2.2. Measurements of Fiber Parameters

Small pieces were extracted from various positions on the strip. The pieces were placed in test tubes and macerated using a mixed solution of equal volumes of glacial acetic acid (98%) (Avantor; VWR International Kft) and hydrogen peroxide (30%) (ES Lab Hungary Ltd.), then heated to 65 °C for 24–28 h in a water bath. We then washed the macerated pieces with distilled water [32]. Afterwards, a small amount of the macerated fibers was placed on glass microscope slides. The fiber and vessel properties were observed using a light microscope equipped with a digital camera (Nikon Eclipse, Nikon, Japan) and ProScan III software (V31XYZE/D, Prior Scientific Instruments Ltd., Wilbraham Road, Fulbourn, Cambridgeshire, CB21 5ET, UK). Separately, from each disc, a total of fifty wood FL (mm) and twenty-five FW (μm), FWT (μm), LD (μm), VL (μm), and VD (μm) measurements were taken.

2.3. Ring Width Measurements

The wood strips were polished using sandpaper to smooth the rough surfaces. The smooth strips were scanned using a scanner (CanonScan LiDE 110, Canon, Japan) [33]. Then, the annual ring widths were measured with ImageJ software (V1.54d, National Institutes of Health, MD, USA).

2.4. Data Analysis

All data were analyzed using R statistical software (V4.3.2 (2023-10-31 ucrt)). At first, the Shapiro–Wilk test was used to check if the data distribution was normal. The test result revealed that no variable follows a normal distribution. Based on that, we used the Kruskal–Wallis nonparametric test to determine the statistical significance instead of AN VA.
nly when the Kruskal–Wallis test revealed significant differences did we use the post hoc test, Dunn pairwise comparison (the Bonferroni method), to identify the differences between groups.

3. Results

Across all counties, wood FL varied between 1.04 and 1.11 mm, while FW, FWT, and LD varied between 15.5 and 18.4 μm, 2.55 and 3.76 μm, and 8.19 and 9.98 μm, respectively. The VL, VW, and RW varied from 118.9 to 126 μm, 191 to 223 μm, and 2.15 to 3.90 mm, respectively (Table 2). The VL and VW dimensions were measured from both early and late wood, resulting in higher standard deviations.

A Kruskal–Wallis test revealed significant differences in FL (kw-squared = 12.4, p = 0.01), FW (kw-squared = 30.21, $p < 0.0001$), FWT (kw-squared = 85.66, $p < 0.0001$), VW (kw-squared = 14.31, p = 0.01), and RW (kw-squared = 195.77, $p < 0.0001$). In contrast, no significant differences were observed for LD (kw-squared = 8.59; p = 0.08) or VL (kw-squared = 3.87, p = 0.42).

The Dunn test (Table 3) showed that only Szabolcs-Szatmár-Bereg had a significantly higher median FL (1.09 mm) than Vas County (1.02 mm). Likewise, there was a significant difference in VW between Bács-Kiskun and Szabolcs-Szatmár-Bereg. The median values of FW (15.93 μm), FWT (2.78 μm), and RW (1.19 mm) were significantly lower in Bács-Kiskun County than in the other counties.

widest VW (227 µm). Similarly, the FW, FWT, and LD parameters were highest in MPGCs, poor growth conditions for mixed species. However, in the case of PGCs, most of the parameters were the lowest compared to those observed in other growth conditions.

There were differences in FL (kw-squared = 25, $p < 0.0001$), FW (kw-squared = 8.76, $p < 0.0001$), FWT (kw-squared = 18.50, $p = 0.0001$), VW (kw-squared = 15.64, $p = 0.0001$), and RW (kw-squared = 56.58, $p = 0.0001$) based on the growth conditions, as shown by the Kruskal–Wallis test. The statistics for LD and VL did not show significant differences (kw-squared = 5.81, $p = 0.05$ and kw-squared = 5.17, $p = 0.08$, respectively). The analysis of the statistics for LD and VL did not significantly vary (kw-squared = 5.81, $p = 0.05$ and kw-squared = 5.17, $p = 0.08$, respectively). The significant differences (Dunn test) between group conditions are shown in Table 5.

Table 4. The descriptive statistics of the fiber and vessel properties of *Robinia pseudoacacia* L. wood grown under GGCs (good growth conditions), PGCs (poor growth conditions), and MPGCs (poor growth conditions (mixed species).

