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Mechanical Properties of Small Clear Wood Specimens of *Pinus patula* Planted in Malawi

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Pinus patula is one of the major exotic species grown in Malawi mainly for saw-timber production. It is native to Mexico. Little has been reported about the mechanical properties of the wood. The objective of this study was to investigate the mechanical properties of *Pinus patula* in more detail, in order to provide a basis for utilizing this resource. The mechanical properties of small clear wood specimens of *Pinus patula* were evaluated using 40 cm logs from 1, 3, 5, 7 and 9 m above the ground. Small clear wood specimens were selected and subjected to a bending test in accordance with Japan Industrial Standards (JIS) air-dry conditions. The growth rate did not affect the mechanical properties measured. There were significant correlations at 1% level between air-dry density and Modulus Of Elasticity (MOE) ($R = 0.85$) and between air-dry density and Modulus Of Rupture (MOR) ($R = 0.83$). There was also a significant correlation between MOE and MOR at 1% level ($R = 0.90$). At about 12% moisture content, the tested five *Pinus patula* families have average MOR and MOE of 105.17 MPa and 10.93 GPa, respectively.

Keywords: *Pinus patula*; Modulus of Elasticity; Modulus of Rupture; Malawi; Air-Dry Density; Wood

Introduction

In Malawi, high demand for wood coupled with high deforestation rates has led to the increase in the adoption of exotic trees and introduction of plantation forestry. Although wood is naturally variable, fast grown trees produce wood, which may be significantly different in properties, compared with wood from slow grown trees. Furthermore, for trees grown as exotic, the wood produced may have different properties from wood of the same species in the original environment.

Pinus patula is one of the major exotic species grown in Malawi. It is planted about 80% of Malawi's 74,000 ha of softwood plantation. It is native to Mexico. Tree height of *Pinus patula* ranges from 30 m to 35 m and the diameter at breast height ranges from 50 cm to 90 cm (Stanger, 2003). Under favorable conditions, it may attain a height of 15 m after 8 years and 35 m after 30 years. The species are mainly used for saw-timber. Despite their wide use for structural purposes among other uses, no detailed mechanical properties research has been done to determine the strength of the species under Malawi growth conditions. This is because, in Malawi, just like many other species, research on *Pinus patula* has concentrated on the height growth, volume and form. Against this background, a study on the wood properties of *Pinus patula* was carried out using the seed orchard established by the Forest Research Institute of Malawi (FRIM).

The broad objective of the study was to find out and analyze genetic factors on wood properties of *Pinus patula* in Malawi, to recommend the possibility of the improvement of wood quality and to contribute to sustainable management for plantation forests. Specifically, the general study looked at the extent of family and within family wood property variation of *Pinus patula* in order to find out if selection for wood property inclusion in tree breeding is possible. Kamala et al. (2013) looked at the growth characteristics and wood density because of their large influence on many other wood properties. A total of 15 trees from five families were studied. The growth rate for the five families was significantly different. The present study looks at the mechanical properties namely: Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and wood density. Modulus of rupture and modulus of elasticity are important properties for the use of wood as a structural material. MOR is an indication of the bending strength of a board or structural member, and MOE is an indication of the stiffness. When analyzed among trees and within a tree, mechanical property variation tends to follow similar patterns to those observed in wood density. The determination of MOR and MOE together with density is important to better understand their relationships. The relationships among these properties are species specific, stronger in others but weaker in other species. These relationships allow prediction of effect of selecting one property to breed on the other properties. The relationships are also important in machine stress grading.

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The main objective of this research was to look at the mechanical properties of *Pinus patula* in more detail, in order to provide a basis for utilizing this resource in Malawi. In general, this research seeks to provide reliable data for comparing the mechanical properties of *Pinus patula* grown in Malawi with various species. It also provides data, which may be used to analyze the influence on the mechanical properties of such factors as: distance of timber from the pith of the tree, height of timber in the tree, etc. The study further seeks to provide data, which can be used to classify the strength of *Pinus patula* grown in Malawi for grading purposes.

Materials and Methods

Sampling

The samples used in this research were collected from Dedza in Central Malawi (altitude 1737 meters above sea level). The orchard used in this study was planted with forty-two families without routine silvicultural treatments. Families were randomized within each block. The total number of treatments (families) was 42 in 4 replications. Plot size was 7 × 7 trees at a spacing of 9 × 9 feet (2.74 × 2.74 m). The plantation was 30 years old, but for unknown reasons, some of the trees studied were less than 30 years old.

