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Impact of Tree Age and Size on Selected Properties of Black Locust (*Robinia pseudoacacia* L.) Wood

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Abstract: Black locust (*Robinia pseudoacacia* L.) is a non-native tree species that occupies a remarkable area in the forests of western Poland. It is mainly cultivated for the bee-keeping purposes as well as for its high quality wood. We investigated the impact of tree age and diameter on the selected structural, physical and mechanical attributes of wood of black locust that grows in conditions of mesic oligotrophic site. We analysed 200 samples originating from 18 trees that varied with age (38, 60 and 71 years old) and diameter (thin, medium and thick specimen selected according to Hartig's method). Individual wood properties were determined along with corresponding European or Polish standards. Structural and mechanical attributes were determined for moisture of 12%. We found significant impact of tree age on tree-ring width, latewood proportion, density, oven-dry density, basic density, share of woody substance, porosity, as well as radial, tangential, longitudinal and volumetric shrinkage, compression strength parallel to grain, static bending, coefficient of compression strength parallel to grain and coefficient of static bending. The older the trees, the higher values of individual attributes were observed. In turn, the effect of tree diameter was less profound and no significant impact of that feature was found for latewood proportion, anisotropy and almost all of the shrinkage parameters. Thin trees exhibited the lowest values of the analysed parameters, while medium ones—the highest. In general, the highest technical quality of the investigated wood can be found in the youngest trees, whose wood characterises with the properties significantly exceeding native Polish tree species such as oak or beech.

Keywords: timber quality; wood properties; black locust; alien tree species

1. Introduction

European forests have been influenced by the human activity for a long time experiencing various forms of utilisation as well as alteration of their shape, organisation and structure [1]. Although the earliest introductions of non-native species (i.e., growing outside their natural range) may be dated back even to the Mesolithic time, it is the discovery of the east banks of the Americas at the end of fifteenth century and the resulted exploration of the environment of these continents that ended up with massive planting of the alien species in European gardens, parks and finally, forests. Later on, in the nineteenth century, also trees from Australia appeared in the 'old World' [1,2]. Currently, there are at least 145 non-native tree species introduced to the forests of Europe and almost half of them originate from North America [3].

Black locust (*Robinia pseudoacacia* L. (Fabaceae)), that originates from the eastern part of North America, namely the Appalachian Mountains and the Ozark Plateau, was introduced to Europe by Jean Robin as early as 1601, as one of the first over-seas tree species [4–6]. Initially used as a park or garden tree, the species was extensively brought into the cultivation in European forests in mid-1700s and 1800s. Further on, it was widely applied in windbreaks and shelterbelts or as a nitrogen-fixing species for land reclamation.

High combustion potential of fast and amply produced wood resulted in eager utilisation as an energy crop. Apart from an ornamental role in parks, gardens and alleys, it was also used as a street tree to mild the urban environment [6,7]. Eventually, black locust has become the most common non-native broadleaved tree species on the continent and an important multipurpose species in many parts of Europe. Nowadays, it covers more than 2.3 million ha with significant area of at least 100,000 ha in Hungary, Ukraine, Poland, Romania, Italy, France, Serbia, Slovenia and Bulgaria [5,6,8]. Bearing that in mind, black locust may be considered as one of the most widespread as well as economically and ecologically important non-native tree species in Europe [6]. On the other hand, it is also included on the list of the most invasive species of the world [9]. The black locust is reported to reduce the biodiversity mostly by limiting the light accessibility to the plants growing beneath the canopy and by changing the microclimate or the soil condition (nitrification and acidification) [10].

Currently, in Poland, black locust occupies ca. 3.35% of forested area, with remarkably high participation in the forests in the western part of the country [4,11]. Annual harvest of black locust timber in Poland amounts to ca. 90 thousand m^3 and has been steadily increasing in recent years [12]. The market interest in that species is mainly based on unique pattern and texture of the wood as well as its excellent natural durability that is praised among producers of garden equipment.

