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ORIGINAL PAPER

Differentiation of selected macrostructural features and the basic wood density on the radius of the stem-cross section of black locust *Robinia pseudoacacia* L. from southern Poland

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ABSTRACT

Black locust has been known in Poland since the nineteenth century. The aim of the present study was to analyse the variability of selected features of black locust wood of native origin, as despite the long-standing cultivation of this species in forests, little is known about the diversity in the features of its wood. The research was conducted in four tree stands located in southern Poland. One core was taken from 15 trees in each stand. The width of sapwood, the width of annual rings, and the basic density of wood were measured in the cores sections. The average width of sapwood was about 1 cm and its share in the cross-sectional area of the stem amounted to ca. 16%. There were no significant differences in the width of sapwood or in its share between black locust trees of different age classes, or between those growing in different habitats. The average width of the annual rings was 2.95 mm; notably, the black locust trees from the mountain forest habitat had broad-grained wood (average above 3 mm), while the wood of trees growing on the mixed forest habitat was narrow-grained (average below 3 mm). The average share of late wood was 67.5%. The average basic density of wood was 0.608 $g \cdot cm^{-3}$; further, it was found that black locust trees growing in the upland forest habitat had a favourable (even) course of wood density values on the radius of the cross-section of the stem.

KEY WORDS

annual rings width, basic wood density, share of latewood, width and share of sapwood

Introduction

Black locust *Robinia pseudoacacia* L. had been introduced to Europe over 400 years ago. The area where it occurs in Europe today amounts to over 2.3 million hectares (Nicolescu *et al*., 2020). In Poland, in 2017, the total area of forest stands containing black locust was over 300 thousand hectares (Zasada, 2017; Nicolescu *et al*., 2020). In Poland, it is considered an invasive species, and one that may threaten biodiversity in environmentally valuable areas (Tokarska-Guzik *et al*., 2012; Danielewicz *et al*., 2018), although some authors also indicate that black locust tree stands may provide a sanctuary for rare and endangered species of fungi (Ślusarczyk, 2012). This tree

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is valued for its attractive colour, pattern, high durability, and high calorific value of wood, as well as for abundant flowering and good honey yield of flowers (Jabłoński and Kołtowski, 1993; Zajączkowski and Wojda, 2012). Logging of black locust wood by the State Forests in Poland is inconsequential at present, and it does not exceed 0.5% of the total annual harvest. Having said that, the volume of harvested wood of this species is gradually increasing. In 2013, this was less than 88 thousand m^3, while five years later (2018) it already amounted to almost 94 thousand m^3 (Bijak and Zastocki, 2021). It is assumed that, as a result of climate change, black locust may expand its area of occurrence in Europe, including Poland (Thurm *et al.*, 2018; Puchałka *et al.*, 2021).

Despite the fact that black locust has been known in Poland since the nineteenth century (Tokarska-Guzik *et al.*, 2012), there is relatively little information on the variability in the properties of native wood thereof (Kozakiewicz and Wiktorski, 2007; Kraszkiewicz, 2008, 2010, 2013; Kraszkiewicz and Szpryngiel, 2009; Kraszkiewicz *et al.*, 2011; Klisz *et al.*, 2014; Kalbarczyk *et al.*, 2016; Bijak and Lachowicz, 2021).

The objective of the present study was to analyse the differentiation of selected features of wood macrostructure and density displayed by black locust from southern Poland.

The scope of work included the analysis of the sapwood width and its share on the cross-section of the stem, as well as the number of rings in the sapwood. In addition, the annual rings width, the share of latewood and the basic wood density were measured and the diversity in these features were analysed along the radius of the stem cross-section.

Materials and methods

The research was conducted in the southern part of Poland, in the area of three Regional Directorates of State Forests (RDSF): in Katowice (two study plots), in Kraków (one plot), and in Krosno (one plot). The habitat and stand characteristics of the study plots are presented in Table 1. It follows that two plots (Ustroń Forest District – plot no. 3; Strzyżów Forest District – plot no. 4) were located in stands growing in an upland forest habitat (UF); one plot (Świerklaniec Forest District – plot no. 1) was located in mixed forest (MixF); and one (Piwniczna Forest District – plot no. 2) – in mountain forest (MnF). The age of the examined stands ranged from 61 to 78 years.

