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Bending test results of plantation poplar clones

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Keywords: cultivated poplar; modulus of rupture; modulus of elasticity; juvenile wood; mature wood; trunk height

ABSTRACT

Since bending strength is one of the most important properties of wood for industrial uses, eight poplar clones were tested for this property. The selected trunks originated from the same location in Hungary and in all cases the samples were taken from the lower part of the trunks. There was one exception, where samples were taken from four different heights of the trunk, to determine the variation of properties in this respect. In all cases, juvenile wood and mature wood were separated to allow a more detailed analysis and comparison. At the same time, comparisons were also made with data from the literature, using the results of the parent species. The clones showed better results in both bending strength and modulus of elasticity compared to the parent species. There were some promising clones with outstanding properties, excepting one species that showed significantly poorer results because it lagged behind in growth. In addition, it was found that trunk height correlates with the mechanical properties of the mature wood, being stable or slightly increased along the height of the trunk.

INTRODUCTION

Plantation wood management is getting even more attention nowadays. One of the aims of these plantations is to provide timber with high quality and volume, to satisfy various industrial demands with short cutting rotations. The use of plantation wood management can reduce the felling of natural forests and meet the increased demand for wood. In our study, we used different poplar clones, since poplars are the most suitable for plantation wood production (Komán 2012). Poplar breeding and crossbreeding of different poplar species have been studied for a long time. According to Keresztesi (1978), poplar clones have been produced since the 1930s. The aim of crossbreeding is to modify one or more characteristics of the species, e.g. wood quality and annual growth, insect and fungal resistance, strength, etc, in a positive way. Bending stress is one of the most common loads on the elements of wood structures, and static bending strength, (or modulus of rupture, *MoR*), is the most important strength characteristic (Molnár 1999). At the same time, the bending modulus of elasticity (*MoE*) of our samples, also important property, was investigated. Elasticity is the property of solid materials to return to their original state after external forces changed their shape or dimensions when the load is removed. Elasticity is an important characteristic in the mechanical processing of wood, e.g. peeling, splitting and bending. The modulus of elasticity expresses the stress required for a specific deformation of the material (Molnár 1999).
This study deals with the qualitative analysis of the wood of some plantation poplar clones in Hungary. We introduce the results of *MoR* and *MoE* tests including the variation of strength along the length of the trunk and a comparison of strength values for mature and juvenile wood.

EXPERIMENTAL METHODS

Eight poplar clones were selected based on their age, to have a relatively homogeneous sample set. All trees were 26-32 years old and originated from the same site, Sárvár-Bajti, Hungary (Fig. 1; Table 1).

