PHYSICAL AND MECHANICAL PROPERTIES OF RED PINE (*PINUS RESINOSA* AIT.) FROM THREE PROVENANCES

S. R. Shukla
Visiting Research Associate

and

D. Pascal Kamdem†
Professor
Laboratory of Wood Science and Technology,
Department of Forestry, 126 Natural Resources Building,
Michigan State University,
East Lansing, MI 48824 (USA).

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ABSTRACT

Physical and mechanical properties of 44-year-old red pine (*Pinus resinosa* Ait.) trees from three different provenances, Oscoda, MI (USA); Kent, NB (Canada), and Manitoba, MA (Canada) grown in Allegan State Forest, Michigan were evaluated. One-way analysis of variance of the properties showed that the differences in the mean values of physical and strength parameters were not inherent to the provenances. The results indicate there is very low genetic diversity of red pine across the wide geographic range of the species.

Keywords: Red pine, *Pinus resinosa*, provenances, genetics, environmental, physical properties, mechanical properties, wood quality parameters.

INTRODUCTION

Red pine (*Pinus resinosa* Ait.) is distributed mostly in the regions of northcentral and northeastern United States extending from New England, New York, and Pennsylvania to the Great Lake States and southeastern Canada. Scattered patches of red pine also occur south of the primary range along the Appalachian Mountains. Red pine has been the major species for reforestation in the Lake States for many years (Lester and Barr 1965). Fowler (1963) evaluated the species variability in red pine from his taxonomic and breeding studies. He reported that the variability was markedly limited in the morphology of leaves from progenies of populations widely separated geographically, in comparisons of morphology and growth of selfed vs. outcrossed progenies, and in comparisons of crosses between local populations vs. widely separated populations. He concluded that red pine, as a species, is highly self-compatible, relatively genetically homogeneous, and carries few deleterious genes (Lester and Barr 1965). Walter and Epperson (2001, 2005) studied the geographical diversity in red pine among many populations across the United States. Their results showed that unlike other pines grown in North America, red pine has very low amounts of genetic diversity although distributed in a wide geographical range. Mosseler et al. (1992) also confirmed relatively homogeneous genetic characteristics of red pine by investigating the random amplified polymorphic DNA markers. In provenance tests, total variation in different traits of morphological characters generally account for about 10% by source population. These traits include survival and growth rates,

† Member of SWST and corresponding author
kamdem@msu.edu

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phenology, wood quality, and branching characteristics (Wright et al. 1972; Fowler and Lester 1970; Mosseler et al. 1992). Provenance work on red pine has been focused on the variations of growth characteristics.

Red pine is an important part of the regional forest and occupies nearly 0.8 MHa, about 4% of the commercial Lake States forest land in Wisconsin, Michigan, and Minnesota (Crow 2002). Red pine mostly occurs in plantations and has an advantage in growth rate as compared to other species common to the Lake States forest (Crow 2002). In the 1993 inventory of Michigan, red pine represented more than 11% of the total volume in the jack pine forest type and 9% of the volume in the white pine forest type, but only 0.5% of the maple-beech-birch (*Acer-Fagus-Betula*) forest type (Schmidt 2002). The wood of red pine is reported to be moderately heavy, moderately strong and stiff, moderately soft, moderately high in shock resistance, and has moderately high shrinkage (FPL 1999). The wood of red pine is generally used for lumber in building construction, cabin logs, and as pulp wood. It is also used for poles, posts, and for fuel. The treated timber is mostly utilized for decking, siding, flooring, sashes, doors, general millwork, boxes, pallets, and crates (FPL 1999).

The relationship between wood relative density and growth rate in red pine trees originating from different initial spacings was studied by Larocque and Marshall (1995). They concluded that stand density strongly affects the wood density. The general trend showed that wood density decreased and earlywood percentage increased as intertree spacing increased. Growth and wood density of 30-year-old red pine was compared in unthinned and thinned sample plots by Paul (1957). Both unthinned and thinned plots of red pine exhibited quite similar overall patterns of wood density, increasing outward from the central portion of the tree and decreasing upward in the growth rings. The author concluded that because wood density values increase throughout the life of the plantation of red pine, the thinned plot may exhibit increased specific gravity until it becomes similar to that of old-growth trees.