This study looked at five of the 42 families. One tree per family was used representing a total of five trees with representative growth rates. **Table 1** shows the growth information of the five trees in terms of height, Diameter at Breast Height (DBH) and height at 15 cm diameter. The 15 cm diameter is the minimum merchantable diameter in Malawi. The mechanical properties of *Pinus patula* were evaluated using 40 cm logs from 1, 3, 5, 7 and 9 m above the ground. The logs were further cut into 20 mm × 20 mm × 32 cm specimens. The total number of small clear wood specimens was 86. A lot of care was taken to avoid any defect on the specimens. The specimens were selected and subjected to a bending test in accordance with Japanese Industrial Standards (JIS) air-dry conditions. The moisture content for the specimens was about 12%.

Data Analysis

In order to find out the relationship between the mechanical properties, scatter plots with regression line were produced using Minitab statistical software. The relationship was compared at individual tree and family levels. Analysis of variance was run at family and height above the ground levels for Modulus Of Elasticity (MOE), Modulus Of Rupture (MOR) and air-dry density. This was done in order to find out the extent of variation of the properties among the families.

Table 1.
Volume growth information of five trees (five families) of *Pinus patula* at 30 years old.

Family	DBH (cm)	Height (m)	Height at 15 cm diameter (m)
1	30.0	26.0	18.9
2	34.0	27.7	20.2
3	28.0	23.2	16.7
4	31.0	23.5	19.3
5	27.0	23	15.1

Mechanical Properties of Juvenile Wood versus Mature Wood

Data from a previous research (Kamala et al., unpubl. data) on tracheid length for the same sample trees was used to determine juvenile and mature wood boundary. The study of the tracheid length of the five families showed that there was a rapid increase of tracheid length up to ring number 10 and then a stable pattern towards the bark. Therefore, ring number 10 was assumed to be the boundary between the juvenile wood and mature wood for *Pinus patula* grown in Malawi. The data for the juvenile wood and mature wood mechanical properties was subjected to an analysis of variance to find out if the variation of the mechanical properties was significant or not.

Grade Yield

Grading standard of physical and mechanical properties of timbers from Southeast Asia and Pacific regions by Forestry and Forest Products Research Institute (FFPRI) in Japan and the South African national standards were used to check the grade yield using MOE and MOR separately. **Tables 2** and **3** show the grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions by Forestry and Forest Products Research Institute and the grades according to the characteristic stress for South African Pine respectively.

Results and Discussion

Mechanical Properties

Table 4 shows the average mechanical properties for the five trees from five families. The average air-dry density was uniform among the families with family five registering a slight increase at 0.54 g·cm^{-3}. MOE was also comparatively uniform with family five producing the highest MOE and MOR of 11.90 GPa and 111.47 MPa respectively.

Table 2.
Grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions by Forestry and Forest Products Research Institute (FFPRI) (1975).

Grade	MOE (GPa)	MOR (MPa)
I	- 7.35	- 58.8
II	7.45 - 10.3	58.9 - 82.4
III	10.4 - 13.2	82.5 - 107
IV	13.3 - 16.2	107 - 130.4
V	16.3 -	131 -

Table 3.
Mechanical grades according to the characteristic stress for South African Pine (SANS 10163, 2003).

Grade	MOE (GPa)
xxx	7.79
Five	9.59
Seven	11.99
Ten	18

Table 4.
Average mechanical properties for the five families (Total five trees).

Family	Air dry density ($g \cdot cm^{-3}$)	MOE (GPa)	MOR (MPa)
1	0.50 (0.11)*	11 (3.42)*	101.34 (35.83)*
2	0.50 (0.07)*	11.54 (3.28)*	107.92 (28.25)*
3	0.50 (0.12)*	10.84 (3.23)*	110.77 (34.15)*
4	0.51 (0.11)*	10.47 (3.51)*	105.97 (32.95)*
5	0.54 (0.09)*	11.90 (3.59)*	111.47 (39.91)*

Note: *Standard deviation.

Table 5 shows the summarized mechanical properties among the five trees from fives families. The maximum MOE and MOR were 16.72 GPa and 185.19 MPa respectively. The maximum air-dry density was 0.69 $g \cdot cm^{-3}$. At about 12% moisture content, the tested five *Pinus patula* families have average MOR and MOE of 105.17 MPa and 10.93 GPa, respectively.