The selection of wood species for different uses is based on variety of criteria that in general include timber availability, wood anatomy, density, strength, seasoning properties, natural durability or case of preservative treatment, freedom from defects, colour and grain [13]. Knowledge about various structural, physical and mechanical properties of wood is of key importance in determining its possible uses [14]. It is even more crucial in case of species whose wood can play the multi-purpose role as presented for the black locust [7].

As the observed climate changes are expected to favour further expansion of black locust both in forested and non-forested areas of Europe [15,16], it is important to extend the knowledge about the potential productivity of this species and about quality of its timber. It is also of great significance to compare the properties of wood of this alien species with those of for local species.

The primary objective of the study was examine (i) the selected structural, physical and mechanical properties of black locust (*Robinia pseudoacacia* L.) wood and (ii) their dependence on tree's age and size. The research was carried out using as the example timber from western Poland, which is one of the principal source areas of black locust raw material in the country.

2. Materials and Methods

For many years, the Department of Forest Utilisation at the Warsaw University of Life Sciences—SGGW has been realising the long-term research on variation in the quality of wood of various tree species. These studies have been carried out using a uniform methodology, which enables wide-spread comparisons among the species. That is why the presented study followed the same protocol as previous research [14].

The research material was collected in the Głogów Forest District (SW Poland, 51.5–51.7 N, 15.9–16.2 E), which is located within the region of the greatest abundance of black locust stands in Poland [4,11]. The mean annual temperature in that area ranges from 8.0 to 9.0 °C, while the average precipitation is rather low and equals 525 mm. The area is located in a transition zone from maritime to continental types within a temperate climate [17]. The predominant growth conditions include dys- and oligotrophic sites (53%) developed mostly on rusty, podzolic and riverine soils.

We selected three normally managed stands with dominant share of black locust in the species composition (Table 1). Age of these stands was determined by calculating tree-rings on the stumps of felled trees and equals to 38 (age class II), 60 (age class III) and 71 (age class IV) years. In each stand we choose six sample trees according to Hartig's method [18].

At first, we established temporary sample plots that contained ca. 110–120 trees. Next, we measured breast height diameter of all those trees and grouped them into three clusters of possibly similar total basal area. Then, from each such a grouping we selected two representative tress to be felled. They represented three diameter (size) classes: 1—thin (range of sample trees diameter: 15.9–34.1 cm), 2—medium (diameter range: 16.8–37.1 cm) and 3—thick (diameter range: 21.7–37.9 cm) specimens.

Table 1. Age (years), mean diameter (D, cm), height (H, m), site index (SI, m), growing stock (V, $m^3 \cdot ha^{-1}$) and black locust fraction (%BL [%]) for the investigated black locust stands.

Age	D	H	SI	V	%BL
38	18	16	25.2	132	100
60	33	21	24.2	158	80
71	35	23	28.8	180	80

From each felled tree, we took two 50 cm long sections. Starting from the breast height (130 cm), one section was cut in a downward direction, while the other one in an upward direction (towards the crown). These sections were then split into the logs. Next, the wood was debarked and split open in order to increase the uniformity of drying. Wood from the internal part of the split logs was cut out in the way that the test samples could be prepared from the outer part of the trunk (mature wood). The obtained material was checked to provide only wood without any defects such as knots, colouring, insect or fungal infections and without reaction wood [19].

According to PN-77/D-04227 standard [20], out of the seasoned logs we prepared short (20 × 20 × 30 mm) and long (20 × 20 × 300 mm) samples for determination of the structural and mechanical properties of the wood. Altogether we obtained 200 samples: 35 samples represented 38 year old trees, 75 originated from 61 year old ones and 90 were from the eldest specimens. With regard to the size classes, 52 samples were from trees from class 1, 71 represented class 2 while 77 represented class 3. These number are enough to provide the statistically sound analyses, which can be confirmed by the similar sample sizes used in other studies on wood properties [21,22].

