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IMPACT OF A FRESH BROADLEAVED FOREST SITE AND FRESH MIXED BROADLEAVED FOREST SITE ON SELECTED PARAMETERS AND RATIOS OF SILVER BIRCH (*BETULA PENDULA* ROTH.) WOOD FIBRE STRUCTURE

The variability of selected ratios characterising the dimensions and shape of silver birch wood fibres was determined based on the site where the trees grow. Two sampling areas were selected, located in the Biała Podlaska Forest District in eastern Poland. Samples for testing were taken from trees approx. 45–50 years old, growing on a fresh broadleaved forest site and on a fresh mixed broadleaved forest site. On these two sites, silver birch occurs most widely as a dominant species, both in terms of stand area and volume, in Poland. A statistical analysis was performed of selected parameters of the wood fibre structure such as length, width, lumen and cell wall thickness, as well as of the wood fibre structure ratios belonging to the basic properties of fibrous pulp: the felting power, flexibility ratio, coefficient of rigidity, Runkel and Mühlsteph ratios, as well as the compactness index. It was demonstrated that the site from which birch material originates has a significant impact on the average values of: fibre length, lumen, flexibility ratio, and the coefficient of rigidity, as well as the Runkel and Mühlsteph ratios. However, analyses did not prove any major impact of the site on the average values of: fibre width and wall thickness, the felting power or the compactness index of silver birch wood.

Keywords: silver birch, fibre structure parameters and ratios, forest site type

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Introduction

The anatomical structure of birch wood comprises: wood fibres, vessels, wood rays and wood parenchyma. The share of the respective components in a single tree is variable, and depends not only on the species, age and location, but on site conditions as well [Hall 1952; Berndt 1963; Braun 1963; Süss 1967].

Fibre dimensions belong to the basic properties of the fibrous pulp. They exert a considerable impact on the structural and strength features of paper products. An analysis of fibre dimensions most frequently entails a definition of their length, diameter, fibre cell wall thickness, lumen, and mutual relations between these parameters.

Technologies of cellulose pulp production take into consideration the differing anatomical structure of softwood and hardwood. In industrial practice, such factors as the site from which the tree species originates, tree age and diameter are not taken into account.

Conducted and published research aimed at determining whether location and tree age,as well as a specific site, have an impact on the components and ratios of the fibre structure of silver birch wood have proved the substantial influence of tree location and age on: length, width, lumen, and wall thickness, as well as the felting power, flexibility ratio, coefficient of rigidity, and Runkel and Mühlsteph ratios of wood fibres, without any significant influence of tree age on the fibre diameter and compactness index. In addition, a considerable, simultaneous, impact of tree location and age on the average values of all the investigated structure components and ratios of silver birch wood fibres has been found [Lachowicz, Paschalis-Jakubowicz 2011]. Moreover, it has been demonstrated that tree diameter has a marked impact on the average values of: fibre length, width, lumen, and wall thickness, as well as the felting power, flexibility ratio, coefficient of rigidity, Mühlsteph ratio and compactness index. No major impact of tree diameter on the average values of the Runkel ratio has been found [Lachowicz 2011].

The possibility that the site where trees grow impacts the parameters and ratios of silver birch wood fibre structure has thus far not been studied. All studies to date have been conducted on fresh broadleaved forest sites.

This study consisted of preliminary research aimed at comparing average values and defining the significance of the impact of a fresh broadleaved forest site and a fresh mixed broadleaved forest site on the parameters and ratios that characterise the shape and transverse dimensions of the wood fibres of silver birch which, besides beech wood, is the most widely used hardwood raw material in the Polish pulp and paper industry.

The results presented in this paper are an introduction to the wide-ranging research on the variability of selected technical quality indices of silver birch roundwood in Poland conducted presently by the Department of Forest Utilization, Warsaw University of Life Sciences (SGGW), Poland.