Some studies have been reported in the literature to highlight the wood properties and potential application of red pine (Bowyer 2002; Deresse and Shepard 2007). Shepard and Shottafer (1992) examined the variations in specific gravity, modulus of rupture (MOR), and modulus of elasticity (MOE) with age for two plantations and a natural stand of red pine. They concluded that the mature period for wood density and modulus of rupture was 39 yr and 40 yr for the modulus of elasticity. They also observed that the mean values of different wood properties for both the juvenile and mature periods in the two plantations were generally equal to or greater than those for the natural stand. In a recent study, Zhu et al. (2007) reported the effects of plantation stand density on tree growth, wood density and different anatomical parameters and chemical composition of 38-year-old red pine grown in Lake Superior State Forest, Michigan. Higher stand density was related to low radial growth, low tracheid diameter and low fiber length. Average ring width was found to be correlated with wood density and tracheid anatomical parameters.

Very little information is available in the literature on the effect of different provenances on wood quality parameters of red pine grown in a particular climatic environment. The present study explores the effect of provenance on some physical and mechanical properties of red pine.

MATERIAL AND METHODS

Raw materials

A total of 15 trees 44-yr-old were selected and felled in December, 2006, and positively identified as red pine (*Pinus resinosa*). Five trees each of three provenances, Oscoda, MI (USA), Kent, New Brunswick, NB (Canada), and Manitoba, MB (Canada) grown in Allegan, MI were selected randomly for the present study. These provenances constitute approximately the middle and two extremes of the natural distribution of red pine in North America. The provenance trials were planted in September 1962 at the Allegan State Forest area, Allegan County, Michigan. The initial spacing during plantation was kept at 2.4 by 2.4 m. These plantations were not subjected to any systematic silvicultural treatments. Table 1 shows the details of various environmental factors at the plantation site in Allegan, MI. The weather data were reported on maximum temperature extremes and mean annual precipitation from 1971 to 2000 (MSCO 2007). The average, maximum, and minimum values of diameter at breast height of logs, heartwood, sapwood, and the bark thickness of red pine trees from three provenances are given in Table 2. All measurements were taken at breast height.

All the logs were marked and numbered and cross-cut directly into 1-m-long bolts centered at breast height. These bolts were sawn into sticks of about 30- by 30-mm cross-section. Two discs each of about 30 mm in thickness were cut from each side of the bolts to collect samples for radial and tangential shrinkage studies. Only clear wood samples without any visible defects such as knots, gum streak, and resin pockets were selected from the sapwood portion for further testing. Each stick was cut to provide maximum number of specimens for testing according to the guidelines provided in ASTM 5536-94 (ASTM 2006b). Samples were kept in the conditioning room maintained at 21°C and 65% relative humidity for more than 2 mo until constant weight before testing. Small clear specimens were tested for the following physical and mechanical properties according to ASTM 143-94 (ASTM 2006a).

TABLE 1. *Environmental factors of the study site at Allegan State Forest, Allegan County, MI.*

Factors	Values
Latitude	42°34′N
Longitude	85°59′W
Altitude	198 m above sea level
Temperature range	−32 to 38°C
Mean annual precipitation	1034 mm
Site	Flat
Soil type	Sandy soil (fairly droughty)
Drainage type	Very well drained

TABLE 2. *Characteristics of the sample trees obtained from the trees grown in Allegan, MI.*

Provenance	Diameter (mm) Avg.	Max.	Min.	Heartwood Avg. (mm)	Sapwood Avg. (mm)	Bark Avg. (mm)
Oscoda, MI	247	272	233	104	64	8
Kent, NB	229	250	210	85	64	7
Manitoba, MA	244	296	223	91	65	9

Physical properties

(i) Moisture content: The moisture content was measured using oven-dry method. Total numbers of specimens used for determining the moisture content from all the tests were 243 and 447 in green and dry conditions, respectively.

(ii) Specific gravity: The specific gravity was determined on samples with moisture contents of 125 and 11% based on oven-dry mass and the specified moisture content volume. Total number of specimens taken for determination of basic specific gravity was 210.