On each research plot, the diameter of breast height (dbh) of all black locusts was measured in the north-south direction, by using a calliper with the accuracy down to 1 mm. Then, in proportion to the number of trees in the respective dbh ranges, 15 sample trees were selected. For each sample tree, the thickness of the bark was measured with the accuracy down to 1 mm, from the northern and southern sides of the stem, using a bark gauge. On this basis, the diameter and surface area of the stem inside bark were determined. From the stem of each examined tree, one core sample was taken at the height of 1.3 m from the ground surface on the north side using a Pressler drill. The collected samples were secured and transported to the laboratory. Each core sample was placed in a special holder, and a thin layer of wood was cut perpendicularly to the course of the wood fibres, using a sharp knife. Then, the number of annual rings included in the sapwood (NSR) was counted and the sapwood width (SW) was measured with a ruler with the accuracy down to 1 mm. Thanks to the obtained data, the share of sapwood on the cross-sectional area of the stem (ShS) was calculated. Using the Epson Expression 12000 XL scanner, cross-sections of core samples were scanned with a resolution of 1200 dpi, thus rendering digital images in bitmap format. With the aid of the CoRecorder software (Cybis Elektronik & Data AB, 2012a), the boundaries of annual rings and zones of early and late wood were determined on digital images. Then, in the CDendro software (Cybis Elektronik & Data AB, 2012b), the widths of annual rings (ARW) and late wood zones were calculated. With the above data at our disposal, we were

Table 1.
Location, habitat and stand characteristic of the test plots[1]

Plot no	RDSF Forest district Forest subdistrict forest address[2] GPS	Species composition[3] (canopy) species/share/age	Forest type	Stocking
1	Katowice Świerklaniec Wymysłów 02-31-3-12-236 -f -00 N: 50.408; E: 19.082	Ol/ 40% / 61; Brz / 20% / 61; Wb/ 20% / 61; **Ak / 20% / 61** So / MJS4 / 61; Os / MJS / 61; Jw / MJS / 61; Db.c / MJS / 61	moist mixed forest	0.9
2	Kraków Piwniczna Zubrzyk 03-21-1-08-317 -k -00 N: 49.376; E: 20.777	Gb / 50% / 71; Bk / 30% / 71; Ol.s / 10% / 71; **Ak / 10% / 71;** Św/ MJS / 71; So/ MJS / 71; Czr/ MJS / 71; Os/ MJS / 51; Bk/ MJS / 51; Gb/ MJS / 51; Czr / MJS / 51; Bk/ MJS / 101	fresh mountain forest	0.7
3	Katowice Ustroń Dzięgielów 02-35-3-14-104 -b -00 N: 49.728; E: 18.734	Jw / 20% / 67; Tp / 20% / 67; Św/ 10% / 67; Brz / 10% / 67; **Ak / 10% / 67;** Ol / 10% / 67; Md / 10% / 67; Brz / 10% / 47	fresh upland forest	0.9
4	Krosno Strzyżów Łętownia 04-22-2-09-305 -h -00 N: 49.955; E: 21.748	Gb / 30% / 78; Md / 30% / 78; Db / 10% / 78; Jd / 10% / 78; Db / 10% / 116; **Ak / 10% / 78;** Jw / MJS / 78; Brz/ MJS / 78; Ol.s / MJS / 55; Lp/ MJS / 116; Gb / PJD5 / 48	fresh upland forest	1.0

[1] data from Forest Data Bank available on website: www.bdl.lasy.gov.pl/portal/en;
[2] data giving the possibility of finding a stand on an interactive map available in Forest Data Bank;
[3] Ak – black locust, Bk – beech, Brz – birch, Czr – bird cherry, Db – oak, Gb – hornbeam, Jd – fir, Jw – sycamore maple, Lp – lime, Md – larch, Os – aspen, Ol – black alder, Ol.s – grey alder, So – pine, Św – spruce, Tp – poplar, Wb – willow;
[4] MJS – in places;
[5] PJD single-trees

able to calculate the percentage share of late wood (SLW) for each annual ring. In order to determine the variability in the examined features of the wood macrostructure on the radius of the stem cross-section, we divided each core sample – starting from the outer circumference – into sections, covering 10 rings. The core section, which comprises the oldest wood, typically contained less than 10 rings. The next step was to determine the basic wood density (BWD), which is the quotient of the mass of absolutely dry wood to its volume in the fully swollen state. The core sample sections were dried to an absolutely dry state in a POL-EKO dryer, model SLW 400 STD, and then weighed on a RADWAG scale, model WPS 210/C with the accuracy down to 0.001g. The wood was then placed in tubes with water until it self-sunk, after which the volume of the sections was measured using the hydrostatic method (Olesen, 1971), on the RADWAG scale mentioned above. The wood densities of the tree cross-section were calculated as the average density of individual core sections, weighted by their shares in the cross-sectional area of the stem (Ericson, 1966). The obtained data were collated; the averages and coefficients of variation were calculated. The following procedures were used in the statistical analyses using Statistica 13 (TIBCO

Software, 2017). The normality of variable distributions was assessed with the Shapiro-Wilk test. If the criterion of normality of distributions was met, then the significance of differences between the two populations was verified using the T test; alternatively, if more populations were compared, then the analysis of variance (ANOVA) and the Scheffé test were used. When the distribution of at least one variable did not meet the criterion of normal distribution, the significance of differences was analysed using non-parametric tests, respectively: U test, Kruskal-Wallis test (K-W test) and multiple comparisons test (M-C test). In our statistical analyses, the significance level of p=0.05 had been assumed.