Materials and methods

The research methodology was based on the same assumptions as in the case of earlier research on silver birch wood in north-eastern Poland. Moreover, it was in line with the methodology applied earlier by the Department of Forest Utilization, Warsaw University of Life Sciences (SGGW), in the course of studies on ratios that characterise the dimensions and shape of wood fibres of major forest tree species [Jednoralski, Oktaba 1998; Oktaba, Paschalis 2001; Oktaba et al. 2002].

Wood fibres with an average 64.8% share in silver birch wood have been studied [Huber, Prütz 1938; Wagenführ, Scheiber 2007].

Wood was harvested in the Biała Podlaska Forest District administered by the Regional Directorate of the State Forests in Lublin. Two sampling areas were set up in the Forest Division, with 45–50 year-old tree stands, located on a fresh broadleaved forest site (FBF) and on a fresh mixed broadleaved forest site (FMBF) (selected on the basis of data from forest management plans). On these two sites, silver birch occurs most widely as a dominant species, both in terms of stand area and volume, in Poland (figures from the Bureau for Forest Management and Geodesy and the Forest Data Bank).

The areas exhibited similar taxation features, such as: age, bonitation, and forest cover.

To select the sample trees, the Hartig method with three tree-diameter classes was applied, based on the average d.b.h basal area:
- class I – trees from the smallest diameter class,
- class II – trees from the medium diameter class,
- class III – trees from the largest diameter class.

Two trees were selected and harvested from each diameter class; consequently, 6 trees were procured from each area. In total, 12 trees were sampled for further tests. Once the sample trees were felled, two 0.5 m long sections were cut out from around the breast-height part of each tree and sampled for anatomic tests.

Birch wood pieces a few centimetres in size were macerated using a mixture of glacial acetic acid and perhydrol. After maceration and rinsing, the fibres were dyed with methyl green to facilitate microscopic measurements. The fibres were measured using a binocular optical microscope with a scale. In the tests, each tree was represented by a population of 30 wood fibres. The anatomic tests were performed on a total of 360 fibres.

Subsequently, the wood fibre structure ratios were calculated based on the fibre length and the parameters that characterise the transverse dimensions of the fibres.

The selected fibre parameters and ratios were those that most comprehensively characterise their dimensional proportions and shape, as well as those that have a decisive impact on the use of birch wood in the pulp manufacturing process and in the pulp and paper industry [Mühlsteph 1941; Runkel 1949; Einspar 1964; Surma-Ślusarska, Surewicz 1985a, 1985b; Przybysz 2005a, 2005b, 2005c].

The following parameters and ratios of silver birch wood fibres were studied:
- wood fibre length (*L*) in [mm]
- wood fibre width (*D*) in [mm]
- wood fibre lumen (*d*) in [mm]
- wood fibre cell wall thickness (*w*) in [mm]
- felting power

$$FP = \frac{L}{D} \tag{1}$$

It is believed that this ratio should be as large as possible, not less than 40. The longer the fibres and the higher the slenderness ratio, the better the mechanical properties of the paper.
- Flexibility ratio

$$\frac{d}{D} \tag{2}$$

The greater the width of the lumen (*d*), or the smaller the fibre diameter (*D*), the higher the flexibility ratio (more flexible fibres) and the greater the suitability of the wood raw material for paper-making purposes.
- Coefficient of rigidity in [%]

$$\Phi = \frac{w}{D} \times 100\% \tag{3}$$

The coefficient of rigidity shows the inversely proportional effect on breaking strength. The higher its values (thicker wall fibres – *w*), the lower the strength values.
- Runkel ratio

$$R = \frac{2w}{d} \tag{4}$$

This indicator has a significant effect on the felting ability of the fibres in the paper-making process and on the strength properties of paper products. The lower its value, the higher the suitability of the raw material for paper-making purposes [Runkel 1949]. This ratio decreases with a decrease in wall thickness (*w*). It is thus lower for thin-walled fibres.
- Mühlsteph ratio

$$M = \frac{D^2 - d^2}{D^2} \tag{5}$$

This indicator shows the inverse trend for the deformation (flattening) of fibres in the drying process [Mühlsteph 1941; Einspar 1964]. The lower the Mühlsteph ratio, the greater the felting tendency.