(iii) Shrinkage: Samples measuring 25 × 25 × 100 mm were used to estimate radial and tangential shrinkage. The total numbers of specimens taken for the determination of radial and tangential shrinkage from the three provenances were 112 and 128, respectively.

Mechanical properties

The mechanical testing was conducted on a computer-controlled Instron testing machine (model 4206) following the ASTM D 143-94 standards (secondary method) for static bending, and compression parallel to grain tests. ASTM D 143-94 standards for compressive strength perpendicular to grain and hardness were modified. The standard loading rates and the technique were used but on specimens measuring 25 × 25 × 150 mm, not the primary size of 50 × 50 × 150 mm. These smaller size specimens were tested to avoid knots and other defects. The use of the smaller specimen size may have an unknown effect on the compressive strength perpendicular to grain and hardness results. Total number of specimens from the sapwood used for static bending, compressive strength parallel and perpendicular to grain, and hardness were 42, 52, 50, 51 respectively.

Statistical analysis

Descriptive statistical analysis of the data obtained on physical and strength properties of red pine from three provenances was carried out using SigmaStat (ver 3.11) software (SYSTAT 2004). In order to investigate the variation of physical and strength parameters among the three provenances, one-way analysis of variance (ANOVA) was performed at the 5% level of significance.

RESULTS AND DISCUSSION

General properties and description of wood

The trees from all three provenances had almost similar size and growth characteristics. The widest range in diameter at breast height was found for the red pine trees from the Manitoba, MA provenance and the smallest variation in trees from Kent, NB provenance (Table 2). The highest and lowest average diameters at breast height (DBH) were exhibited by trees from Oscoda, MI (247 mm) and Kent, NB (229 mm) provenances respectively. As shown in Table 2, the average heartwood diameter and sapwood thickness at the breast height of red pine from three provenances varied in the range of 85 to 104 mm and 64 to 65 mm, respectively. The average bark thickness was found almost uniform in the range of 7 to 9 mm. Heartwood of red pine varies in color from pale red to reddish brown while the sapwood is generally yellowish white. The sapwood and heartwood distinction was made based on color variation. The growth rings have distinct latewood and earlywood, and wood is generally straight-grained.

Wood physical properties

Average values of the physical properties, radial and tangential shrinkage and basic specific gravity of red pine trees from Oscoda, MI; Kent, NB; and Manitoba, MA provenances, are presented in Tables 3 and 4, respectively. Radial and tangential shrinkage values from green to oven-dry conditions lie in a very narrow range of 3.47% to 3.67% and 5.27% to 5.69%, respectively for the three provenances. Table 3 also depicts the ratio of the tangential to radial shrinkage for the three provenances. The average values were compared with the values reported in the literature (FPL 1999) and are presented in Table 3. Radial shrinkage values of red pine from the present study were comparable with the reported values while tangential shrinkage values were much smaller than the values listed in the literature (FPL 1999). The ratio of tangential to radial shrinkage for three provenances lies in the range of 1.50 to 1.62. The same ratio for the red pine from the literature is 1.89. The difference in the shrinkage values may be attributed to some of the factors such as age of the trees, origin, growing conditions, and portion of tree for sampling (FPL 1999). Data of radial and tangential values were subjected to ANOVA analysis at 5% level of significance. Table 5 provides the F-values and P-values of the ANOVA analysis. The results showed that the means were not significantly different among the three provenances at 95% level of confidence.

The basic specific gravity (SG) in green and

TABLE 3. *Radial and tangential shrinkage values.*

	Provenance						
	Oscoda, MI		Kent, NB		Manitoba, MA		
Shrinkage properties	Avg.	SD	Avg.	SD	Avg.	SD	(From FPL 1999)
Radial (%)	3.52	0.41	3.47	0.57	3.67	0.52	3.8
Tangential (%)	5.69	0.83	5.27	1.20	5.52	0.77	7.2
Ratio of tangential/radial shrinkage	1.62		1.52		1.50		1.89