Results

In total, the analysis of selected wood characteristics was carried out on core samples taken from 60 trees, growing in four study plots located in southern Poland. The smallest thickness was found for the black locust trees growing in plot no. 1, where the average diameter at breast height was 21.2 cm. In plots nos. 2 and 3, the averages were respectively: 25.9 and 29.9 cm. The thickest trees were found in plot no. 4, where the average diameter at breast height was 42.4 cm. The variability of the feature was similar on all plots, and its coefficient ranged from 26.5% (plot no. 1) to 33.3% (plot no. 2).

According to the survey description, the age of the investigated black locusts ranged from 61 (in plot no. 1) to 78 years (in plot no. 4). However, taking into account the invasiveness of this species (Tokarska-Guzik *et al.*, 2012; Obidziński and Woziwoda, 2016) – manifested, inter alia, in intensive vegetative reproduction and the related possibility of younger specimens in the stand – the age of the studied black locust trees was determined on the basis of the number of rings in core samples taken from stems, from the height of dbh, adding 4 years. This is because at that specific age, a black locust tree reaches the height of 1.3 m (Jaworski, 2005). By this token, all the examined trees were classified into three age classes. Class I (up to 20 years) comprised only three specimens, one each from plots no. 2, 3 and 4; and these trees were not taken into account in statistical analyses related to the age of the trees. 29 black locust trees were included in class II (21-40 years old), and 28 were assigned in class III (41-60 years old).

In order to analyse the differences in wood characteristics between trees growing in different habitats, all studied black locusts were classified into three types of habitats, that is, MixF (plot no. 1), UF (plots nos. 3 and 4) and MnF (plot no. 2). The average age of the examined trees growing on these three habitat types was 39, 38, and 42 years, respectively. The performed analysis of variance did not show that age differences were statistically significant (p=0.46). It can therefore be assumed that in further statistical analyses, possible differences in the examined wood characteristics, occurring between black locust trees growing in different types of habitats, do not result from differences in the age of the trees.

In the sapwood zone, all examined black locusts had an average of 4 rings of annual growth (Table 2). The highest mean value – of 5 rings – was recorded in the area of 2, whereas on other plots this value was the same everywhere, amounting to 3 rings. The variability of the feature within the study plots was slightly greater than the differences between them. The minimum NSR was determined to be 1 ring, the maximum – 7 rings. It was found that trees of age class III had significantly more NSR compared to class II (T test: p=0.035) (Table 3), and that black locust trees growing in MnF had significantly more NSR compared to the other two habitats (ANOVA: p=0.0012) (Table 2).

SW for the entire tested material was 9.7 mm on average (Table 2). The average values on individual plots ranged from 7.8mm (plot no. 3) to 12.2 mm (plot no. 2). The narrowest sapwood found during the tests was only 1.2 mm wide, and it contained merely 1 ring; whereas the widest was 27.9 mm, and it contained 7 rings. Higher SW variability was noted within the respective study plots than between them. There were no significant differences found in SW between the age classes II and III (U test: p=0.676). The mean value for younger trees was 9.3 mm, and for older trees, it was 10.3 mm (Table 3). There were also no significant differences found in SW between trees growing in different habitats (K-W test: p=0.248).

Table 2.

Basic statistics of the number of annual rings in sapwood (NSR), sapwood width (SW), share of sapwood (ShS), annual ring width (ARW), share of latewood (SLW) and basic wood density (BWD) on test plots

Test plot No.	Type of statistic	NSR [rings]	SW [mm]	ShS [%]	ARW [mm]	SLW [%]	BWD [g·cm^{-3}]
1 (MixF)	min.	1	1.5	3.2	1.11	51.4	0.499
	mean	**3**	**8.4**	**15.5**	**2.42**	**67.8**	**0.611**
	max	6	15.7	29.4	4.19	79.3	0.691
	V [%]	37.6	49.5	41.6	39.3	12.2	8.8
2 (MnF)	min.	2	3.99	7.1	1.92	47.3	0.493
	mean	**5**	**12.2**	**18.5**	**3.27**	**65.0**	**0.600**
	max	7	27.9	28.3	4.94	75.5	0.747
	V [%]	31.6	54.2	32.7	24.8	11.0	10.0
3 (UF)	min.	1	1.2	2.0	2.38	60.0	0.482
	mean	**3**	**7.8**	**16.0**	**3.26**	**67.1**	**0.624**
	max	4	14.2	45.3	4.76	79.4	0.709
	V [%]	40.6	54.7	71.3	21.6	7.5	9.5
4 (UF)	min.	1	6.4	4.7	1.92	60.2	0.538
	mean	**3**	**10.3**	**12.7**	**2.84**	**69.9**	**0.598**
	max	6	15.2	19.8	5.12	82.1	0.683
	V [%]	37.6	27.8	42.5	27.8	10.3	6.7
Upland forest (total)[1]	min.	1	1.2	2.0	1.92	60.0	0.482
	mean	**3**	**9.0**	**14.4**	**3.05**	**68.5**	**0.611**
	max	6	15.2	45.3	5.12	82.1	0.709
	V [%]	41.1	41.9	62.2	25.1	9.1	8.4
Total[2]	min.	1	1.2	2.0	1.11	47.3	0.482
	mean	**4**	**9.7**	**15.7**	**2.95**	**67.5**	**0.608**
	max	7	27.9	45.3	5.12	82.1	0.747
	V [%]	23.2	20.8	15.1	13.8	3.0	2.0

MixF – mixed forest; UF – upland forest; MnF – mountain forest; V – coefficient of variation; [1] statistics for two stands growing on habitat of upland forest; [2] A total of 4 forest stands, statistics calculated for 'Upland Forest (total)' were not taken into account

Table 3.

