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Slenderness of trees in black locust stands

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Abstract. This paper investigates the slenderness of black locust (*Robinia pseudoacacia*) trees in relation to the biosocial status of the trees, stand age class, crown parameters and habitat type. The research material was collected on 35 research plots in the Sława Śląska, Sulechów and Głogów forest districts in western Poland and comprises 1058 trees. For each tree, we measured height (h) as well as diameter at breast height (d) and determined its biosocial status (Kraft class), crown length (CL) and relative crown length (rCL). The age class and habitat type were assessed at the plot level. Because the obtained values for slenderness (s=h/d) diverged significantly from the normal distribution, we used Kruskal-Wallis and Mann-Whitney tests to investigate the influence of the above-mentioned parameters on the h/d ratio. Black locust slenderness ranged from 0.31 to 1.95 with an average of 0.91 (standard deviation 0.24). It furthermore differed significantly between Kraft classes (the higher the biosocial status, the lower the slenderness) and age classes (the older the trees, the lower their slenderness). We also found a significant effect of the habitat type (in oligotrophic sites trees formed more slender trunks than in mesotrophic sites) and crown parameters on the h/d ratio (decreasing with increasing crown length and relative crown length). The obtained results suggest that the slenderness of black locust does not differ substantially from native broadleaved trees in Poland.

Keywords: *Robinia pseudoacacia*, slenderness, Kraft class, age class, crown parameters

1. Introduction

Damage caused by wind or snow is recognised in forestry as one of the most serious threats that can result in significant economic losses, especially in managed stands (Zajączkowski 1991; Peltola 2006; Zachara 2006; Bruchwald, Dmyterko 2010, 2011, 2012). One of the measures characterising the stability of a tree (or tree stand), and thus specific resistance to the impact of wind or snow, is the slenderness. According to the classification proposed by Burschel and Huss (1997) for coniferous species, trees with a slenderness of <0.8 should be considered stable, but when this parameter assumes values of >1.0, trees are at risk of breaking or falling. However, Abetz and Klädtke (2002) believe that slenderness can also be a measure of the urgency for thinning.

Slenderness is shaped by the conditions and the space in which the tree grows (Orzeł 2007; Kaźmierczak et al. 2008a, b, 2009, 2011, 2015; Kaźmierczak 2012). Difficult conditions increase competition for the resources required by trees to develop, resulting in uneven growth and increased growth in a chosen direction. As a consequence, different shapes and structures of trees are observed. If the growth space is large, the radial increment is greater than the increase in height, which results in a lower slenderness. In turn, when the distribution of trees is dense and there is greater competition for light, the increase in height reaches greater values and the tree is more slender. Slenderness can be shaped by tree tending treatments performed in a forest stand (Jaworski 2004), resulting, for example, in crown length variation (Korzeniewicz et al. 2016).

Studies to date on tree slenderness in Poland have focused primarily on native forest-forming species. Rymer-Dudzińska (1992a, b), Kaźmierczak (2012) and Kaźmierczak et al. (2015) analysed this issue for Scots pine trees. The slenderness of Norway spruce was investigated by Orzeł and Socha (1999) and Kaźmierczak et al. (2008b), whilst that of the Eu-

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ropean larch was investigated by Kaźmierczak et al. (2011, 2012). In the case of deciduous species, common oak (Rymer-Dudzińska, Tomusiak 2000; Kaźmierczak et al. 2008a, 2009), European beech (Rymer-Dudzińska, Tomusiak 2000) and juvenile silver birch (Korzeniewicz et al. 2016) have been analysed. In turn, Orzeł (2007) studied the slenderness of various species of trees in the Niepołomice Forest (including pine and larch). In terms of alien species, which are not the main components of Polish stands but are also exposed, amongst others, to damage from snow or wind, no studies on slenderness exist thus far in the national literature.

The aim of this study was to (i) analyse the slenderness of trees in black locust stands, taking into account forest habitat type, age class and biosocial position, and (ii) assess the relationship of these characteristics with selected crown parameters.