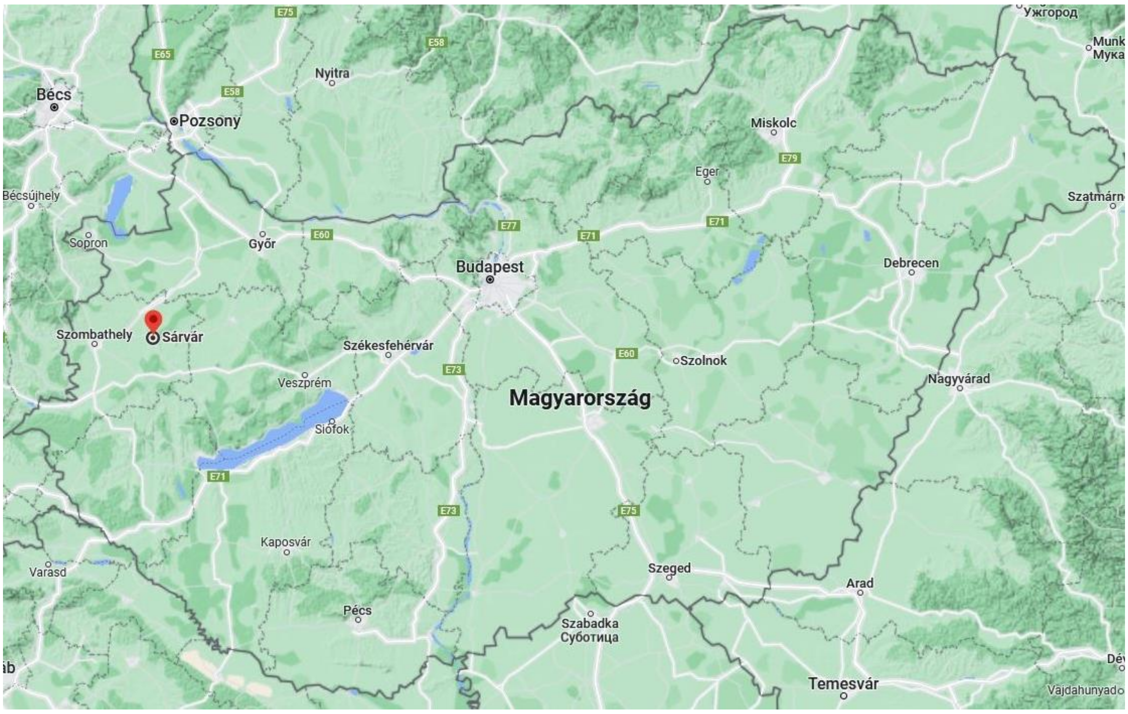

Figure 1: Topographic map of Hungary, with the selection of area Sárvár-Bajti (source: Google 2022)

Table 1: Basic data of the studied poplar clones

Clone name	Group	Sample log position above ground [m]
Durvakérgű	*Populus deltoides*	1-2
I-214	*Populus × euramericana*	1-2
Koltay	*Populus × euramericana*	1-2; 5-6; 10-11; 17-19
Kornik-21	*Populus maximowiczii × Populus × berolinensis*	1-2
Unal	*Populus × interamericana*	0-1
Pannónia	*Populus × euramericana*	1-2
Raspalje	*Populus × interamericana*	0-1
Villafranca	*Populus alba*	2-3

The euramerican poplars (*Populus × euramericana* (Dode) Guinier) are spontaneous and artificial hybrids of *P. deltoides* Marsh. and *P. nigra* L. interamerican poplars (*Populus × interamericana* Brockh.) are hybrids of *P. trichocarpa* and *P. deltoides* (Molnár and Farkas 2016). The sample logs 1-metre-long were taken from the lower part of the tree trunks between 0 and 3 metres, with the exception of Koltay (see Table 1). For Koltay, four parts of the trunk from different heights were selected (heights of 1-2, 5-6, 10-11, 17-19 metres above ground) and were used in the study, specified as Koltay #2, #6, #11, #18-19. These sections were treated separately to investigate the differences in the properties along the height of the trunk. Specimens from section Koltay #18-19 were treated together due to their small diameter, i.e. the low number of specimens. After drying, bending specimens were prepared solely from timbers containing the pith, with 20 x 20 mm cross-section and a length of 300 mm. The bending test specimens was marked to precisely define the position of the specimens in the timber (Fig. 2). As an example, in Fig. 2, the specimen number D11/3-21 means that the third plank (middle plank) of the 11 m high trunk section of tree species

D was used. The letter D in the tests stands for Koltay. The minus sign indicates the left part of the plank and No. 21 indicates the first specimen of lath No. 2. After specimen production they were conditioned at 20 °C and 65% relative humidity until they reached a constant mass. The three-point bending test method was used according to standard ISO 13061-3:2014, with a support span of 240 mm, the distance between the centres of the rollers. The load was applied at a rate of 8 mm/min. During the bending tests, the tangential sides of the specimens were placed horizontally.