Basic statistics of studied wood features in age classes[1]

Age class	Type of statistic	NSR [rings]	SW [mm]	ShS [%]	ARW [mm]	SLW [%]	BWD [g·cm^{-3}]
II	min.	1	1.5	3.2	1.57	58.7	0.482
	mean	**3**	**9.3**	**15.4**	**3.00**	**67.6**	**0.611**
	max	6	18.2	29.4	4.94	76.7	0.709
	V [%]	37.7	48.7	45.6	28.0	7.5	9.8
III	min.	1	1.2	2.0	1.11	47.3	0.513
	mean	**4**	**10.3**	**15.0**	**2.87**	**66.7**	**0.602**
	max	7	27.92	28.3	5.12	82.1	0.747
	V [%]	40.9	53.0	44.6	32.7	12.9	8.2

[1] explanations of abbreviations of wood features – as in Table 2

The mean ShS on the cross-sectional area of the stem for all the examined trees was 15.7% (Table 2), which corresponds to 8.3% share of sapwood on the radius. The average values of the feature on individual test plots ranged from 12.7% (plot no. 4) to 18.5% (plot no. 2), which corresponds to 6.6% and 9.8% share of sapwood on the radius. No significant ShS differences were determined in the cross-sectional area of the stem between the age class II and III black locusts (T test: p=0.832), whereas the mean values were measured as: 15.4% and 15.0%, respectively (Table 3). There were also no significant differences found in ShS between trees growing in different habitats (K-W test: p=0.125).

The mean ARW of all the examined trees was 2.95 mm, arising from mean values in the individual study plots between 2.42 (plot no. 1), and 3.27 mm (plot no. 2) (Table 2). The variability of the feature was greater within the specific study plots than between them. In the first case, the coefficients of variation ranged from 21.6% (plot no. 3) to 39.3% (plot no. 1), whereas in the second case, it amounted to 13.8%. The smallest width of a single ring measured during the tests was 1.11 mm (plot no. 1), while the largest was 5.12 mm (plot no. 4). There were no significant differences in ARW between trees of age class II and III (T test: p=0.592). The mean value of this characteristic for younger individuals was 3.00 mm, and for older individuals, it was 2.87 mm (Table 3). Having said that, it was found that black locusts growing in the MnF site had significantly wider ARWs compared to those growing in the MixF site (ANOVA: p=0.016) (Table 2).

The average SLW of all studied black locusts was 67.5% (Table 2). In individual study plots, the average values oscillated between 65.0% (plot no. 2) and 69.9% (plot no. 4). The differentiation in this particular feature within the study plots was relatively small, as the coefficient of variation ranged from 7.5% (plot no. 3) to 12.2% (plot no. 1). Even less differentiation was found between the tested study plots; as in this case, the value of the coefficient was only 3.0%. The smallest SLW, measured during the research in a single ring, amounted to 47.3% (plot no.2), and the largest – to 82.1% (plot no. 4). There were no statistically significant differences in SLW found between younger and older trees (T test: p=0.579). The mean value of this feature obtained for age class II of black locust was 67.6%, and for age class III, it was 66.7% (Table 3). There were also no statistically significant differences found in the share of late wood between black locust growing in different habitats (ANOVA: p=0.292).

The mean BWD of the studied black locusts reached 0.608 $g\cdot cm^{-3}$ (Table 2). In individual study plots, these values ranged from 0.598 $g\cdot cm^{-3}$ (plot no. 4) to 0.624 $g\cdot cm^{-3}$ (plot no. 3). Among the tested features, BWD showed the smallest differentiation. The coefficient of variation within the individual examined plots ranged from 6.7% (plot no. 4) to 10.0% (plot no. 2), while between the plots, it was only 2.0%. The lowest BWD of a single, five-rings section was 0.482 $g\cdot cm^{-3}$ and it was found in a core taken from black locust growing on plot no. 3. The highest BWD occurred in a core section from plot no. 2 and it amounted to 0.747 $g\cdot cm^{-3}$. There were no significant differences in BWD between age classes II and III (T test: p=0.524). The mean value of this feature for older trees was 0.602 $g\cdot cm^{-3}$, whereas for younger trees it was 0.611 $g\cdot cm^{-3}$ (Table 3). There were also no significant differences established in BWD between trees from different habitats (ANOVA: p=0.782).