2. Materials and methods

The research material was obtained from 35 black locust stands growing in western Poland, in the Sława Śląska and Sulechów forest districts (Regional Directorate of the State Forests in Zielona Góra) and Głogów Forest District (RDSF in Wrocław). These stands grew in the habitats most often occupied by black locust – the fresh mixed coniferous forest (BMśw, 18 cases) and the fresh mixed broadleaved forest (LMśw, 17 cases), which were developed on rusty soils. The selected study stands were characterised by a species composition with share of black locust of >7 (only in three cases it was <5). The age of the studied species ranged from 16 to 86 years. Most stands were in the age class II (13 cases) and III (11 cases). Information on the share and age of black locust was taken from the Informatics System of the State Forests database.

In each stand, in a representative location, we established a study plot consisting of at least 100 black locusts occurring in the canopy layer. For every third tree, the total height and crown base height were determined using a Vertex hypsometer and the diameter was measured with a caliper diameter gauge. In addition, each tree was assigned a biosocial position using the Kraft classification. In total, data for 1058 black locusts were collected. Then the slenderness (S) was calculated, which is the ratio of tree height and its diameter. Crown length (CL [m]) and its share in relation to the height of the whole tree, that is, relative crown length (rCL [%]), were calculated based on the measured crown base height and tree height.

As the distribution of the slenderness was not consistent with the normal distribution (Shapiro–Wilk test, W = 0.9801, $p < 0.001$), the Kruskal–Wallis test was used to analyse the differences in slenderness between Kraft classes and between age classes. The Mann–Whitney test was used to assess the impact of forest habitat type and dominant/suppressed stand status. Using the regression and correlation analysis, the relationship between black locust slenderness and crown parameters was established. Statistical analyses were performed with the PAST 3.16 program (Hammar et al. 2001) with a significance level of 0.05.

3. Results

The diameter at breast height (DBH) of tested black locusts ranged from 6.5 to 66.2 cm, with an average of 24.4 cm and a standard deviation of 11.0 cm. The height of these trees varied from 5.6 to 34.9 m, with an average of 20.2 m and a standard deviation of 5.8 m. The values of the slenderness t of the studied black locusts ranged from 0.31 to 1.95, with an average of 0.91, a median equal to 0.89 and a standard deviation of 0.24 (Table 1). The lowest crown base height was 1.4 m, whilst the highest was 20.0 m, with an average of 10.3 m and standard deviation of 3.6 m. Crown length varied from 1.4 to 25.8 m, with an average of 9.9 and

Table 1. Minimum (Min), maximum (Max), mean (M), standard deviation (SD) and coefficient of variability (CV [%]) of slenderness of analysed black locust with regard to biosocial position, age and site type

Characteristics of trees		N	Min	Max	M	SD	CV
Kraft's class	1	161	0.37	1.33	0.78a	0.17	22.1
	2	437	0.33	1.88	0.86b	0.20	23.3
	3	260	0.31	1.64	0.92c	0.22	24.3
	4a	96	0.48	1.89	1.03d	0.25	23.9
	4b	45	0.56	1.81	1.12de	0.29	26.2
	5a	59	0.40	1.95	1.16e	0.28	24.3
Age class	I	36	1.03	1.95	1.39a	0.25	17.8
	II	395	0.51	1.87	0.98b	0.19	19.2
	III	326	0.38	1.84	0.91c	0.21	23.1
	IV	126	0.45	1.29	0.85d	0.17	20.5
	V	175	0.31	1.30	0.68e	0.18	27.1
TSL	BMśw	540	0.4	1.95	0.94a	0.25	26.0
	LMśw	518	0.31	1.84	0.87b	0.23	26.1
Total		1058	0.31	1.95	0.91	0.24	26.4

N – number of trees; TSL – site type (BMśw – fresh mixed coniferous forest, LMśw – fresh mixed broadleaved forest); the same letter by the mean (M) indicates lack of significant differences at p=0.05

a standard deviation of 4.2 m. In the case of the studied black locust, the crown accounted for 10–95% of tree height, occupying on an average almost half the length of the trunk. The coefficient of variability, amounting to 26.4% for slenderness, indicates an average variation in the value of this parameter amongst the studied trees. It is comparable to the variability of height and relative crown length, and almost twice smaller than that in the case of DBH and crown length.

