista näytekappaleista valmistettiin pienempiä näytteitä ytimestä pintaan päin olevan vaihtelun selvittämiseksi. Kaikkiaan tutkimuksessa mitattiin 19 750 kuidun ja 11 400 putkilosolun pituus.

Pisimmät kuidut ja putkilosolut olivat rungossa, sitten juurissa ja lyhimmät oksissa. Kaikissa näissä puun osissa solulajien pituus kasvoi selvästi ytimestä pintaan päin, joskin kasvu oli juurissa vähäisempää kuin muualla. Solujen pituus aleni rungossa ja oksissa tyvestä kärkeen päin, mutta juurissa lisääntyi. Samanlaisia havaintoja on tehty myös havupuista.

Regressionalyysissä parhaat solulajien pituuden vaihtelua selittävät tekijät olivat paikkaa kuvaavia muuttujia. Näistä tärkein oli etäisyys ytimestä joko vuosilustoina tai millimetreinä mitaten.

Koivulajien erot olivat vähäiset, joskin hieskoivun solut olivat yleensä pidemmät kuin rauduskoivun.