We used the short samples to determine: the tree-ring width (TRW), latewood fraction (%LW) and compression strength parallel to the grain (Rc_{12}), while the long ones served for assessment of static bending (Rg_{12}) and modulus of elasticity in static bending (Eg_{12}). These measurements were carried out in accordance with national Polish standards [23–25]. After static bending determination, we prepared another set of 20 × 20 × 30 mm samples out of the long ones for linear radial, tangential and longitudinal as well as volumetric shrinkage (βmaxR, βmaxT, βmaxL and βmaxV, respectively) measurements, which were performed following PN-82/D-04111 standard [26].

Tree-ring and latewood widths were measured on scanned (1200 dpi) images of the radial planes of the short samples using CooRecorder 7.8 software (Cybis Elektronik & Data AB, Saltsjöbaden, Sweden). All measurements of the mechanical properties of the wood were carried out on ZD-10 universal strength-testing machine.

The samples for wood density determination were weighed on the scale with 0.001 g accuracy and measured by an electronic calliper with the nearest of 0.01 mm. The moisture of the samples amounted to ca. 12%, ca. 30% and 0% (reached after drying in 105 °C) during assessment of density (G), basic density (Gb) and oven-dry density ($G_{0\%}$), respectively. Wood density as well as moisture were determined according to appropriate Polish standards [27,28].

Based on the obtained G and Rc_{12}, Rg_{12} and Eg_{12} results, we determined coefficients of compression strength parallel to grain (JRc = Rc_{12}/G), static bending (JRg = Rg_{12}/G) and modulus of elasticity in static bending (JEg = Eg_{12}/G). To express dimensional change per a 1% moisture content variation, we calculate the coefficients of shrinkage parameters (KβR, KβT, KβL and KβV), assuming the fibre saturation point at the moisture content equal to 30%. Tangential and radial shrinkages served to determine anisotropy

$(A\beta = \beta maxT/\beta maxR)$. The wood porosity was calculated based on oven-dry density $(C = 100\% \cdot (1 - G_{0\%}/1500))$.

For the distribution of almost all analysed black locust wood properties significantly differed from the normal one (Shapiro–Wilk test), we used Kruskal–Wallis non-parametric alternative for analysis of variance as well as post-hoc Mann–Whitney paired comparisons to determine the effect of the age or diameter class on the mean values of the investigated parameters. Calculations were carried out in PAST4 software [29] and the significance level of 0.05 was assumed.

3. Results

3.1. Structural Properties

We found a strong effect of the age class on the tree-ring width ($H_{KW} = 29.53$; $p < 0.001$). with all classes significantly differing one from another. Mean TRW was the highest for trees in age class II, while the smallest for age class III. The greatest variability of that feature was observed for the age class IV, while the lowest one for age class III (Figure 1a). Diameter class also influenced TRW in a great measure ($H_{KW} = 14.44$; $p < 0.001$), however, no significant difference was found between classes 1 and 2. The highest average radial increment was observed for the thickest trees. The thinnest trees showed the smallest variability, while the medium ones characterised the highest (Figure 1b).
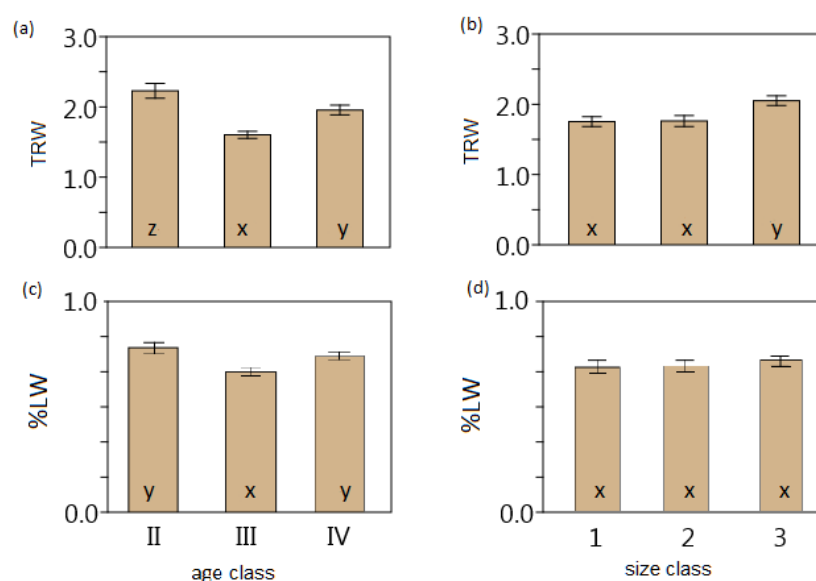