Significant differences were found in the slenderness of trees belonging to different Kraft classes ($p < 0.001$, Table 1). Average slenderness reached the highest values for suppressed trees (1.16 ± 0.28). The lowest slenderness was found for dominant trees (0.78 ± 0.17). The differentiation of slenderness in the Kraft classes was similar. Values of the coefficient of variability ranged from 22.1% to 26.2%. A significant difference in slenderness was also found when comparing the dominant and suppressed stands ($p < 0.001$). Dominated and suppressed trees were characterised by a higher mean slenderness than dominant, co-dominant and subdominant trees (1.09 ± 0.27 vs. 0.86 ± 0.21). However, the coefficient of variability of slenderness was similar and amounted to 24.2% for the dominant individuals and 25.1% for the suppressed ones.

Black locust slenderness also significantly depended on the stand's age class ($p < 0.001$, Table 1). The highest average was found for trees from age class I (1.39 ± 0.25), and the lowest was found for black locusts from the oldest age class V (0.68 ± 0.18). In turn, the greatest variability of slenderness is found in the oldest stands, whilst the lowest is in the youngest ones (a coefficient of variation of 27.1% and 17.8%, respectively).

The average slenderness of black locusts growing in fresh mixed conifer habitat was 0.94 ± 0.25 and was significantly higher ($p < 0.001$, Table 1) than in the case of fresh mixed broadleaved habitat (0.87 ± 0.23). The coefficient of variability of black locust slenderness in the analysed habitat types of forest was very similar (26.0% and 26.1%, respectively).

The crown length and crown relative length are characterised by a significant negative dependence on the slenderness of the studied locust trees (Figure 1). The correlation coefficient for these relationships was −0.345 and −0.263 ($p < 0.001$ in both cases).

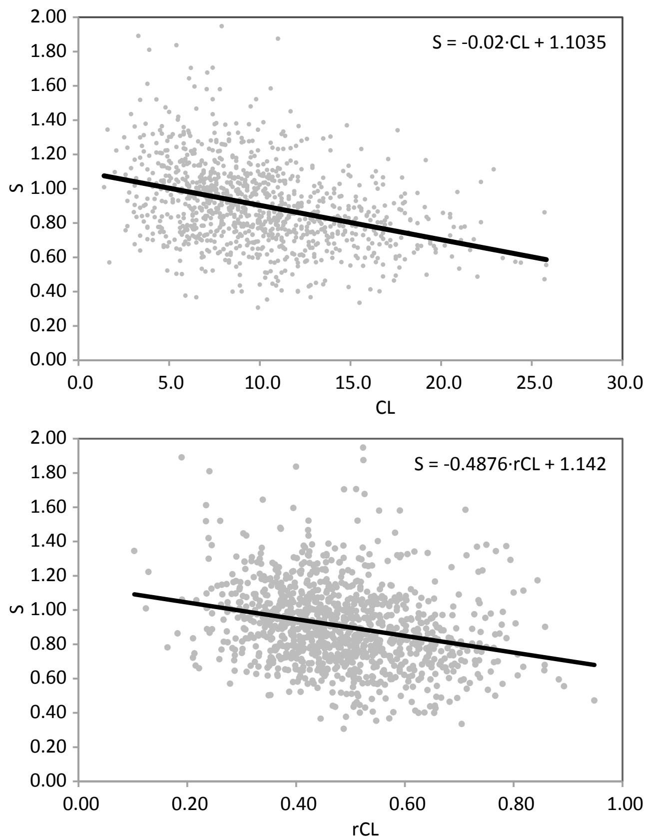

Figure 1. Dependence of slenderness (S) on crown length (CL [m]) and relative crown length (rCL (%))

4. Discussion

So far, research has been conducted in Poland on the slenderness of native tree species representing the largest share of occurrence in forests. The variability of this coefficient was analysed depending on age, habitat and biosocial position, as well as in relationship to the biometric features of the trees and stands. As an introduced species, black locusts have a much smaller area of occurrence and have not yet been the subject of slenderness analysis.