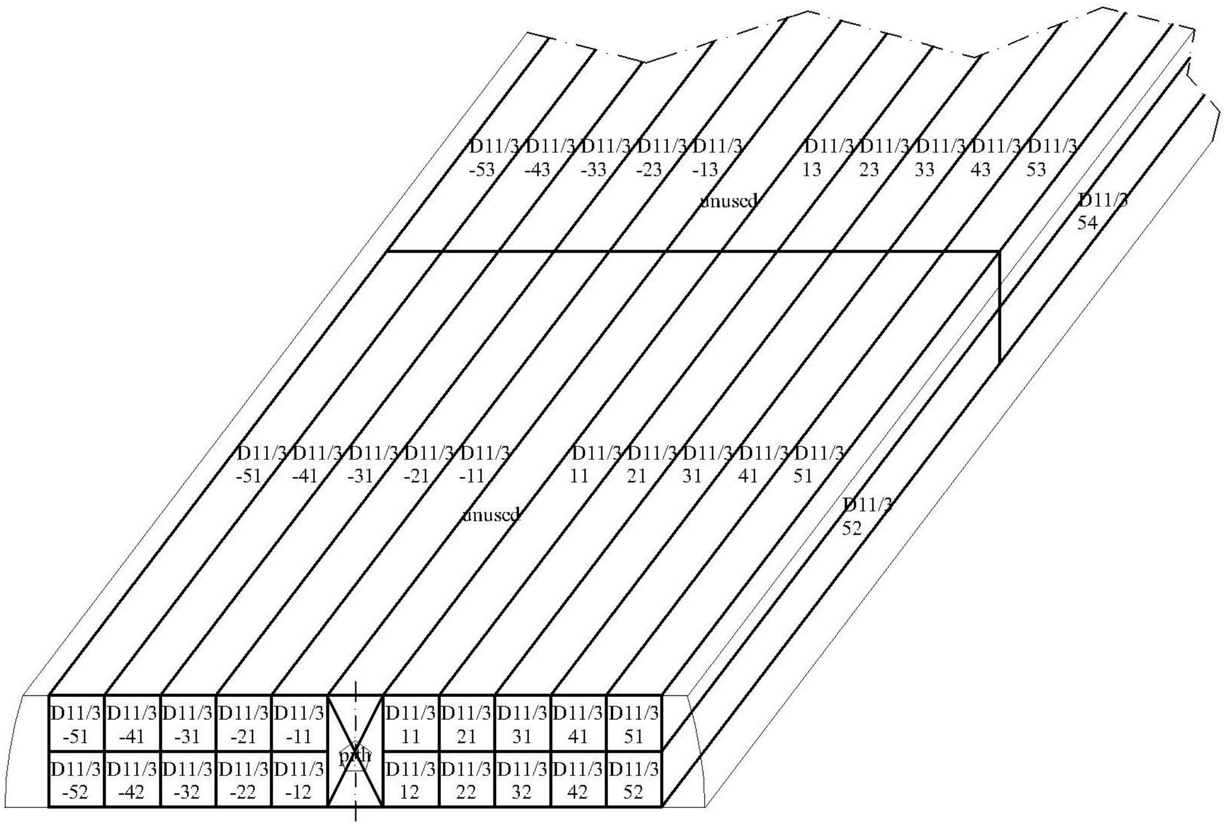

Figure 2: Marking of the specimens. The first specimens can be found on the left and right of pith

Both *MoR* and *MoE* were automatically calculated by the Instron 4208 universal material testing machine (Instron Corporation, USA) according to Eq. 1 and Eq. 2, respectively (ISO 13061-3:2014, ISO 13061-4:2014).

$$\sigma_{b,W} = \frac{3P_{max}l}{2bh^2} MoR = \frac{3P_{max}l}{2bh^2} \quad (1)$$

$$MoE = \frac{Pl^3}{4bh^3 f} \quad (2)$$

where P_{max} [N] is the maximum load, l [mm] is the support span, b [mm] is the specimen width and h [mm] is the specimen height. P [N] is the difference between 40% and 10% of the maximum load, f [mm] is the deflection value associated with P.
Following the bending tests, the moisture contents (*MC*) of the specimens were determined using the drying test method according to standard ISO 13061-1:2014. In order to make our results comparable both with each other and with the literature values, the values of *MoR* and *MoE* were converted to a *MC* of 12% using the standardised correction formulae ($MoR_{12\%}$ and $MoE_{12\%}$ according to ISO 13061-3:2014, ISO 13061-4:2014). One-way ANOVA Fisher LSD test was used to compare selected data. Differences were marked as significant at $p < 0.05$.