Figure 1. Mean (bar) ± standard error (whiskers) tree-ring width (TRW [mm]) and latewood proportion (%LW) in age (**a,c**) and tree size (**b,d**) classes. The same letter (x, y or z) indicates homogenous groups ($p < 0.05$).

Tree age impacted average proportion of latewood ($H_{KW} = 40.76$; $p < 0.001$) with significantly lower values noted for age class III. The greatest variability of %LW was found for the age class IV, while the lowest one for age class II (Figure 1c). We observed no effect of diameter class on %LW in the analysed trees ($H_{KW} = 3.64$; $p = 0.1621$) either. The highest average proportion of latewood was observed for the thickest trees. They also characterised with the lowest %LW variability, while the highest one was observed for the thinnest trees (Figure 1d). On the other hand, %LW turned to be significantly positively correlated with the TRW (r = 0.786, $p < 0.001$).

3.2. Physical Properties

Tree age and size significantly affected wood density (G), basic density (Gb) and oven-dry density ($G_{0\%}$) (Table 2). The highest values of all analysed density parameters were noted for trees in age class II, while the smallest one for samples from age class IV. In

terms of the influence of tree diameter classes, the highest densities were observed for the thinnest trees, while the lowest for the thickest ones. We found the highest G variability for the age class III and the thinnest trees, while for Gb and $G_{0\%}$ such was observed for the age class III and the medium-thick trees (Table 2).

Table 2. Basic characteristics of black locust wood density (G, kg·m^{-3}), basic density (Gb, kg·m^{-3}) and oven-dry density (G0%, kg·m^{-3}) as well as porosity (C, %) in relation to tree's age class (II–IV) and size class (1–3) as well as parameters of Kruskal–Wallis comparison (K-W).

Density	Age/Size Class	Mean	Minimum–Maximum	Standard Error	K-W
G	II	859.7 a	788.8–927.3	5.39	H = 104.70 $p < 0.001$
	III	749.3 b	674.9–833.2	4.35	
	IV	717.8 c	643.8–815.4	3.62	
	1	722.1 a	665.8–841.9	5.76	H = 25.02 $p < 0.001$
	2	673.6 b	643.8–917.7	4.58	
	3	595.8 b	663.1–927.3	3.60	
Gb	II	824.4 a	748.3–883.2	5.14	H = 104.50 $p < 0.001$
	III	706.3 b	606.8–784.9	4.48	
	IV	668.5 c	590.0–766.7	3.37	
	1	769.9 a	609.9–796.5	8.58	H = 27.42 $p < 0.001$
	2	725.1 b	590.0–883.2	7.92	
	3	638.3 b	606.8–848.5	5.33	
$G_{0\%}$	II	707.5 a	658.0–745.1	3.52	H = 104.90 $p < 0.001$
	III	624.0 b	538.8–686.3	3.86	
	IV	595.3 c	535.7–667.0	2.54	
	1	762.1 a	550.5–690.3	8.96	H = 21.43 $p < 0.001$
	2	716.4 b	535.7–745.1	8.17	
	3	630.9 b	538.8–726.9	5.80	
C	II	45.04 a	41.12–50.11	0.34	H = 104.90 $p < 0.001$
	III	52.91 b	47.67–59.54	0.30	
	IV	55.43 c	48.83–60.67	0.22	
	1	55.09 c	46.90–59.34	0.36	H = 21.44 $p < 0.001$
	2	51.66 a	41.12–60.67	0.53	
	3	52.24 b	43.43–59.54	0.52	

The same letter by the mean within age or size class indicates lack of significant difference at 0.05 determined with post-hoc Mann–Whitney test.