The average value of the slenderness of black locusts found in this study was comparable to the values provided for beech (Rymer-Dudzińska, Tomusiak 2000). A similar average slenderness for the oak tree was also determined by Kaźmierczak et al. (2008a, 2009), whilst Rymer-Dudzińska and Tomusiak (2000) give a much lower values for this species. The result obtained by Korzeniewicz et al. (2016) for birch is significantly higher, but these authors studied juvenile tree stands.

In turn, the variability of slenderness found for black locust is higher than that observed in other species. Rymer-Dudzińska and Tomusiak (2000) had values for oak and beech that were about 8–10 percentage points lower. Also in the case of young birches (Korzeniewicz et al. 2016), the variation in the slenderness of trees was lower than that in the black locust tested. However, Kaźmierczak et al. (2008a) found a similar variability of slenderness for the oak as the one presented in this study.

As observed in other species, we confirmed an influence of tree age on slenderness in the case of black locust. A significant decrease in the value of this indicator with increased age was also found for oak (Rymer-Dudzińska, Tomusiak 2000; Kaźmierczak et al. 2009), beech (Rymer-Dudzińska, Tomusiak 2000), larch (Orzeł 2007; Kaźmierczak et al. 2011, 2012) and pine (Rymer-Dudzińska 1992a, b; Orzeł 2007; Kaźmierczak 2012).

The studies on slenderness conducted to date emphasise an increase in its value as the biosocial position of the tree worsens. Rymer-Dudzińska (1992b), Kaźmierczak (2012) and Kaźmierczak et al. (2015) observed this trend for pine; Kaźmierczak et al. (2011) for larch; and Kaźmierczak et al. (2009) for oak. Also in the case of black locust, suppressed and dominated trees were characterised by a higher value of slenderness than dominant trees from the stand.

Aside from the parameters of the trunk itself, tree slenderness also depends on the characteristics of the crown, which was pointed out, amongst others, by Jelonek et al. (2013), Kaźmierczak et al. (2015), Tomczak et al. (2015) or Korzeniewicz et al. (2016). In the present study, a significant negative correlation was confirmed for black locust slenderness between crown length and relative crown length. However, Rymer-Dudzińska and Tomusiak (2000) did not observe a link between the slenderness of oaks and beeches and relative crown length. Similar results were obtained by Kaźmierczak et al. (2012) for larch. In turn, Korzeniewicz et al. (2016) showed a significant negative relationship between slenderness and crown features. The correlation coefficient with crown length was −0.399 and −0.424 with relative crown length.

Slenderness also depends on the amount of space that the tree has at its disposal to grow in (Kaźmierczak 2012; Kaźmierczak et al. 2012; Korzeniewicz et al. 2016). The greater it is, the higher is the increase in diameter compared to the increase in height, and thus the tree trunks are less slender. The height-to-diameter ratio can be regulated by silviculture treatments, shaping the area available for tree growth by appropriately spacing the plants as well as through the timing and intensity of cleaning and thinning.

5. Conclusions

The black locust is characterised by an average value of slenderness at a level similar to native species of deciduous trees (oak, beech and birch). However, the coefficient of variability of this feature is slightly higher.

Forest habitat type, the age and biosocial position of the trees as well as crown parameters have a significant impact on the slenderness of the black locust. Higher values of the slenderness coefficient are found for trees growing in fresh mixed coniferous habitats, those in lower age classes, those belonging to a dominated stand and those with a shorter crown length.

Conflict of interest

The authors declare the lack of potential conflicts of interest.

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Contribution of the authors

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