– Compactness index

$$\frac{D^2 - d^2}{L} \tag{6}$$

Fibre dimensions are basic pulp properties that determine its paper--making capacity. The microscopic method of measuring the fibre structure parameters presented in this paper and used to determine the ratios that characterise the dimensions and shape of the fibres is extremely laborious, but accurate. Other methods also currently exist, such as the computer image analysis method, making it possible to determine the dimensional characteristics of fibres and their shape in a speedy and comprehensive manner. The results of this study should help identify the parameters and ratios of the wood fibre structure of silver birch in Poland.

The results obtained were subjected to statistical analysis to determine the impact of the site on the respective wood fibre structure parameters and ratios. For this purpose, the Mann-Whitney U test was applied. All calculations and statistical analyses were made using the Statistica 9 program.

Results

The average values and the impact of the site on the parameters and ratios of the silver birch wood fibres are presented in the table.

The average length of the wood fibres on the FBF site was 1.58 mm, and this decreased to 1.49 mm on the FMBF site as site fertility deteriorated. The statistical analysis demonstrated the considerable impact of the site on the average length of the birch wood fibres. The average value of the fibre width of the birch wood was higher on the FBF site, standing at 0.0227 mm, and lower on the FMBF site – 0.0221 mm. It was established that the average values of the fibre width of the birch wood originating from the FBF site and the FMBF site did not differ substantially in statistical terms. Higher average values of the fibre lumen depending on the site were calculated on the FBF site (0.0043 mm), and lower on the FMBF site (0.0035 mm). The considerable impact of the site on the values of the fibre lumen of the birch wood was demonstrated. The average value of the wall thickness of the silver wood fibres on the FBF site was 0.0092 mm, and increased slightly to 0.0093 mm as site fertility deteriorated. As regards the samples in this study, no substantial differences between the fibres from the trees growing on the FBF site and on the FMBF site were demonstrated.

Table 1. Impact of site on average values of wood fibre structure parameters and ratios determined by means of the Mann-Whitney U test (significant at p < 0.05)

Features	Forest site	Average	Standard deviation	Minimum	Maximum	p
Length [mm]	FBF	1.58	0.17878	1.22	2.14	0.000163*
	FMBF	1.49	0.21732	0.98	2.04	
Width [mm]	FBF	0.0227	0.00339	0.0175	0.0300	0.137034
	FMBF	0.0221	0.00438	0.0125	0.0325	
Lumen [mm]	FBF	0.0043	0.00159	0.0020	0.0080	0.000006*
	FMBF	0.0035	0.00127	0.0020	0.0080	
Wall thickness [mm]	FBF	0.0092	0.00129	0.0067	0.0130	0.481457
	FMBF	0.0093	0.00195	0.0047	0.0148	
Felting power	FBF	70.76	10.85565	48.98	101.46	0.105642
	FMBF	70.22	17.41321	38.09	135.51	
Flexibility ratio	FBF	0.186	0.05357	0.080	0.320	0.000008*
	FMBF	0.160	0.05046	0.073	0.300	
Coefficient of rigidity [%]	FBF	40.70	2.67837	34.00	46.00	0.000009*
	FMBF	41.98	2.52288	35.00	46.36	
Runkel ratio	FBF	4.89	1.89951	2.12	11.50	0.000008*
	FMBF	5.92	2.31939	2.33	12.75	
Mühlsteph ratio	FBF	0.9626	0.02057	0.8976	0.9936	0.000008*
	FMBF	0.9717	0.01728	0.9100	0.9947	
Compactness index	FBF	0.00032	0.00008	0.00016	0.00050	0.695440
	FMBF	0.00033	0.00013	0.00009	0.00080	

FBF – fresh broadleaved forest
FMBF – fresh mixed broadleaved forest

A higher average value of the felting power of the wood fibres was found in the trees growing on the FBF site – 70.76, while the felting power went down to 70.22 on the FMBF site as site fertility decreased. The statistical analysis of the material did not prove any substantial impact of the site on the average value of the felting power of the birch wood fibres.