Average porosity equalled 52.7%, ranging from 41.1 to 60.7%. We found significant effect of both tree's age or size (on that feature. The highest values were noted for the oldest or the thinnest trees, while the lowest for the youngest ones and medium-sized (Table 2).

Mean shrinkage amounted to 5.1% on radial, 6.8% on tangential and 0.3% on longitudinal cross-sections, while the average volumetric shrinkage equalled to 11.7%. These properties characterised with rather small variability as standard deviation was low—0.74%, 1.12%, 0.22% and 1.63% for βmaxR, βmaxT, βmaxL and βmaxV, respectively. We found significant impact of tree's age on analysed shrinkage measures. In case of βmaxR ($H_{KW} = 72.86$, $p < 0.001$), βmaxT ($H_{KW} = 80.01$, $p < 0.001$), βmaxL ($H_{KW} = 25.93$, $p < 0.001$) and βmaxV ($H_{KW} = 77.62$, $p < 0.001$) all age classes differed one from another. On the contrary, there was no significant effect of size class on βmaxR ($H_{KW} = 0.03$, $p = 0.984$), βmaxT ($H_{KW} = 2.09$, $p = 0.351$) and βmaxV ($H_{KW} = 0.71$, $p = 0.700$). Only for βmaxL we found that tree diameter impacted the value of that parameter significantly ($H_{KW} = 12.13$, $p = 0.002$) with the highest mean observed for the thinnest trees (Table 3).

Table 3. Basic characteristics of radial (βmaxR, %), tangential (βmaxT, %), longitudinal (βmaxL, %) and volumetric (βmaxV, %) shrinkage and their respective coefficients (KβR, KβT, KβL and KβV, %) as well as anisotropy (Aβ, %) of black locust wood in relation to tree's age class (II–IV) and size class (1–3) as well as parameters of Kruskal–Wallis comparison (K-W).

Parameter	Age/Size Class	Mean	Minimum–Maximum	Standard Error	K-W
βmaxR	II	6.19 c	4.73–7.15	0.09	H = 72.86 $p < 0.001$
	III	4.97 b	3.73–6.57	0.06	
	IV	4.72 a	3.44–5.76	0.05	
	1	4.99 a	3.77–6.57	0.08	H = 0.03 $p = 0.984$
	2	5.12 a	3.88–7.15	0.10	
	3	5.06 a	3.44–6.78	0.08	
βmaxT	II	8.34 c	6.78–9.52	0.12	H = 80.01 $p < 0.001$
	III	6.74 b	5.13–8.90	0.09	
	IV	6.15 a	4.27–8.24	0.09	
	1	6.50 a	4.27–8.24	0.12	H = 2.09 $p = 0.351$
	2	6.80 a	4.70–9.52	0.15	
	3	6.84 a	4.80–8.96	0.13	
βmaxL	II	0.17 a	0.03–0.39	0.02	H = 25.93 $p < 0.001$
	III	0.30 b	0.03–0.82	0.02	
	IV	0.39 c	0.07–1.02	0.03	
	1	0.42 b	0.03–0.97	0.03	H = 12.13 $p = 0.002$
	2	0.29 a	0.03–1.02	0.03	
	3	0.29 a	0.03–0.82	0.02	
βmaxV	II	14.16 c	11.46–16.09	0.18	H = 77.62 $p < 0.001$
	III	11.64 b	9.04–14.16	0.13	
	IV	10.92 a	8.45–14.00	0.13	
	1	11.53 a	8.45–14.00	0.17	H = 0.71 $p = 0.700$
	2	11.82 a	8.98–16.09	0.22	
	3	11.80 a	8.65–15.02	0.18	
KβR	II	0.21 c	0.16–0.24	0.003	H = 73.42 $p < 0.001$
	III	0.17 b	0.12–0.22	0.002	
	IV	0.16 a	0.11–0.19	0.002	
	1	0.17 a	0.13–0.22	0.003	H = 0.03 $p = 0.987$
	2	0.17 a	0.13–0.24	0.004	
	3	0.17 a	0.11–0.23	0.002	
KβT	II	0.28 c	0.23–0.32	0.003	H = 78.87 $p < 0.001$
	III	0.22 b	0.17–0.30	0.003	
	IV	0.20 a	0.14–0.27	0.003	
	1	0.22 a	0.14–0.27	0.004	H = 2.02 $p = 0.363$
	2	0.23 a	0.16–0.32	0.005	
	3	0.23 a	0.16–0.30	0.005	
KβL	II	0.01 c	0.00–0.01	0.000	H = 25.91 $p < 0.001$
	III	0.01 b	0.00–0.03	0.001	
	IV	0.01 a	0.00–0.03	0.001	
	1	0.01 a	0.00–0.03	0.001	H = 12.10 $p = 0.002$
	2	0.01 b	0.00–0.03	0.001	
	3	0.01 b	0.00–0.03	0.001	
KβV	II	0.47 c	0.38–0.54	0.007	H = 76.62 $p < 0.001$
	III	0.39 b	0.30–0.47	0.005	
	IV	0.36 a	0.28–0.47	0.004	
	1	0.38 a	0.28–0.47	0.006	H = 0.72 $p = 0.698$
	2	0.39a	0.30–0.54	0.007	
	3	0.39a	0.29–0.50	0.006	