Figure 1 shows that in each habitat type, the black locust ARW decreased along the radius, in the direction from the core to the periphery. In the case of MixF, this decrease is very smooth over the entire radius. Trees from UF and MnF were characterized by a more dynamic decrease in the value of the feature; and in the first case, from the core section (V) to section II, ARW decreased by about 40%, whereas in the second case it decreased by about 55%. The BWD of black locust growing in MixF increased gradually from the core to the periphery, and the increase

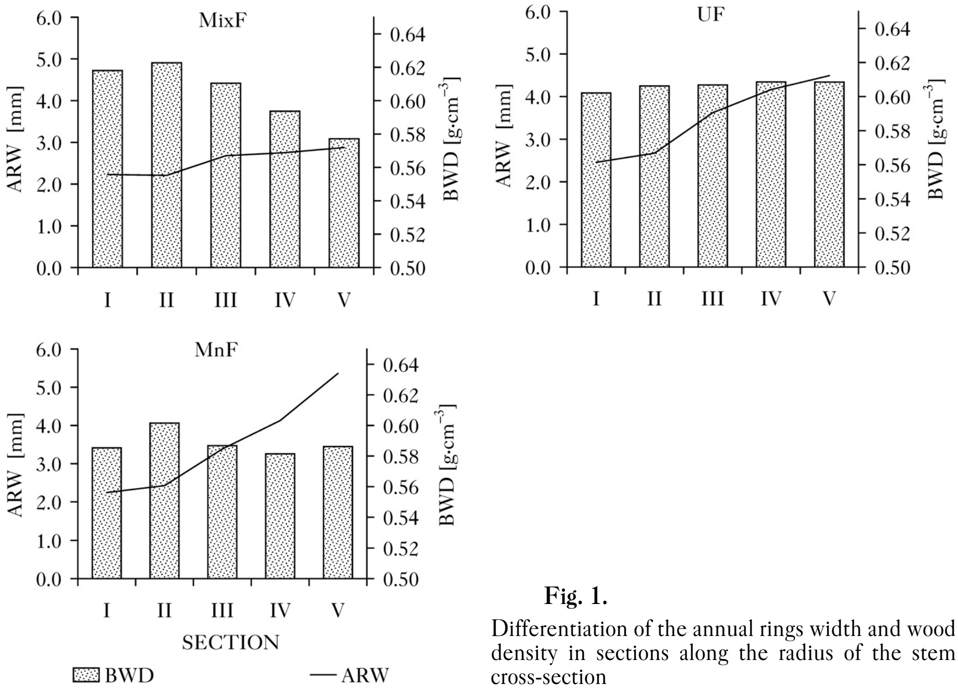

Fig. 1.
Differentiation of the annual rings width and wood density in sections along the radius of the stem cross-section

from section V (0.572 g·cm^{-3}) to section II (0.623 g·cm^{-3}) was about 9%. In trees growing in MnF, the BWD over most of the cross-sectional radius was very even, and it ranged from 0.581 to 0.587 g·cm^{-3}; only in section II the value of the feature was slightly higher and amounted to 0.602 g·cm^{-3}. In the case of trees growing in UF, the BWD value was very even over the entire radius of the cross-section and ranged from 0.602 to 0.609 g·cm^{-3}.

Figure 2 shows that in each habitat type the highest SLW values were found close to the core (sections IV and V), then a decrease in the value of the feature from the core to the bark was noted.

Discussion

Black locust forms ring-porous wood with coloured heartwood (Žegklitz and Marek, 2013). The presence of coloured heartwood in wood increases its natural durability, and the more intense the colour of the heartwood and the bigger its share in the stem, the greater the durability (Krzysik, 1974; Krajewski and Witomski, 2005). In the present study, the trees were characterized by relatively narrow sapwood, the average width of which was about 1 cm, and it covered an average of 4 rings (on average from 3 to 5 on individual study plots). Very similar values have been quoted by Galewski and Korzeniowski (1958), and by Kozakiewicz and Wiktorski (2007). Another North American species, cultivated in Polish forests – the red oak *Quercus rubra* L. – also forms a narrow sapwood zone, although it is still slightly wider than black locust (on average approx. 7 rings) (Wąsik and Michalec, 2020). The share of sapwood (ShS) on the cross-sectional area of the examined trees was determined to be on average less than 16%, which corresponds to about 8% share of this wood zone on the radius. No significant ShS differences were found between black locusts of varying ages, and growing in different forest habitats. It follows, therefore, that regardless of the age of the trees and the type of forest habitat on which they grow, the obtained raw material