RESULTS AND DISCUSSION

After processing the measurements and performing the necessary data corrections, the results of juvenile and mature wood specimens were separated. The separation was based on the fact that juvenile wood has less strength than mature wood. The determination of juvenile wood by this method does not give an accurate result per tree ring. In most cases, the first specimens on the left and on the right side of the pith showed lower *MoR* values. Therefore, these specimens were ranked as juvenile wood. Fig. 3a shows the variation of *MoR* of Unal along the cross-section of the timber. Specimens A1/2-1 and A1/21 show significantly lower values, which is the result of juvenile wood (see also Fig. 2). In Fig. 3b the values of *MoE* of the same specimens are plotted as on Fig. 3a, but in this case the evolution of *MoE* can be seen along the radial direction, starting from the pith. An increasing trend of values can be observed further away from the pith, which is consistent with the literature (Molnár 1999).
For clones where the second specimen also showed a low *MoR*, the boundary between juvenile wood and mature wood was drawn between the second and the third specimen, even if the second one may include partially mature wood. This could only occur in clones with thick growth rings. Such results were obtained with the wood of I-214. For I-214, an increase in *MoR* in the radial direction was also observed, but to a lesser extent.

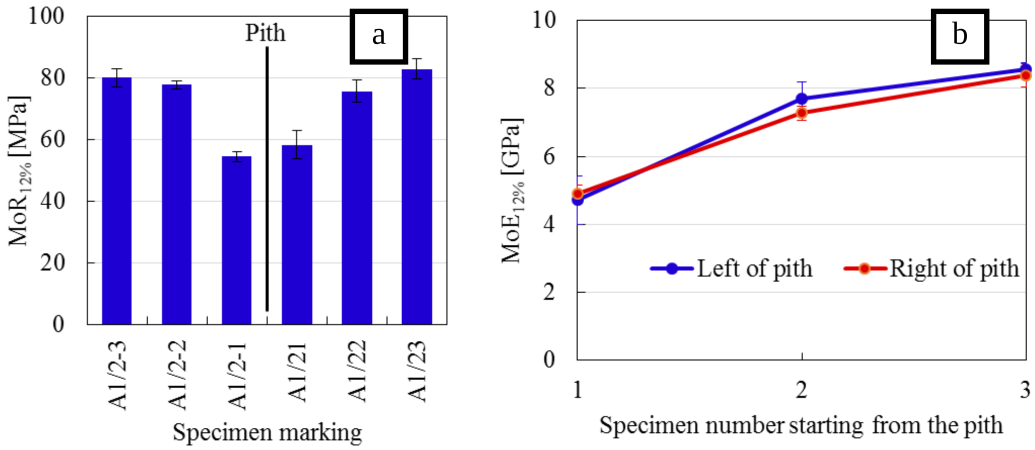

Figure 3: Average bending strength ($MoR_{12\%}$) values of Unal along the diameter of the trunk (a) and its modulus of elasticity ($MoE_{12\%}$) values starting from the pith (b)