dry conditions was computed for red pine trees from Oscoda, MI; Kent, NB; and Manitoba, MA provenances and is given in Table 4. The average values of the basic SG from the present study were compared with the published literature (FPL 1999). It was noticed that the basic SG values in green and dry conditions (12% EMC) were lower than the reported values. The ranges of reduction in the average basic SG in green condition and 12% EMC of red pine from three provenances were 8.8 to 11.5% and 4.1 to 6.9%, respectively when compared with the published FPL averages. One-way ANOVA was performed for testing the significance of variation of basic SG for the red pine trees from the three provenances and results (F-values and P-values) are presented in Table 5. The differences in the mean values of basic SG among the three provenances were not great enough to exclude the possibility that the difference was due to random sampling variability and provenances. Similar observations were made by Peterson (1968) about the red pine provenance uniformity. Among 10 provenances studied, only one deviated from the rest by more than 0.02. In a stand where growth environment is equal or comparable, differences in the average values of whole-stem relative density among the trees are mostly attributed to the differences in the genotype. Zobel and Talbert (1984) summarized that 70% of the overall variation in the relative density in a species is due to differences that occur in a given stand. The remaining 30% is accounted for by differences among provenances and sites.

Wood mechanical properties

Average values of the mechanical properties such as flexural MOR, MOE, compression parallel and perpendicular to grain, and hardness are listed in Table 4. The values are obtained for samples at 12% EMC. The strength of wood is commonly expressed as MOR, which is a measure of the ultimate short-term load carrying capacity of a piece of wood when the load is applied slowly. MOE is a direct measurement of the timber resistance to deflection under load and has traditionally been used as an index of the stiffness. MOR and MOE values of red pine in the present study ranged from 51.55 to 55.28 MPa and 5.43 to 5.94 GPa, respectively. The values of MOR and MOE from the present study and those reported in the literature (FPL 1999) are presented in Table 4. The lower values of flexural properties in the present study may be attributed to the lower relative density of the specimens selected only from the sapwood portion of the trees. Other factors responsible for the large difference may be the age of the trees, their origin, growing conditions, and portion of tree for sampling (FPL 1999). The results of the present study obtained from ASTM "secondary method" may not be directly comparable to the data available in the open literature using ASTM "primary method" with larger specimen size of 50 × 50 mm. The low values of this study may probably be due to the presence of juvenile wood at age 44 yr. However, more studies need to be done to confirm the percentage of juvenile wood in red pine at this age. One-way ANOVA

TABLE 4. *Mechanical properties of red pine at 12% EMC.*

		Provenances						From FPL (1999)	
		Oscoda, MI		Kent, NB		Manitoba, MA		Red pine grown in	
	Property	Avg.	SD	Avg.	SD	Avg.	SD	USA	Canada
Specific gravity	Green	0.365	0.025	0.374	0.036	0.363	0.025	0.41	0.39
	12%	0.386	0.031	0.393	0.042	0.386	0.029	0.46	—
Flexural	MOR (MPa)	51.62	6.39	55.28	7.03	51.55	5.95	76.0	70.0
	MOE (GPa)	5.43	0.96	5.76	1.22	5.94	1.35	11.2	9.5
Compression	MCS (MPa)	27.73	3.62	28.91	5.12	30.13	6.57	41.9	37.9
	CS perpendicular to grain at 2.5 mm (MPa)	8.02	0.90	8.69	1.12	7.84	1.34	—	—
Side hardness (kN)		2.06	0.39	2.23	0.53	2.10	0.26	2.5	—

TABLE 5. *One-way ANOVA of physical and mechanical properties of red pine from three provenances grown in Allegan, MI (level of significance = 5%).*

Property		Provenances from Oscoda (MI), Kent (NB), Manitoba (MA)	
		F-value	P-value
Specific gravity	Green	1.721	0.181
	12%	2.148	0.119
Shrinkage	Radial (%)	1.619	0.203
	Tangential (%)	2.165	0.119
Flexural	MOR (MPa)	1.355	0.270
	MOE (GPa)	0.733	0.487
Compression	MCS (MPa)	0.955	0.392
	CS perpendicular to grain at 2.5 mm (MPa)	2.624	0.083
Side hardness (kN)		0.858	0.430

of MOR and MOE among the three provenances at 5% level of significance are presented in Table 5. The P-values for both MOR and MOE are higher than the level of significance, and therefore the three provenances do not differ significantly in terms of strength and stiffness.