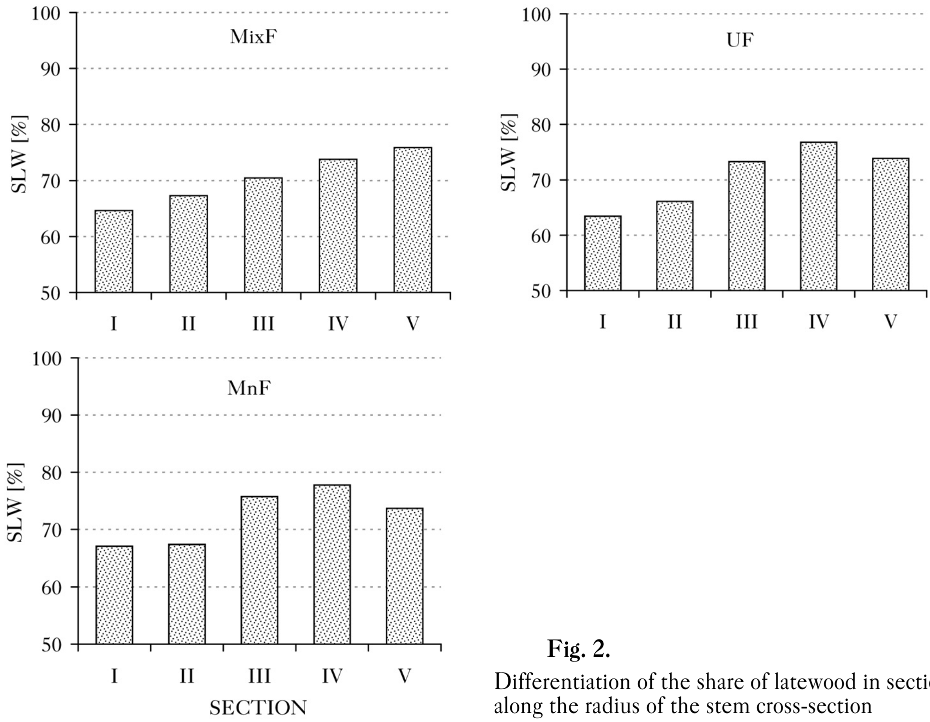

Fig. 2.
Differentiation of the share of latewood in sections along the radius of the stem cross-section

should be characterized by a similar – and relatively high – natural durability of wood. The heartwood of black locust is considered to be very durable, so much so that it can be used in the open air for about 80 years (Galewski and Korzeniowski, 1958; Forest Products Laboratory, 1999).

The mean ARW of the studied black locusts was 2.95 mm on average. It was found that black locust growing in MnF had significantly wider ARW (mean value 3.05 mm) compared to those growing in MixF (mean value 2.42 mm). Black locust wood from the MnF habitat should therefore be treated as broad-grained, i.e. more than 3 mm wide (Krzysik, 1974). Slightly lower ARW values (mean of 2.14 mm) had been obtained for black locust from stands located in western Poland (Klisz *et al.*, 2014) and those in south-western Poland (about 2.0 mm) (Bijak and Lachowicz, 2021). Similar ARW values of 2.99 mm were obtained in Belgium (Pollet *et al.*, 2012). Slightly higher average features – namely, 3.4 mm – were obtained in black locust trees growing in Poland in urban conditions in Wrocław (Kalbarczyk *et al.*, 2016), and those growing in Greece (also 3.4 mm) (Adamopoulos and Voulgaridis, 2002). It follows that black locust trees growing in Poland develop at a rate not different from those growing in other parts of Europe. On the other hand, clearly wider rings (about 5 mm) were found in black locust in the Henan province in northern China (Wang *et al.*, 2017).

SLW of the examined black locusts was 67.5%. In the wood of black locust trees growing in south-western Poland, this share was slightly higher and ranged from approx. 70% to approx. 80% (Bijak and Lachowicz, 2021). In another North American deciduous species growing in Polish forests – namely, northern red oak – this share was lower, and it amounted to less than 60% (Wąsik and Michalec, 2020).

BWD for all examined trees was on average 0.608 g·cm^{-3} (608 kg·m^{3}). A similar value of this feature was obtained for black locust in Belgium (Pollet *et al.*, 2012). Assuming total volumetric shrinkage in the range of between 10.2% (Meier 2023) and 14.16% (Bijak and Lachowicz 2021), the calculated oven dry wood density (ODWD) would range from 677.1 to 711.8 kg·m^{-3}. Similar ODWD values were obtained for black locust wood from south-western Poland by Bijak and Lachowicz (2021) (specifically, between 624 and 770 kg·m^{-3}). The air-dry (12% moisture) wood density of black locust (ADWD) can be assumed in a fairly broad range, that is from 580 to even as much as 900 kg·m^{-3} (Wagenführ and Scheiber, 1989). Assuming a volumetric shrinkage coefficient of 0.34% (Meier, 2023) to 0.47% (Bijak and Lachowicz, 2021), the calculated mean ADWD (mean of the values: 728.6 and 754.6 kg·m^{-3}) of the investigated black locust trees would be 741.6 kg·m^{-3}. According to Krzysik's (1974) classification, the examined trees form heavy wood, the ADWD of which ranges from 710 to 800 kg·m^{-3}. Similar ADWD values are quoted for black locust trees from North America (770 kg·m^{-3}), Greece (750 kg·m^{-3}), and Belgium (734 kg·m^{-3}) (Adamopoulos *et al*., 2007; Pollet *et al*., 2012; Meier, 2023). Taking into account the strong relationship between the density of black locust wood and its mechanical properties (Niklas, 1997), it should be assumed that the raw material obtained in the future from the investigated black locust trees will not be inferior to wood from other regions of the world in terms of strength.