Tables 6 and **7** show the analysis of variance (Anova) results for MOE and MOR respectively. The Anova results show that stem height had no significant effect on the mechanical properties. The results also show that despite the differences in growth rate among the five trees from the five families, the mechanical properties were not significantly different among them. This shows that growth rate had no effect on the mechanical properties of the species.

This result is comparable to the results by Anon (1947) for South African *Pinus patula*. He also reported no correlation between timber strength and rate of growth. Craib (1939) also concluded that the rate of growth did not affect lumber strength in *Pinus patula*. The absence of influence of growth rate on mechanical properties is an advantage to forest managers who prefer higher growth rate to increase the volume yield of plantations because the higher growth rate will not affect the strength of the lumber produced. However caution should be taken because although the density of softwoods is generally not related to growth rate, density is directly related to the percentage of latewood in a growth ring (Shmulsky & Jones, 2011). There is typically a large difference in density between earlywood and latewood. For this reason, relatively wide latewood zones indicate relatively high density. Because the strength of wood increases with density, wide growth rings exhibiting a low proportion of latewood may be of concern in products where strength is important (Shmulsky & Jones, 2011). As long as the increased growth rate does not decrease the proportion of latewood within growth rings, there should be no problem in applying silvicutural practices that increase the growth rate.

After applying these silvicultural practices, it will be also important to find out the effect of increase of growth rate on the wood properties. The lack of significant strength properties variation among the five families is positive news for house and building construction where there is a need to develop uniform wood products from sustainable sources. *P. patula* has proved to be an ideal timber for construction in South Africa. More research on lumber strength and variation in Malawi should allow further development of the species for these high value products.

Table 8 shows mechanical properties of *Pinus patula* from other countries at about 12% moisture content. In terms of MOE, at 11.5 GPa, the Mexican *Pinus patula* had slightly higher values than that of Malawi. The MOE values were almost the same as that of Colombia and South Africa at 10.8 GPa. Malawi *Pinus patula* bending strength and stiffness compare favorably with the same species grown in other countries listed in **Table 8**. Thus, its wood products (such as lumber, composite panels, and structural composite lumber products) can compete successfully with same products in the huge construction markets of Southern Africa. This is especially true for Oriented Strand Board (OSB), laminated veneer lumber (LVL), and structural composite lumber (such as parallel strand lumber

Table 5.
Summary of the mechanical properties (86 specimens).

	Air dry density ($g \cdot cm^{-3}$)	MOE (GPa)	MOR (MPa)
Minimum	0.33	4.14	51.78
Maximum	0.69	16.72	185.19
Std	0.09	3.19	31.46
Average	0.51	10.93	105.17
CV	17.87	29.88	29.53

Table 6.
MOE analysis of variance summary for family and stem height (86 specimens).

Source	DF	Type III SS	Mean Square
Family	4	1827.11	456.77 NS
Stem height	4	1171.92	292.97 NS
Error	78	93292.23	1196.05

Note: NS: Not Significant at 1 % level.

Table 7.
MOR analysis of variance summary for family and stem height (86 specimens).

Source	**DF**	**Type III SS**	**Mean Square**
Family	4	19.10	4.88 NS
Stem height	4	22.15	5.33 NS
Error	78	875.36	11.22

Note: NS: Not Significant at 1 % level.

Table 8.
Mechanical properties of *Pinus patula* from other countries (as cited by Wright, 1994).

Location	**Mechanical property**	**Reference**
Colombia	MOE—10.8 GPa	(Anon, 1980)
New Zealand	MOE—7.65 GPa MOR—70.6 MPa	(Bier, 1983)
Mexico	MOE—11.5 GPa MOR—91.5 MPa	(Ordonez et al., 1989)
South Africa	MOE—10.8 GPa MOR—71.6 MPa	(Otto & Van Vuren, 1976)
Malawi	MOE—10.93 Gpa MOR—105.17 MPa	This study

(PSL), and laminated strand lumber (LSL).

Relationships among Wood Properties

Research has shown increased density to be strongly linked to favorable strength, stiffness, hardness and working properties of sawn timber, as well as wood pulp yield and paper-making quality. The relationships among the mechanical properties in this study were linear and positive.

Figures 1-3 show the relationships among air-dry density, MOR and MOE. There were significant correlations at 1% level between air-dry density and MOE (R = 0.85) and between air-dry density and MOR (R = 0.83). There was also a significant correlation between MOE and MOR at 1% level (R = 0.90). These results are also comparable with results for East African grown *Pinus patula* where wood density correlated significantly with all green and dry lumber strengths (FFPRI, 1975).