The flexibility ratio of the wood fibres exhibited a higher average value of 0.186 on the FBF site, and a lower average value of 0.160 on the FBF site. The statistical analysis showed the considerable impact of the site on the average value of the flexibility ratio of the birch wood fibres.

The average value of the coefficient of rigidity of the wood fibres on the FBF site stood at 40.70%, and rose to 41.98% on the FMBF site as site fertility worsened. Lower values of the fibre rigidity coefficient may have an advantageous effect on the paper-making properties of the fibre. The studied material showed the considerable impact of the site on the average value of the coefficient of rigidity of the birch wood fibres.

The Runkel ratio of the wood fibres had a lower average value in the trees from the FBF site – 4.89, while the ratio was higher in the trees from the FMBF site – 5.92. The statistical analysis demonstrated the major impact of the site on the average value of the Runkel ratio of the wood fibres in the samples studied.

Lower average values of the Mühlsteph ratio, a measure of the fibres' proneness to flattening during the processes of compressing and drying that are crucial for the paper industry, were noted in the trees growing on the FBF site – 0.9626. Higher average values of the investigated ratio were found on the FMBF site – 0.9717. The statistical analysis demonstrated the considerable impact of the site on the average value of the Mühlsteph ratio of the birch wood fibres.

The average values of the compactness index of the wood fibres had lower values in the trees from the FBF site – 0.00032, and higher values in the trees from the FMBF site – 0.00033. The statistical analysis did not show any substantial impact of the site on the average value of the compactness index of the wood fibres in the samples studied. studied material.

Conclusions

An analysis of the results of this research on the impact of the site on selected parameters and ratios of the silver birch wood fibre structure makes it possible to draw the following conclusions:

1. The site from which birch material originated had a crucial impact on the average values of: the fibre length, lumen, flexibility ratio, coefficient of rigidity as well as Runkel and Mühlsteph ratios. However, analyses did not show any major impact of the site on the average values of: fibre width and wall thickness, as well as the felting power and compactness index of the silver birch wood.
2. The silver birch trees growing on the FBF site had better potential paper-making qualities owing to the higher fibre flexibility ratio (wide lumen), lower values of the coefficient of rigidity and Runkel ratio (thinner wall), as well as a lower Mühlsteph ratio (greater proneness to felting).
3. The detected changes in the average values of the fibre structure ratios of the silver birch wood may be useful in the utilization of this valuable raw material in the process of pulp manufacture for purposes of paper production.
4. The substantial differences in the majority of the studied properties confirm the relevance of undertaking more comprehensive research to compare the values of fibre structure parameters and ratios of silver birch wood depending on the site, also in other raw material bases of this species.

References

Berndt J. [1963]: Badania anatomiczne drewna krajowych gatunków rodzaju *Betula* L. (Anatomical studies of domestic wood species of the genus *Betula* L.). Studia Societatis Scientiarum Torunensis, Sectio D, VI: 1–41

Braun H.J. [1963]: Die Organisation des Stammes von Bäumen und Sträuchern. Stuttgart, Wissenschaftliche Verlagsgesellschaft

Einspar D.W. [1964]: Tappi 47 [4]:130

Hall J.W. [1952]: The comparative anatomy and phylogeny of the Betulaceae. Botanical Gazette 113 [3]: 235–270