The rings of black locust trees growing in MixF mildly decreased ARW from the pith (section V) to the bark (section I), while in trees growing un UF and MnF, the corresponding decrease in ARW was more dynamic, and it was most clearly marked in black locust trees growing in MnF. Decreasing value of ARW from the pith to the bark was also observed in black locust in Greece (Adamopoulos and Voulgaridis, 2002), Belgium (Pollet *et al*., 2012), and China (Wang *et al*., 2017).

The BWD of the investigated black locusts on the stem cross-sectional radius was observed to be relatively even. It was determined to be most even in the case of trees growing in the UF habitat. It can therefore be expected that the raw material obtained in the future from UF should be characterized by the least differentiated mechanical properties of wood on the cross-section of the stem. A similar, even course on the radius of the cross-section of the stem had been observed in the case of BWD of red oaks growing in forest habitats in southern Poland. A more diverse course of the trait of this species was recorded in coniferous forest habitats, where, moreover, BWD was significantly lower compared to forest habitats (Wąsik and Michalec, 2020). Therefore, it cannot be ruled out that also in black locust trees growing in coniferous habitats, the BWD will be shaped differently compared to forest habitats. However, in order to confirm this, further, targeted research needs to be carried out.

In each type of forest, SLW decreased in the direction from the pith to the bark, but these decreases were not large, as they amounted to several percentage points. It should be noted that the obtained SLW values may be subject to errors resulting from the difficulty of clearly determining the boundary between earlywood and latewood within the same increment, which was caused by the irregular arrangement of large pores of earlywood. Similar difficulties were also pointed out in studies of red oak wood growing in southern Poland (Wąsik and Michalec, 2020). This may be the reason for the different course of SLW and BWD on the radius of the trunk cross-section, because usually a higher SLW value corresponds to a larger BWD.

Conclusions

- The studied black locust trees formed narrow sapwood, about 1 cm wide, covering an average of 4 annual rings. The share of sapwood (ShS) in the cross-sectional area amounted to less than 16%, and did not differ significantly between the age classes of the examined trees, or the types of habitats on which they grew. Therefore, it can be surmised that regardless of the age of black locust trees, or the habitat on which they grow, the wood raw material obtained in the future will be characterized by a similar, relatively high natural durability.

- The average width of annual rings (ARW) was calculated as 2.95 mm. Black locust trees from the mountain forest habitat (MnF) formed broad-grained wood (mean value over 3.0 mm), while those from the mixed forest habitat (MixF) formed narrow-grained wood (mean value up to 3.0 mm). Black locust trees growing in Poland do not differ from the trees growing in other parts of Europe in either the width of the rings or the characteristics of their course on the radius in the cross-section of the stem.
- The share of late wood (SLW) averaged 67.5% and was slightly higher than the average for red oak (mean value of less than 60%), growing in Poland.
- The average basic wood density (BWD) was determined to be 0.608 g·cm^{-3}. The black locust growing in the upland forest habitat (UF) had a more favourable – that is, more even – course of wood density on the radius of the cross-section of the stem compared to the other two types of habitats (MixF and MnF).
- With the assumed shrinkage coefficient, the calculated air-dry wood density (ADWD), amounting to 741.6 g·cm^{-3}, allows us to classify the wood of the tested black locust trees as heavy wood.

Authors' contributions

R.W. – conceptualization, methodology, investigation, data curation, writing parts of original draft; K.M. – investigation, writing parts of original draft; MG: writing parts of original draft.

Conflicts of interest

The authors declare no conflict of interest.

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STRESZCZENIE

Zróżnicowanie wybranych cech makrostruktury i gęstości umownej drewna na promieniu przekroju poprzecznego pnia robinii akacjowej *Robinia pseudoacacia* L. z Polski południowej

Celem prezentowanej pracy była analiza zróżnicowania wybranych cech drewna robinii wzrastających w Polsce południowej. Badania prowadzono w czterech drzewostanach (tab. 1), z których dwa wzrastały na siedlisku lasu wyżynnego (UF), a po jednym – lasu mieszanego (MixF) oraz lasu górskiego (MnF). W każdym drzewostanie zmierzono pierśnicę wszystkich robinii, następnie proporcjonalnie do liczebności drzew w przedziałach pierśnic wybrano 15 drzew próbnych, z których pobrano po jednym odwiercie od północnej strony pnia. Na odwiertach określano liczbę przyrostów w bielu (NSR) oraz mierzono szerokość bielu (SW) i obliczano jego procentowy udział w powierzchni przekroju poprzecznego pnia (ShS). Odwierty skanowano oraz mierzono szerokość słojów (ARW) i stref drewna późnego. Na podstawie uzyskanych danych obliczono udział drewna późnego (SLW). Począwszy od obwodu, odwierty dzielono na sekcje obejmujące po 10 przyrostów. Dla każdej sekcji określono umowną gęstość drewna (BWD). Wiek badanych drzew oszacowano na podstawie liczby przyrostów w odwiertach, dodając 4 lata, tj. wiek, w którym przeciętnie robinia osiąga wysokość 1,3 m.