Table 3. *Cont.*

Parameter	Age/Size Class	Mean	Minimum–Maximum	Standard Error	K-W
Aβ	II	1.35a	1.17–1.62	0.015	H = 3.96 p = 0.138
	III	1.36 a	0.99–1.81	0.016	
	IV	1.31 a	0.94–1.67	0.017	
	1	1.31 a	1.00–1.67	0.021	H = 2.45 p = 0.294
	2	1.33 a	0.94–1.61	0.018	
	3	1.36 a	1.01–1.81	0.015	

The same letter by the mean within age or size class indicates lack of significant difference at 0.05 determined with post-hoc Mann–Whitney test.

Average coefficients of radial, tangential, longitudinal and volumetric shrinkage equalled to 0.17%, 0.22%, 0.01% and 0.39%, respectively. In addition, their variability was low as standard deviations amounted to 0.03%, 0.04%, 0.01% and 0.05%, respectively. Age significantly diversified the analysed material with regard to KβR (H_{KW} = 73.42, $p < 0.001$), KβT (H_{KW} = 78.87, $p < 0.001$), KβL (H_{KW} = 25.91, $p < 0.001$) and KβV (H_{KW} = 76.62, $p < 0.001$). We found no significant effect of size class on KβR (H_{KW} = 0.03, $p = 0.987$), KβT (H_{KW} = 2.02, $p = 0.363$) and KβV (H_{KW} = 0.72, $p = 0.698$). Only in case of KβL tree diameter impacted the value of that parameter significantly (H_{KW} = 12.10, $p = 0.002$) with the highest mean observed for the thinnest trees (Table 3). Average anisotropy equalled 1.34% ranging from 41.1 to 60.7%. No significant effect of either age (H_{KW} = 3.96, $p = 0.138$) or size (H_{KW} = 2.45, $p = 0.294$) was found. The highest values were noted for the middle-aged or the thickest trees, while the lowest for the oldest or thinnest ones.

All analysed shrinkage parameters were significantly correlated with the wood density. Higher density resulted in higher values of βmaxR, βmaxT, βmaxV, KβR, KβT, KβV and Aβ, while negative relationship was found for βmaxL and KβL.