The compressive strength parallel to grain values of three red pine provenances are presented in Table 4. Compressive strength parallel to grain is also known as maximum crushing strength (MCS) of wood. From the literature, the average air-dry MCS values for red pine grown in USA and Canada were 41.9 and 37.9 MPa, respectively (FPL 1999). These values are higher than those exhibited by the red pine from the three provenances investigated in this study. The compressive MOE values were found to vary in a very narrow range of 3.04 to 3.18 GPa. The MCS data were subjected to the one-way ANOVA and the results of the analysis are given in Table 5. The P-value for MCS is 0.392 which is greater than the value of the level of significance (0.05). This shows that the means of compressive strength parallel to grain is not significantly different among the three provenances.

The compressive strength (CS) perpendicular to grain was computed for all the three provenances and average values are given in Table 4. These values also vary within a narrow range of 7.84 to 8.69 MPa. As shown in Table 5, the P-value from the ANOVA results is 0.083 which also shows that the means of the compressive strength perpendicular to grain from three provenances do not vary significantly from each other.

Hardness is a measure of the resistance of wood to the indentation. Side hardness values for the three red pine provenances are presented in Table 4. The average values for Oscoda (MI), Kent (NB) and Manitoba (MA) provenances were 2.06, 2.23, and 2.10 kN, respectively. When compared with the value of side hardness in air-dry condition for red pine grown in USA, slightly lower values were exhibited by the three provenances (Table 4). The side hardness data were subjected to one-way ANOVA analysis for ascertaining if the differences in the means are statistically significant. The results of analysis (F-value and P-value) are presented in Table 5. The P-value is found to be 0.430, which is greater than the level of significance (0.05). This means that the differences in the mean values among the three provenances are not great enough to exclude the possibility that the difference is due to random sampling variability and there is not a statistically significant difference in the side hardness.

Zobel and Talbert (1984) emphasized that wood variability exerts a significant influence on wood physical and mechanical properties and, consequently, affects its utilization. Knowledge or information on wood variability will help in the better utilization of wood material in a more efficient way. Evaluation and comparison of physical and mechanical properties showed that red pine from different provenances do not vary when grown under identical growth environment. Low values of strength properties may indicate some proportion of juvenile wood in red pine at the age of 44 yr (Shepard and Shottafer 1992). Variability of the chemical composition: lignin, cellulose, holocellulose, and extractive contents and types will be investigated later to confirm the low variability in the chemical, physical and mechanical properties of red pine. Such information will be very useful for the utilization of red pine as a raw material for the bioenergy in terms of technological development for the production of high quality plantation timbers for value-added products.

CONCLUSIONS

Red pine (*Pinus resinosa* Ait.) from three (Oscoda, MI (USA); Kent, NB, (Canada) and Manitoba, MA (Canada)) provenances grown in Allegan State Forest area, Michigan were selected for the study. Basic specific gravity, radial and tangential shrinkage, flexural MOR, MOE, compressive strength properties parallel and perpendicular to grain, and side hardness were determined for the sapwood portion of the logs near breast height, and compared among the provenances using one-way ANOVA. The analysis showed that the differences in the mean values of physical and strength properties were not statistically significant among three provenances. All three provenances demonstrated similar behavior based on the local growth environment irrespective of their origin. Our results are consistent with other studies that indicate that red pine has very low genetic diversity across the wide geographic range of the species.

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REFERENCES

American Society for Testing and Materials (ASTM). 2006a. Standard test method for small clear specimens of timber. D 143-94 (Reapproved in 2000). American Society for Testing and Materials. West Conshohocken, PA.

———. 2006b. Standard practice for sampling forest trees for determination of clear wood properties. D 5536-94 (Reapproved in 2004). American Society for Testing and Materials. West Conshohocken, PA.