Strefa drewna bielastego badanych robinii obejmowała średnio 4 słoje (tab. 2). U drzew III klasy wieku stwierdzono istotnie więcej przyrostów w bielu w stosunku do klasy II, natomiast u wzrastających na siedlisku lasu górskiego istotnie więcej przyrostów w tej strefie w porównaniu z pozostałymi dwoma siedliskami. Średnia szerokość bielu wyniosła 9,7 cm (tab. 2) i nie stwierdzono istotnych różnic tej cechy zarówno między robiniami młodszymi i starszymi, jak i wzrastającymi na różnych siedliskach. Podobne wartości liczby przyrostów w bielu i jego szerokości uzyskano w innych badaniach robinii na terenie Polski. Udział bielu w powierzchni przekroju poprzecznego pnia wyniósł średnio około 16% (tab. 2). Nie stwierdzono istotnych różnic szerokości bielu i jego udziału między robiniami różnych klas wieku oraz między wzrastającymi na różnych siedliskach. Niezależnie od wieku oraz typu siedliska lasowego, na którym rosły robinie, pozyskany w przyszłości surowiec powinien więc charakteryzować się podobną wysoką naturalną trwałością drewna.

Średnia szerokość przyrostu rocznego wyniosła 2,95 mm (tab. 2). Nieco niższe średnie wartości tej cechy notowano na obszarach leśnych w innych rejonach Polski, podobne w Belgii, a nieco wyższe w Grecji. Przyrost radialny robinii rosnących na terenie Polski nie odbiega więc od przyrostu drzew w innych krajach Europy. Wyraźnie szersze słoje notowano natomiast u robinii w Chinach. Przyrosty badanych robinii zmniejszały swoją szerokość od rdzenia do obwodu (ryc. 1), z tym że w przypadku siedliska lasu mieszanego spadek ten był łagodny, natomiast dla siedlisk lasu wyżynnego i lasu górskiego bardziej dynamiczny. Podobnie kształtowała się szerokość przyrostów rocznych na promieniu przekroju poprzecznego pnia u robinii w Grecji, Belgii oraz Chinach.

Średni udział drewna późnego badanych drzew wyniósł 67,5% (tab. 2) i był nieco niższy w porównaniu do wartości podawanych dla robinii z Polski południowo-zachodniej (70-80%) oraz nieco wyższy w porównaniu z drewnem dębu czerwonego pochodzącego z Polski południowo-wschodniej. Nie stwierdzono statystycznie istotnych różnic tej cechy między robiniami młodszymi i starszymi oraz między rosnącymi na różnych siedliskach.

Średnia gęstość umowna drewna badanych robinii wyniosła 0,608 $g \cdot cm^{-3}$ (tab. 2). Nie stwierdzono istotnych różnic gęstości drewna między robiniami II i III klasy wieku oraz między rosnącymi na różnych siedliskach. Gęstość drewna u robinii z siedliska lasu mieszanego wzrastała stopniowo od rdzenia w kierunku obwodu (ryc. 1). W przypadku drzew z siedliska lasu górskiego na większej części promienia wartość tej cechy była bardziej wyrównana. Najbardziej wyrównane wartości na promieniu osiągała gęstość drewna u robinii z lasu wyżynnego (ryc. 1), można zatem przypuszczać, że surowiec pozyskany w przyszłości z robinii wzrastających na tym siedlisku powinien charakteryzować się na przekroju poprzecznym pnia najmniej zróżnicowanymi właściwościami mechanicznymi drewna.

Obliczona gęstość drewna absolutnie suchego badanych robinii wyniosłaby od 677,1 do 711,8 $kg \cdot m^{-3}$. Zbliżone wartości tej cechy uzyskano w badaniach drewna robinii pochodzących z Polski południowo-zachodniej. Natomiast obliczona średnia gęstość drewna powietrzno-suchego (przy wilgotności drewna ok. 12%) wyniosłaby 741,6 $kg \cdot m^{-3}$, co plasuje drewno badanych drzew w grupie gatunków tworzących drewno ciężkie (710-800 $kg \cdot m^{-3}$). Podobne wartości gęstości drewna powietrzno-suchego podawane są dla robinii z terenów Grecji i Belgii, a także dla rosnących na kontynencie północnoamerykańskim. Biorąc pod uwagę silny związek gęstości drewna robinii z jej właściwościami mechanicznymi, należy zakładać, że surowiec pozyskany w przyszłości z badanych drzew nie będzie ustępował wytrzymałością drewnu robinii z innych regionów świata.