3.3. Mechanical Properties

On average, the compression strength parallel to the grain for the whole material amounted to 75 MPa, spanning from 55 to 89 MPa. Mean static bending for the whole material equalled 155.5 MPa, with the range of that feature from 81 to 202 MPa. In turn, average value of modulus of elasticity in static bending for the whole material amounted to 14,228.4 MPa, with the range from 10,342 to 19,846 MPa. We found moderate impact of the age class on the Rc12 (H_{KW} = 8.42; $p < 0.015$). No significant difference was found between age classes II and III. Tree diameter diversified analysed trees in greater measure (H_{KW} = 34.09; $p < 0.001$). All analysed diameter classes differed significantly one form another. There was a strong effect of both age (H_{KW} = 58.25; $p < 0.001$) and diameter (H_{KW} = 20.09; $p < 0.001$) on Rg12 values. In case of these variables all classes differed significantly one from another. We found no effect of age class (H_{KW} = 0.68; $p = 0.710$) on the modulus of elasticity in static bending. However, the diameter influenced that parameter significantly (H_{KW} = 7.68; $p = 0.022$), with medium sized trees characterised the highest Eg12 (Table 4).

Table 4. Basic characteristics of compression strength parallel to the grain (Rc12, MPa), static bending (Rg12, MPa), modulus of elasticity in static bending (Eg12, MPa) and their coefficients (JRc, JRg, JEg, respectively, km) of black locust wood in relation to tree's age class (II–IV) and size class (1–3) as well as parameters of Kruskal–Wallis comparison (K-W).

Parameter	Age/Size Class	Mean	Minimum–Maximum	Standard Error	K-W
Rc12	II	77.2 b	64.6–87.0	1.0	H = 8.42
	III	75.1 b	55.1–88.6	1.0	$p = 0.015$
	IV	74.2 a	63.1–83.6	0.5	
	1	69.9 a	57.6–82.5	1.0	H = 34.29
	2	77.8 c	63.9–88.6	0.7	$p < 0.001$
	3	76.0 b	55.1–86.7	0.6	
Rg12	II	178.1 a	153.7–202.1	2.5	H = 58.25
	III	153.2 b	80.9–179.4	2.2	$p < 0.001$
	IV	148.8 c	116.5–180.9	1.4	
	1	147.6 a	119.1–180.9	2.1	H = 0.09
	2	161.3 c	116.5–202.1	2.1	$p < 0.001$
	3	155.7 b	80.9–198.6	2.3	
Eg12	II	16,423 a	12,084–19,846	385.4	H = 0.685
	III	13,939 a	10,342–17,319	186.7	$p = 0.710$
	IV	13,601 a	10,441–19,838	154.3	
	1	13,052 a	10,342–16,458	202.3	H = 7.68
	2	14,808 b	10,731–19,846	249.7	$p = 0.022$
	3	14,471 a	11,548–18,562	207.8	
JRc12	II	9.03 a	7.84–10.07	0.10	H = 34.29
	III	10.07 b	8.50–11.22	0.09	$p < 0.001$
	IV	10.33 b	9.07–11.10	0.05	
	1	9.74 a	8.03–11.10	0.11	H = 9.19
	2	10.16 b	7.84–11.22	0.09	$p < 0.001$
	3	10.05 b	7.85–11.18	0.08	
JRg12	II	20.7 b	17.1–22.8	0.24	H = 36.92
	III	20.4 a	10.5–23.0	0.24	$p < 0.001$
	IV	20.8 c	14.7–26.1	0.20	
	1	20.4 a	17.6–24.8	0.22	H = 24.07
	2	21.0 b	14.7–26.1	0.24	$p < 0.001$
	3	20.4 a	10.5–22.9	0.22	
JEg12	II	1906 a	1476–2200	37.9	H = 3.42
	III	1857 a	1532–2242	18.7	$p = 0.181$
	IV	1891 a	1568–2433	14.3	
	1	1807 a	1530–2151	23.0	H = 11.32
	2	1917 b	1632–2433	18.6	$p = 0.003$
	3	1897 b	1476–2242	17.8	

The same letter by the mean within age or size class indicates lack of significant difference at 0.05 determined with post-hoc Mann–Whitney test.