The correlation of MOR and MOE with specific gravity is typically very strong, as reported by Shottafer et al. (1972) and Shepard & Shottafer (1992) for red pine, Wolcott (1985) for red spruce, and Han (1995) for red maple. However, in some coniferous species, such as *Abies fabri*, *Picea asperata*, and *Pinus massoniana*, the relationship of MOE to specific gravity is weaker than the relationship between MOR and specific gravity (Zhang, 1997), and this was also found to be true in fast-growing red pine (Deresse, 1998). It has been reported that wood samples having similar specific gravity can also exhibit significantly different strength values due to factors that may be associated to other factors to which specific gravity is less sensitive (Perem, 1958; Zhang, 1995; Deresse, 1998). Correlations in this study indicate that controlling density would have a positive effect on some mechanical properties.

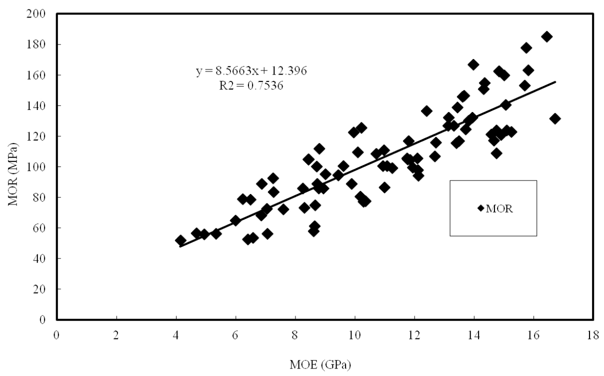

Figure 1.
Relationship between specific MOR and MOE among the five families.

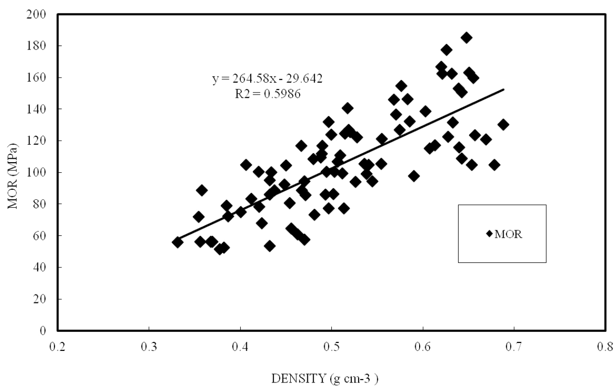

Figure 2.
Relationship between specific MOR and density among the five families.

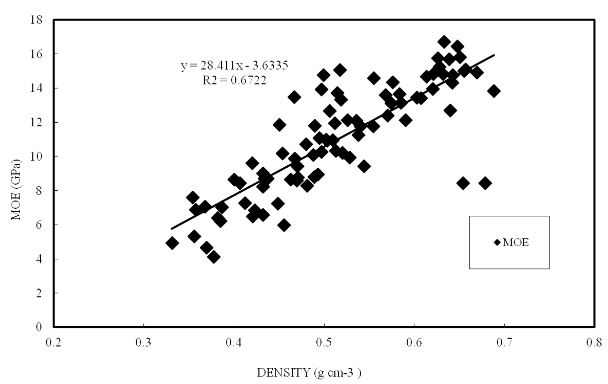

Figure 3.
Relationship between specific MOE and density among the five families.

Mechanical Properties and Grade Yield of Juvenile Wood versus Mature Wood

Tables 9 and **10** show the analysis of variance results for juvenile and mature woods among the five trees for MOE and MOR respectively. Significant variation was noted between juvenile wood and mature wood in terms of mechanical properties.

Figures 4-7 show the grade yield for both juvenile and mature wood according to MOE and MOR using grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions (FFPRI, 1995). The grade yield for MOE in juvenile wood was highest for Grade II followed by Grade I. Grade III and Grade IV was lower. There was no grade yield for Grade V according to MOE in juvenile wood (**Figure 4**). The grade yield for MOR in juvenile wood was highest for Grade III followed by Grade II and Grade I. Grade IV was lower and the grade yield for Grade V was the lowest (**Figure 5**).

Table 9.
MOE Analysis of variance summary for juvenile and mature wood (86 specimens).

Source	DF	Type III SS	Mean Square
MOE Juv/MAT	1	565.99	565.99**
Error	86	314.25	3.65

Note: **Significant at 1 % level.