Where juvenile and mature wood could not be distinguished based on *MoR* and *MoE*, or where there was little difference between them, the first specimens relative to the pith were used as juvenile wood. For Villafranca, this forced selection of the juvenile wood - mature wood boundary was done only for comparability, although the results of *MoR* show that the juvenile wood may have a different extent.
The average *MoR* of clones for both mature and juvenile wood are presented in Fig. 4. Considering their relatively small deviance, our results and their division into mature and juvenile wood are good. According to the study of Demjén et al. (2020), the boundary between juvenile wood and mature wood of these poplar clones can be drawn at about 16-17 years. There are two exceptions regarding the boundary: it is at years 24-25 for Koltay and at years 13-14 for Unal. Since these results are based on the fiber length analysis of each annual ring, they are more exact compared to the results of our study. Our test specimens were prepared continuously from the pith outwards, so the first one should always have significantly lower values than the ones further out, regardless of the boundary between juvenile wood - mature wood. The second specimen is likely to contain this boundary annual ring, which is determined on a somewhat arbitrary basis. Therefore, the proportion of mature wood is sometimes higher and sometimes lower in this specimen. At the same time, there is not as great a difference between the properties of juvenile wood and mature wood as there would be compared a specimen of juvenile wood close to the pith with a specimen of mature wood close to the sapwood. In conclusion, it is important to emphasise that we have defined the boundary line in terms of distance from the pith, not in terms of the number of annual rings. This means that the significantly different tree ring widths may cause discrepancies between the results of the two types of study.

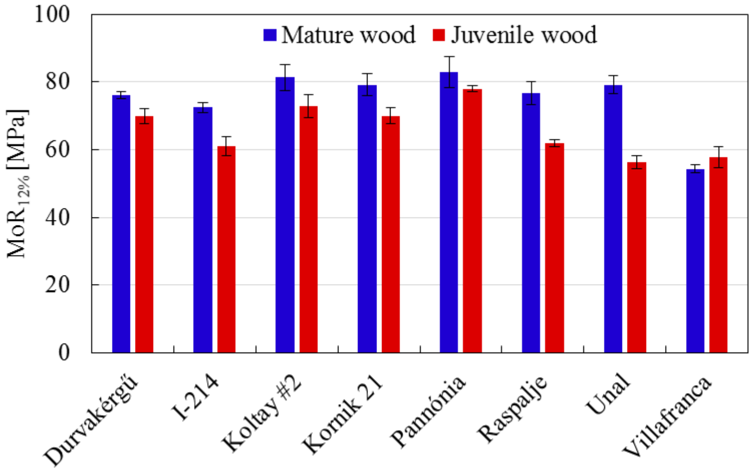

Figure 4: Average bending strength ($MoR_{12\%}$) of both mature wood and juvenile wood of the clones

The results were evaluated using the values of the literature of the parent species. The comparisons were made as follows: Durvakérgű, Raspalje and Unal were compared with *Populus deltoides*; I-214, Koltay, Kornik-21 and Pannónia were compared with *Populus nigra*; Villafranca was compared with *Populus alba* (Molnár and Farkas 2016, Köbölkuti et al. 2019) in Table 2. The genetic study of these clones show the same results regarding their parent species (Köbölkuti et al. 2019). Based on the literature, the average *MoR* of the parent species are as follows: 65.0 MPa for *P. nigra*, 67.5 MPa for *P. alba* and 60.1 MPa for *P. deltoides* (Qibin Yu et al. 2008, Molnár and Farkas 2016, Meier 2022).

Table 2: Differences in both bending strength (MoR) and modulus of elasticity (MoE) of these poplar clones compared to the parent species

	MoR		*MoE*	
	Mature wood compared to literature	**Juvenile wood compared to literature**	**Mature wood compared to literature**	**Juvenile wood compared to literature**
Durvakérgű	28%	-8%	19%	-7%
I-214	13%	-16%	-3%	-14%
Koltay #2	26%	-10%	4%	-3%
Kornik-21	23%	-11%	3%	-5%
Pannónia	29%	-6%	17%	-10%
Raspalje	29%	-19%	22%	-25%
Unal	33%	-29%	13%	-40%
Villafranca	-18%	6%	-29%	7%

Table 2 shows that significantly higher *MoR* results were obtained compared to the values of parent species. This may be partly due to a secondary impact of breeding (quality-improvement) and partly due to the good site conditions. The only exception is the Villafranca, which is a fast-growing clone with good quality potential according to the literature (Molnár and Farkas 2016), but in our case, probably due to the growing site or the dominance of the surrounding tree species, this could not be confirmed. It is also likely that due to the narrow annual rings of the Villafranca, there was already plenty of mature wood already in the first of specimens close to the pith (Fig. 2), which may confused our evaluation.