Coefficient of compression strength parallel to grain for the whole material equalled 10 km, with the range of that feature from 7.8 to 11.2 km. Values of coefficient of static bending for the whole material ranged from 10.5 to 26.1 km, equalling 20.6 km on average. In turn, coefficient of modulus of elasticity in static bending amounted for the whole material to

1881 km on average, ranging from 1476 to 2433 km. We found that JRc12 values significantly varied with respect to age (H_{KW} = 57.55; $p < 0.001$) and diameter (H_{KW} = 9.12; $p = 0.010$) class. There was a strong effect of the age class on the JRg12 (H_{KW} = 36.92; $p < 0.001$) and all of the analysed ones differed one from another significantly. Similar pattern was found for diameter classes (H_{KW} = 24.07; $p < 0.001$), however, no significant difference was found between classes 2 and 3. No effect of the age class on the JEg12 (H_{KW} = 3.41; $p = 0.181$) was reported. In the case of tree thickness classes, we observed significant influence of that feature on, coefficient of modulus of elasticity in static bending (H_{KW} = 11.32; $p = 0.003$). No significant difference was found again between classes 2 and 3 (Table 4).

4. Discussion

Thanks to its exceptional properties, black locust wood must be considered for a ensured a wide variety of applications as a construction material [30] or important source of energy [31], especially when cultivated on degraded or reclaimed lands [32]. Widening range of possible use of black locust wood [7] and still fragmented knowledge about its structural, physical and mechanical properties [21,33,34] requires research that will provide sufficient information that can be utilised in both forestry and timber industry. That is of key importance, especially when rising harvest and demand for wood of that species is concerned [6,12].

Wood density is a key trait in determining wood quality because it exhibits a strong correlation with other properties. Obtained values of black locust wood density confirm previous findings classifying that wood as a dense one [22,33–36]. Similarly to Kraszkiewicz [31], we found significant decrease of wood density with age of the trees. Our findings about significant relationship between wood density and mechanical properties of black locust wood also confirm previous observations [37].

Black locust wood is considered as dimensionally stable [34,35]. Recorded shrinkage parameters are in general higher than reported in previous studies [34,38], but still a bit lower that presented by Pollet et al. [22]. According to classification presented by Krzysik [35], analysed wood, based on βmaxV or KβV values, can be described as one with medium shrinkage behaviour. Obtained very low values of anisotropy indicate that black locust wood is in general less vulnerable to distortions.

Observed values of compression strength parallel to the grain for black locust are higher than ones for native birch [39,40], beech and oak [41]. Modulus of elasticity in static bending is remarkably higher than reported for black locust of Greek origin [21,42]. On the other hand, they are similar to values presented for trees of Hungarian origin [42]. Obtained values are close to ones provided for beech and oak in Poland [41].

Size and age affect various changes in tree structure and function, influencing processes of growth, germination, reproduction or carbon storage [43]. As reviewed by Rocha et al. [44] wood may exhibit great variation in its properties and performance in specific conditions which results from both genetic and environmental factors that also directly and indirectly are related to the age and size of trees. We found in general significant effect of age on investigated structural, physical and mechanical properties of black locust wood, while tree size was of lesser importance. Changes in various wood properties along tree's age were previously reported for silver birch [14,45], radiata pine [46], loblolly pine [47], jack pine [48] or eucalyptus [49]. In the case of tree size, the picture of relationship between wood traits and tree dimensions is not straightforward. Analyses of wood density with regard to diameter or height for seven tropical species revealed diverse effect of the investigated size parameters [50]. In turn, the density and shrinkage parameters of black spruce turned to be significantly related to the tree diameter [51]. The significant influence of tree size on selected structural, physical and mechanical traits of silver birch wood was also found [39,40]. Our studies confirm that complex pattern of the dependence of wood properties on tree size as its effect was not found for shrinkage parameters, while a significant relationship was detected for density and other mechanical properties.

5. Conclusions

This study analysed the impact of tree age or size (diameter) on the selected structural, physical and mechanical properties of wood of black locust growing in greater abundance in western Poland. The obtained results indicated that age significantly influences the majority of investigated wood properties. In general, the older the trees, the higher values of individual attributes are observed. In turn, tree size affects wood features to a lesser extent. Particularly, no effect of diameter on shrinkage attributes was found. Thin trees exhibited the lowest values of the analysed parameters, while medium ones—the highest ones. In general, wood of the best technical quality can be found in the younger black locusts.

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