Table 10.
MOR Analysis of variance summary for juvenile and mature wood (86 specimens).

Source	DF	Type III SS	Mean Square
MORJuv/MAT	1	40618.47	40618.47**
Error	86	44476.93	517.17

Note: **Significant at 1 % level.

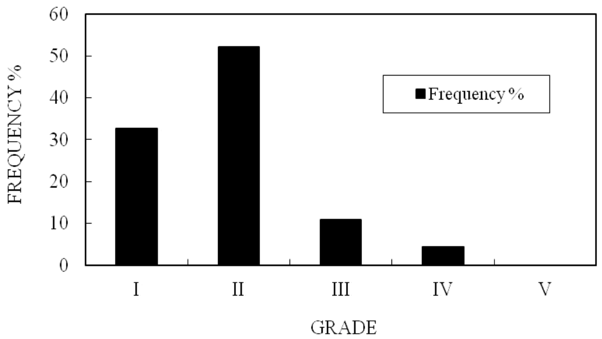

Figure 4.
Specimen grade allocation in terms of MOE of juvenile wood according to Grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions by FFPRI (1975). See Table 2.

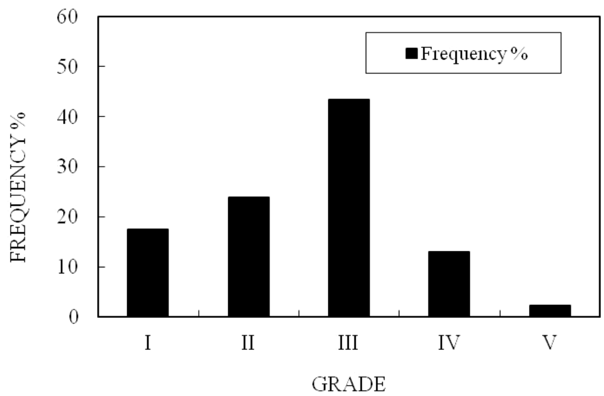

Figure 5.
Specimen grade allocation in terms of MOR of Juvenile wood according to Grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions by FFPRI (1975). See Table 2.

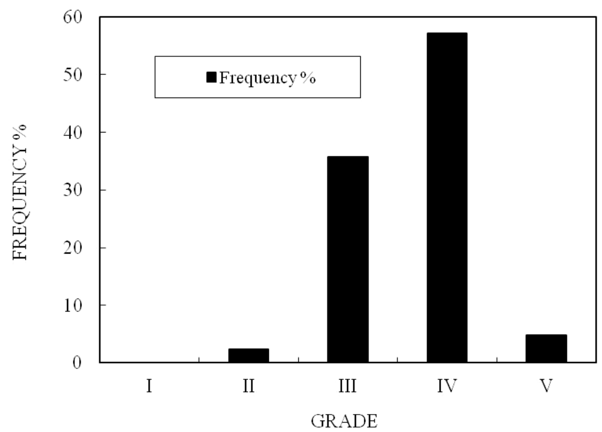

Figure 6.
Specimen grade allocation in terms of MOE of mature wood according to Grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions by FFPRI (1975). See Table 2.

The grade yield for MOE in mature wood was highest for Grade IV followed by Grade III. Grade V and Grade II was lower. There was no grade yield for Grade I according to MOE in mature wood (Figure 6).

The grade yield for MOR in mature wood was highest for Grade V followed by Grade IV and Grade III. Grade II was lower and there was no grade yield for Grade I according to MOR in mature wood (Figure 7).

Figures 8 and 9 show grade yield for both juvenile and mature wood according to the South African national standards. The grade yield for MOE in juvenile wood was highest for Grade five at followed closely by Grade XXX. Grade Seven was lower and the lowest grade yield according to MOE in juvenile wood was in Grade Ten (Figure 8).

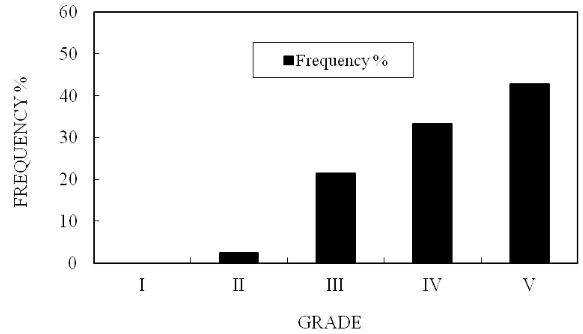

Figure 7.
Specimen grade allocation in terms of MOR of mature wood according to Grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions by FFPRI (1975). See Table 2.