Growth Conditions	Statistic	FL (mm)	FW (µm)	FWT (µm)	LD (µm)	VL (µm)	VW (µm)	RW (mm)
GGC	Mean	1.12	16.9	3.33	8.34	125	227	3.68
	Median	1.11	16.87	3.21	7.98	143.61	202.98	3.34
	Min	0.80	12.32	1.70	5.04	91.92	103.61	1.05
	Max	1.42	22.96	5.20	13.32	228.55	366.73	5.67
	Std	0.139	2.87	0.745	1.97	43.6	87.9	1.25
PGC	Mean	1.06	17.0	3.09	8.93	118	182	2.70
	Median	1.05	16.29	3.05	8.86	137.04	169.94	2.74
	Min	0.81	11.19	1.65	5.09	82.14	96.69	1.43
	Max	1.39	23.98	4.82	13.80	202.76	299.64	3.81
	Std	0.119	2.93	0.582	2.18	45	95.9	0.67
MPGC	Mean	1.04	18.4	3.76	9.14	122	215	3.68
	Median	1.02	18.44	3.72	8.89	142.08	171.71	3.91
	Min	0.95	13.46	2.24	5.06	92.43	141.53	1.36
	Max	1.34	22.47	5.06	13.89	196.24	209.66	6.02
	Std	0.155	2.71	0.757	2.40	42.2	78.9	1.25

Min = minimum; Max = maximum; Std = standard deviation.

Table 5. Post hoc pairwise comparisons between GGCs (good growth conditions), PGCs (poor growth conditions), and MPGCs (poor growth conditions for mixed trees).

Parameter	Comparison	Z-Statistic	Adjusted *p*-Value
FL	GGC vs. PGC	4.36	0.0001
	GGC vs. MPGC	3.60	0.0005
FW	GGC vs. PMGC	−2.90	0.005
	MPGC vs. PGC	2.72	0.009
FWT	GGC vs. MPGC	−262	0.01
	GGC vs. PGC	2.50	0.01
	MPGC vs. PGC	4.06	0.0001
VW	GGC vs. PGC	3.9	0.0001
RW	GGC vs. MPGC	−3.89	0.0001
	GGC vs. PGC	4.02	0.0001
	MPGC vs. PGC	7.43	0.0001

The variability in the annual ring width from pith to bark for each county is shown in Figure 3. The curve shows that Bács-Kiskun County has the narrowest annual rings, while those of Szabolcs-Szatmár-Bereg and Vas Counties show the widest width.

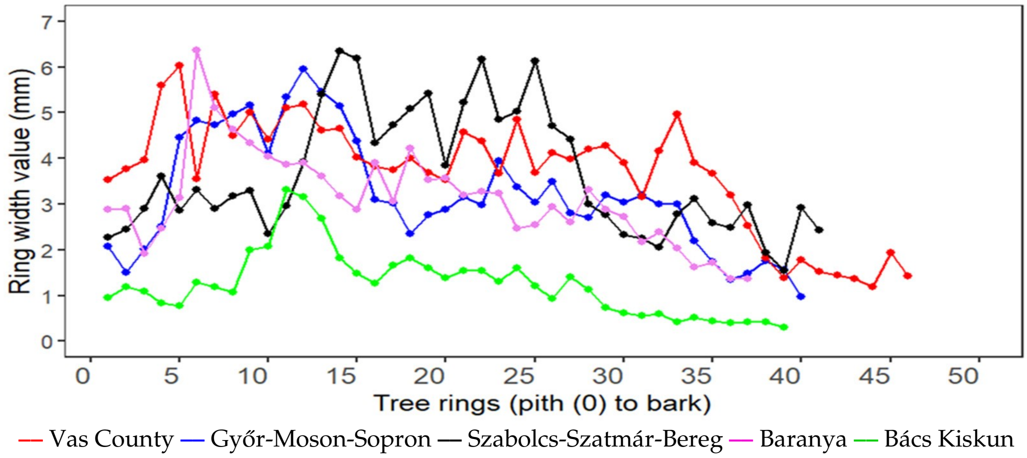

Figure 3. Variability among counties in annual ring width from pith to bark of wood of *Robinia pseudoacacia* L. wood.

Regarding growing conditions, MPGCs (mixed trees) and GGCs (good growth conditions) showed the greatest annual ring widths, respectively. PGCs (poor growth conditions), on the other hand, displayed the narrowest widths (Figure 4).