It is very difficult to separate juvenile wood from mature wood under industrial conditions, and not using juvenile wood for production - which is often present in high proportions - would result in serious financial and environmental losses. Thus, clones which have similar properties for their juvenile wood and mature wood need to be developed for industry. This requirement is mainly fulfilled by the Durvakérgű and

Pannónia, but the Koltay also gave promising results. The two best clones showed a difference of only 6-10% between these two parts for both *MoR* and *MoE*. Considering the bottom part of the Koltay, similar differences were obtained, in addition to the fact that all three clones had particularly good results, mature wood average *MoR*: 80 MPa and *MoE* 8.7 GPa. In addition, the growth volume of these three clones did not lag behind the other clones, so overall they performed very well.

The averages of *MoR*s of Koltay are in Fig. 5 for better visibility of the evolution of *MoR* along the trunk height. The mature wood of Koltay had higher values for all trunk sections compared to the literature value, with an average of 15.6 MPa. Along the trunk height, the *MoR* of the mature wood was constant from the ground to the middle of the trunk, and then showed a slight increase towards the canopy. This is in agreement with the literature. The juvenile wood showed more variability. For Koltay #2, relatively high value was obtained, not far behind the mature wood (-10%). For both Koltay #6 and Koltay #11, *MoR* of juvenile wood was well below the mature wood (averagely -31%). For Koltay #18-19 a mature wood - juvenile wood boundary has been drawn only out of necessity, because it was not possible to establish a clear distinction between these two parts of wood, similar to Villafranca. Even if this boundary was most likely not relevant, the juvenile wood has very high *MoR* values in the light of the results obtained so far.

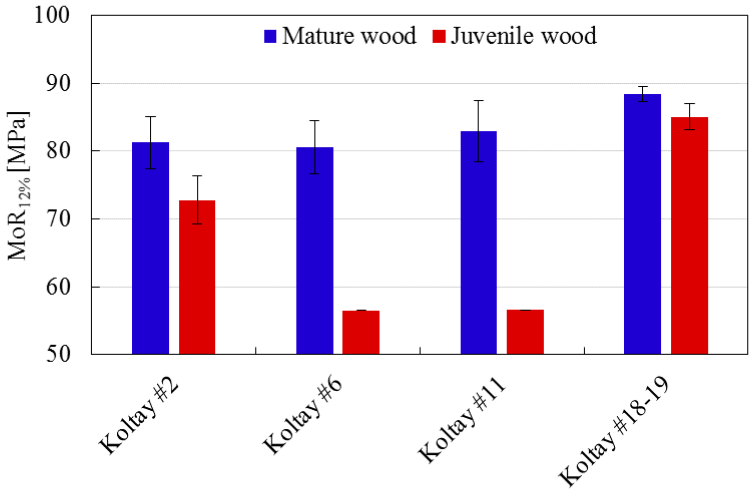

Figure 5: Variations of bending strength ($MoR_{12\%}$) along the trunk of the Koltay

For the evaluation of *MoE*, the literature values of the parent species of the clones were used again. The average *MoE* of the parent species are 8.0 GPa for *P. nigra*, 8.9 GPa for *P. alba* and 7.1 GPa for *P. deltoides* (Qibin Yu et al. 2008, Molnár and Farkas 2016, Meier 2022). The average *MoE* of clones for both mature and juvenile wood can be seen in Fig. 6, while the differences to the literature in Table 2. Comparing Fig. 4, Fig. 5 and Fig. 6 it can be concluded that the values of *MoE* change clone by clone relatively similarly to the results of *MoR*. The reasons of these differences must be the same as for *MoR*. However, the results of *MoE* are much closer to the literature averages of the parent species. Values from Table 2 show significant differences compared to the literature, except I-214, Koltay #2 and Kornik-21. Although literature data represent an average of several studies, it is unfortunately difficult to make accurate comparisons. We do not know the important details, such as the growing area, or the age, the circumstances of growth, and the location of the specimens inside the tree, etc.