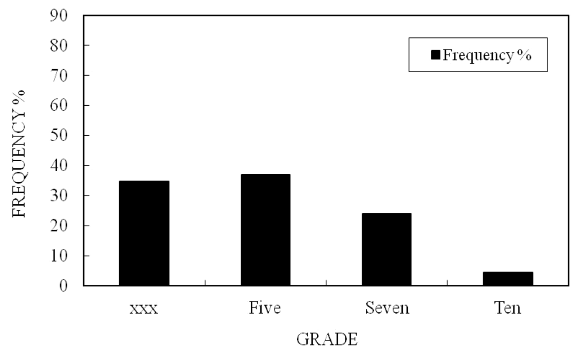

Figure 8.
Specimen grade allocation in terms of MOE of Juvenile wood according to the South African standards (XXX is the rejects category). See Table 3.

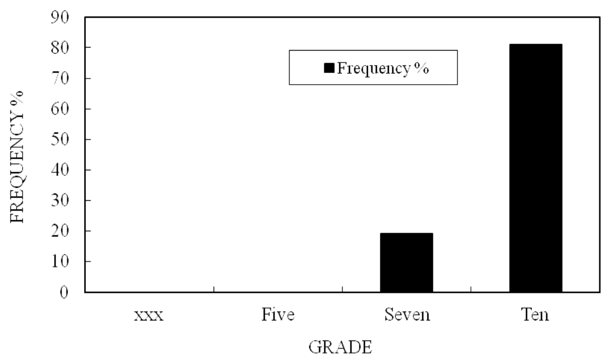

Figure 9.
Specimen grade allocation in terms of MOE of mature wood according to the South African standards (XXX is the rejects category). See Table 3.

The grade yield for MOE in mature wood was highest for Grade Ten at followed by Grade Seven. Grade II was lower and there was no grade yield for Grade Five and XXX with both grades yielding according to MOE in mature wood (**Figure 9**).

The grade yield according to MOE and MOR was different for juvenile wood and mature wood. Some grades had high yields in juvenile wood but low yields in mature wood. In other cases, grades with high yield in juvenile wood were non-existent in mature wood. The results show that mature wood yielded more grades with high values of MOE and MOR. This clearly shows that mature wood for *Pinus patula* is superior in strength and grade than juvenile wood. The implication for this is that mature wood and juvenile wood should be used for different purposes to avoid underutilization. Uniform use of juvenile wood and mature wood for structural purposes would be potentially dangerous because juvenile wood has inferior mechanical performance. To improve lumber strength, one can process logs of older trees and minimize the use of the interior portion of the log. Correct drying of the boards will increase the most important lumber strength traits of modulus of rupture and modulus of elasticity. Export of dried lumber of *P. patula* occurs and should increase if uniformity can be maintained.

The common steps in establishing grades for lumber are: testing of small clear specimens according to guidelines, establishing strength values and allowable properties, establishing visual grading rules and lastly verifying grades using in-grade testing. The contribution of this research towards creating an acceptable grading system is that it has clarified the variation of mechanical properties. More mechanical properties data, through testing of small clear wood specimens, from other areas in Malawi need to be accumulated.

This research has established first steps in assigning allowable mechanical properties for *Pinus patula* grown in Malawi. After accumulating more small clear wood specimen data, testing using the "in grade" approach, in which large representatives samples of full size lumber can be tested to destruction is recommended to compare the results. This will help in the assignment of standard grades that will ensure the efficient utilization of *Pinus patula* structural lumber in Malawi.

Conclusion

At about 12% moisture content, the tested five *Pinus patula* families have average MOR and MOE of 105.17 MPa and 10.93 GPa, respectively. There were significant correlations at 1% level between air-dry density and MOE (R = 0.85) and between air-dry density and MOR (R = 0.83). There was also a significant correlation between MOE and MOR at 1% level (R = 0.90). There was no significant variation in MOE and MOR among the five families. Stem level variation in MOE and MOR is not significant. Mature wood of *Pinus patula* has more superior mechanical performance than juvenile wood. The growth rate did not affect the mechanical properties of the species. This study suggests that it is potential to simultaneously improve tree growth, density, and some mechanical properties of the wood of this species. The results of this study are a foundation that will provide a technical basis for the machine grading of *Pinus patula* structural lumber in Malawi.

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