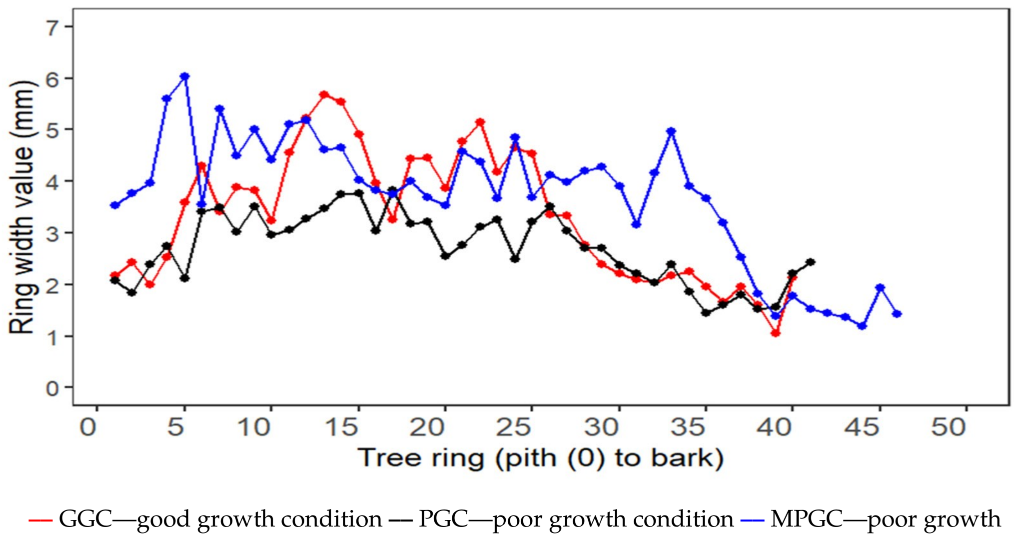

Figure 4. Variability among growth conditions in width of annual rings from pith to bark of *Robinia pseudoacacia* L. wood.

4. Discussion

Robinia pseudoacacia L. trees grow widely around the world, including in Hungary [34]. They have been used for several important purposes [7,35]. In our study, fibers, vessels, and ring width were investigated in several counties and under different growth conditions. These investigated parameters are crucial for the evaluation of wood characteristics [3,25]. Fibers play an important role in determining the mechanical properties of wood, such as strength, flexibility, and durability, which are necessary for applications in construction, furniture production, and tool handles. The characteristics of the vessel influence the porosity and permeability of the wood, which are critical in drying, seasoning, and preservative treatments. In addition, ring width is an indicator of growth rate, which is related to wood density and overall mechanical performance [36].

Regarding the variability between sites, our results indicate that significant differences in FL occurred only between Szabolcs-Szatmár-Bereg and Vas Counties, and similarly between Bács-Kiskun and Szabolcs-Szatmár-Bereg for VW. Significant differences were also observed between several counties for FW, FWT, VW, and RW (Table 3). In contrast, there were no differences for LD or VL in any counties. We found that all counties had almost similar characteristics, except Bács-Kiskun County, which had the lowest values for FW, FWT, and RW and the highest VW, while Szabolcs-Szatmár-Bereg and Vas Counties had the best characteristics.

Previous studies mentioned that there are many factors that cause variations in wood anatomical features between sites. These factors include the type of soil and its corresponding nutrient and moisture availability [37]. For instance, water availability significantly determines wood vessel and fiber sizes specifically in *Robinia pseudoacacia* L. [38]. In dry climates or areas with variable water availability, plants typically develop narrower vessels with thicker walls, which reduces the probability of embolism during drought conditions [39]. Conversely, areas with increased and stable water availability can produce larger vessels and fiber diameters [40,41]. Also, under favorable growing conditions, the ring widths increase [42–45]. In addition, genetic adaptations likely interact with environmental pressures to alter traits such as fiber wall thickness, vessel diameter, and ring width in response to specific site conditions [46]. Significant variations in fiber properties and growth rings of *Robinia pseudoacacia* L. wood were observed within a single growth ring [15] and within the radial direction (between early and late wood) [11,47]. Furthermore, regarding tree ages, old trees had longer fiber lengths than the youngest trees [48,49]. In comparison to our findings, the fiber length ranged between 1.04 and 1.11 mm, which is higher than values given by [48] and lower than values reported by [49] for trees aged 60 and 71 years.

In terms of growth conditions, GGCs—good growth conditions—showed the greatest fiber, vessel, and ring widths compared to PGCs and MPGCs—poor and mixed growth conditions. Interestingly, the MPGCs had better parameters than PGCs (poor growth conditions), which indicated that the mixed trees have better properties because of different root structures and canopies, allowing for more efficient use of sunlight, water, and nutrients. These reduce the competition and promote better growth conditions, which can enhance fiber properties and growth rate. Previous research has indicated that high-quality sites yield high-quality timber from *Robinia pseudoacacia* L. [7]. ur findings confirmed this due to the long fibers and wide ring widths.

The ring width patterns in our study resemble the curves identified by [11,13,28]. The widths of the annual rings decreased from pith to bark, which is attributed to the age of the cambium (ring width diminished as age increased). ther species, such as *Alnus glutinosa*, also display a comparable pattern [50].

5. Conclusions

Across all counties, we observed significant differences in FL only between Szabolcs-Szatmár-Bereg and Vas Counties, as well as between Bács-Kiskun and Szabolcs-Szatmár-Bereg, in terms of VW. In contrast, there were notable variations in FW, FWT, and RW between many counties. But there were no significant differences in LD and VL. Furthermore, we found that GGCs and MPGCs produce the best fiber properties and the widest ring widths. Future studies will focus on chemical, physical, and mechanical properties to provide additional information regarding these areas of study and growth conditions.