Bowyer, J. L. 2002. Red pine utilization and markets. Pages 124–130 *in* D. W. Gilmore and L. S. Yount, eds. Proc. Red Pine SAF Region V. Conference. Staff Paper No. 157. College of Natural Resources, University of Minnesota, St. Paul, MN.

Crow, T. R. 2002. Pages 1–2 Introduction *in* D. W. Gilmore and L. S. Yount, eds. Proc. Red Pine SAF Region Staff Paper 157. College of Natural Resources, University of Minnesota, St. Paul, MN.

Deresse, T. and R. K. Shepards. 2007. Wood properties of red pine (*Pinus resinosa* Ait.). CFRU Information Report 42 (Maine Agricultural and Forest Experiment Station Miscellaneous Report 412). College of Natural Sciences, Forestry, and Agriculture, Maine Agricultural and Forest Experiment Station, University of Maine, Orono, ME. 12 June 2007 http.//www.umaine.edu/mafes/elec_pubs/miscrepts/mr412.pdf

Fowler, D. P. 1963. Effects of inbreeding in red pine *Pinus resinosa* Ait. Unpublished Ph.D. Dissertation. Yale University. New Haven, CT. 164 pp.

———, and D. T. Lester 1970. Genetics of red pine. United States Forest Service, Washington Office Research Paper WO-8.

FPL. 1999. Wood Handbook: Wood as an Engineering Material. Gen. Tech. Rep. FPL-GTR-113. U.S. Department of Agriculture. Forest Service. Forest Product Laboratory, Madison, WI. 463 pp.

Larocque, G. R., and P. L. Marshall. 1995. Wood relative density development in red pine (*Pinus resinosa* Ait.) stands as affected by different initial spacings. Forest Sci. 41(4):709–728.

Lester, D. T., and G. R. Barr 1965. Provenance and progeny tests in red pine. For. Sci. 11(3):327–340.

Mosseler, A., K. N. Egger, and G. A. Hughes. 1992. Low levels of genetic diversity in red pine confirmed by random amplified polymorphic DNA markers. Canadian J. For. Res. 22:1332–1337.

MSCO. 2007. Michigan State Climatologist's Office, Department of Geography, Michigan State University, East Lansing, MI 48824. http://climate.geo.msu.edu/stations/0128. (8 June 2007).

Paul, B. H. 1957. Growth and specific gravity responses in a thinned red pine plantation. J. Forestry 55(7):510–512.

Peterson, T. A. 1968. Variation in radial growth patterns and specific gravity of red pine (*Pinus resinosa* Ait.). Forest Prod. J. 18(11):63.

Schmidt, T. L. 2002. Highlights–Red pine in the northern Lake States. Pages 3–16 *in* D. W. Gilmore, and L. S. Yount, eds. Proc. Red Pine SAF Region V. Technical Conference. Paper No. 157. College of Natural Resources, Department of Forest Resources, University of Minnesota, St. Paul, MN.

Shepard, R. K., and J. E. Shottafer. 1992. Specific gravity and mechanical property—age relationships in red pine. Forest Prod. J. 42(7/8):60–66.

SYSTAT. 2004. SigmaStat ver 3.11 statistical analysis software. Systat Software, Inc., San Jose, CA (USA).

Walter, R., and B. K. Epperson. 2001. Geographic pattern of genetic variation in *Pinus resinosa*: area of greatest diversity is not the origin of postglacial populations. Molecular Ecology 10:103–111.

Walter, R., and B. K. Epperson. 2005. Geographic pattern of genetic diversity in *Pinus resinosa*: contact zone between descendants of glacial refugia. American J. Botany. 92(1):92–100.

Wright, J. W., R. A. Read, D. T. Lester, C. Merritt, and C. Mohn. 1972. Geographic variation in red pine: 11-year data from the North Central states. Silvae Genetica 21: 205–222.

Zhu, J. Y., C. T. Scott, K. L. Scallon, and G. C. Myers. 2007. Effects of plantation density on wood density and anatomical properties of red pine (*Pinus resinosa* Ait.). Wood Fiber Sci. 39(3):502–512.

Zobel, B. J., and J. Talbert. 1984. Applied forest tree improvement. John Wiley & Sons, Inc., New York. 505 pp.