Huber B., Prütz G. [1938]: Über den Anteil von Fasern, Gefässen und Parenchym am Aufbau verschiedener hölzer. Holz als Roh-und Werkstoff [10]: 377–381

Jednoralski G., Oktaba J. [1998]: Wybrane wskaźniki struktury włókien drewna buka (*Fagus sylvatica* L.) z północnej i południowej bazy surowcowej w Polsce (Selected indicators of beech wood fibre structure (*Fagus sylvatica* L.) from northern and southern resource base in Poland). Przemysł Drzewny [6]: 22–24

Lachowicz H. [2011]: Wpływ grubości drzew na wartości wybranych parametrów i wskaźników struktury włókien drewna brzozy brodawkowatej (*Betula pendula* Roth.). (The effect of tree thickness on selected parameters of silver birch (*Betula pendula* Roth.) wood fiber structure). Przegląd papierniczy 67 [5]: 321–326

Lachowicz H., Paschalis-Jakubowicz P. [2011]: Zmienność wybranych wskaźników struktury włókien drewna brzozy brodawkowatej (*Betula pendula* Roth.) w północno-wschodniej Polsce. (Variability of the wood fibre structure indices for silver birch (*Betula pendula* Roth.) in north−eastern Poland). Sylwan 155 [7]: 446–458

Mühlsteph W. [1941]: Wbl. Papierfabr 72 [14]: 201

Oktaba J., Paschalis P. [2001]: Zmiany budowy cewek drewna świerka Picea abies (L.) Karst. w drzewostanach będących pod wpływem emisji przemysłowych (Changes in structure of spruce Picea abies (L.) Karst. wood tracheids from industrial polluted forests). IV Krajowe Sympozjum „Reakcje biologiczne drzew na zanieczyszczenia przemysłowe", 29.05-1.06.2001, Poznań-Kórnik, 781–792

Oktaba J., Paschalis P., Staniszewski P. [2002]: Selected indicators of pine and spruce wood technical quality from the forest being under the impact of industrial pollution. Folia Forestalia Polonica Seria A [44]: 77–86

Przybysz K. [2005a]: System kontroli jakości masy włóknistej. Cz. I. Cel i zadania systemu. (The pulp quality control system. Part. I. Purpose and objectives of the system). Przegląd Papierniczy 61 [2]: 87–90

Przybysz K. [2005b]: System kontroli jakości masy włóknistej. Cz. II. Wymiary i kształt włókien (The pulp quality control system. Part. II. The dimensions and shape of the fibres). Przegląd Papierniczy 61 [4]: 212–216

Przybysz K. [2005c]: Metody pomiaru odkształcalności włókien papierniczych mas włóknistych. (Methods for measuring the deformability of fibres of paper pulp). Przegląd Papierniczy 61 [11]: 689–693

Runkel R.O. [1949]: Papier 3 [23/24]: 476

Surma-Ślusarska B., Surewicz W. [1985a]: Wpływ wieku drzew i siedliska na wydajność i właściwości mas celulozowych siarczanowych. Część I: Drewno sosnowe. (The effect of the age of wood and of the habitat on the yield and properties of kraft pulps. Part I. Pine wood). Folia Forestalia Polonica Seria B [16]: 67–86

Surma-Ślusarska B., Surewicz W. [1985b]: Wpływ wieku drzew i siedliska na wydajność i właściwości mas celulozowych siarczanowych. Część II: Drewno bukowe. (The effect of the age of wood and of the habitat on the yield and properties of kraft pulps. Part II. Beech wood). Folia Forestalia Polonica Seria B [16]: 87–104

Süss H. [1967]: Über die Längenänderungen der Parenchymstränge, Holzfasern und Gefässglieder von Laubhölzern im Verlauf einer Zuwachsperiode. Holz als Roh-und Werkstoff, 25, H. [10]: 369–377

Wagenführ R., Scheiber Chr. [2007]: Holzatlas. Leipzig, VEB Fachbuchverlag