Another way of comparison is with specific literature data on I-214, Pannónia and Villafranca poplar clones (Molnár and Farkas 2016). The *MoR*s of the mature wood of the clones we studied are 25%, 23% and -16% higher, respectively, while the differences in *MoE* are 45%, 44% and 11%. Considering that the Villafranca lagged behind in growth, its test results are probably not representative of those successfully grown in many other areas, so it will be omitted from the following analysis. The results for I-214 and Pannónia were significantly higher than the values of literature used for comparison. This implies that the literature studies probably included all parts of the tree (juvenile wood, mature wood and sapwood) or were carried out on wood so young that mature wood could not have even developed. Of course, differing test conditions may also occur differences in results. The needs of these two clones and the characteristics of their growing site were particularly well matched, and the weather conditions in the growing years were also well suited to their requirements. Another analytical option is to compare our samples only with the literature value of the most common poplar in Hungary, I-214, for full comparability. The results of our sample were compared with the literature value of I-214 (58.0 MPa and 5.33 GPa; Molnár and Farkas 2016) using ANOVA. We found statistically significant similarity for *MoR* for I-214 juvenile, Koltay #6 juvenile, Koltay #11 juvenile, Raspalje juvenile, Unal juvenile, Villafranca juvenile and Villafranca mature wood, and for *MoE* for Unal juvenile and Villafranca mature wood. In the latter three cases there were only slight similarities, and the results of Villafranca are not conclusive. This means that even if there is a higher similarity, it is with the juvenile part of the samples tested (i.e. weaker characteristics). In other words, the clones studied typically have significantly better *MoR* and *MoE* than the poplars in use today.

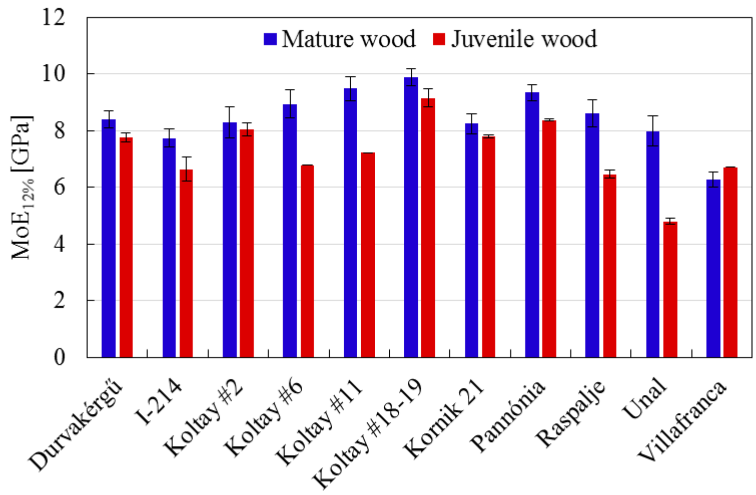

Figure 6: Average bending modulus of elasticity ($MoE_{12\%}$) of both mature and juvenile wood of the clones

In the future of this study, we believe that by comparing the presented results with specific genetic patterns of these clones, correlations could be established. By identifying the gene sequences responsible for the expression of certain wood properties, a marker-based selection could be used to significantly shorten the breeding process of poplars for timber-purposes.

CONCLUSIONS

The 3-point bending test of 7 poplar clones (Durvakérgű, I-214, Koltay, Kornik-21, Unal, Pannónia and Raspalje) showed higher bending strength compared to the literature values of their parent species. The results for juvenile wood were close to or not far below the mature wood. The only exception was Villafranca, where it was not possible to clearly distinguish mature wood and juvenile wood and the results were much poorer than any literature results. This could be due to the poor growth of the tree. The development of bending strength along the trunk from bottom towards the canopy of Koltay was tested. The bending strength of the mature wood slightly increased towards the canopy, in agreement with the literature. The modulus of elasticity behaved mostly similar to the values of bending strength for the eight clones. The two most promising clones in terms of homogeneity of bending strength and modulus of elasticity values for mature and juvenile wood were Durvakérgű and Pannónia; however, Koltay is also a very promising cultivar regarding its growth and its mechanical properties. Their mature wood has a bending strength of 80 MPa and modulus of elasticity of 8.7 GPa, which can be considered as very good results for the poplar species with relatively low density.

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REFERENCES

Demjén, A., Komán, Sz., Németh, R., Schantl, I., Benke, A., Borovics, A., Cseke, K., Köbölkuti, Z.A. and Báder, M. (2020) Nyárfa klónok juvenilis faanyagának meghatározása rosthosszúság alapján. In: *Alföldi Erdőkért Egyesület Kutatói Nap*, Eds. Csiha, I. and Csiha, S. Alföldi Erdőkért Egyesület, Lakitelek, pp. 28-33. ISBN 978-615-80594-7-3.

Google (2022) Topographic map of Hungary, Sárvár-Bajti selected. <https://www.google.hu/maps/dir//47.2575126,16.9792176/@47.1796551,18.1856296,7.83z/data=!4m2!4m1!3e0!5m1!1e4> Accessed: 30.06.2022.

ISO 13061-1 (2014) *Physical and mechanical properties of wood - Test methods for small clear wood specimens - Part 1: Determination of moisture content for physical and mechanical tests*. International Organization for Standardization, Geneva, Svájc.

ISO 13061-3 (2014) *Physical and mechanical properties of wood — Test methods for small clear wood specimens - Part 3: Determination of ultimate strength in static bending*. International Organization for Standardization, Geneva, Svájc.

ISO 13061-4 (2014) *Physical and mechanical properties of wood — Test methods for small clear wood specimens - Part 4: Determination of modulus of elasticity in static bending*. International Organization for Standardization, Geneva, Svájc.

Keresztesi, B. (1978) *A nyárak és füzek termesztése*. Mezőgazdasági Kiadó, Budapest, Hungary.

Komán, Sz. (2012) *Nemesnyár-fajták korszerű ipari és energetikai hasznosítását befolyásoló faanatómiai és fizikai jellemzők*. Doktori diszertáció, Nyugat-Magyarországi Egyetem.

Köbölkuti, Z.A., Cseke, K., Benke, A., Báder, M., Borovics, A., and Németh, R. (2019) Allelic variation in candidate genes associated with wood properties of cultivated poplars (*Populus*). *Biologica Futura* **70**: 1-9. DOI: 10.1556/019.70.2019.32

Meier, E. (2022) *The Wood Database*. <https://www.wood-database.com> Accessed: 30.06.2022.

Molnár, S. (1999) *Faanyagismeret*. Mezőgazdasági Szaktudás Kiadó, Budapest, Hungary.

Molnár, S. and Farkas, P. (2016) Nemes nyár (euramerikai nyárak) – *Populus × euramericana*. In: *Földünk ipari fái*, Eds. Molnár, S., Farkas, P., Börcsök, Z., Zoltán, Gy., Photog. Richter, H.G. and Szeles, P. ERFARET Nonprofit Kft, Sopron, pp. 95–99. ISBN 978-963-12-5239-2.

Qibin Yu, S.Y., Pliura, Z.A., Mackay, J., Bousquet, J. and Perinet, P. (2008) Variation in mechanical properties of selected young poplar hybrid crosses. *Forest Science* **54**(3): 255-259.