THE EFFECTS OF DWARF MISTLETOE ON THE WOOD PROPERTIES OF LODGEPOLE PINE[1]

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ABSTRACT

The effects of dwarf mistletoe (*Arceuthobium americanum* Nutt. ex. Engelm.) on the wood properties of lodgepole pine (*Pinus contorta* Dougl.) were studied. The results indicate: a decline in modulus of elasticity, modulus of rupture, and work to proportional limit in both infected and noninfected wood from the infected trees; a higher specific gravity of the infected wood; a higher percentage of alcohol-benzene extractives in the infected wood; an increase in longitudinal shrinkage in both infected and noninfected wood from the same tree; a lower percentage of latewood in wood from infected trees; no significant difference in growth ring width between infected and control wood; narrower growth rings in the noninfected regions of infected trees; a decrease in tracheid length in both infected and noninfected wood from the same tree; an increase in microfibril angle in both infected and noninfected wood from the same tree.

This is the first study to show that both infected wood and noninfected wood from the same tree are definitely inferior to wood from noninfected trees in strength and longitudinal shrinkage characteristics.

Additional keywords: *Pinus contorta*, modulus of elasticity, specific gravity, longitudinal shrinkage, microfibril angle, tracheid length, extractives content, static tests, flexural strength.

INTRODUCTION

Dwarf mistletoe (*Arceuthobium americanum* Nutt. ex. Engelm.), a parasitic plant, causes serious damage to lodgepole pine (*Pinus contorta* Dougl.) throughout much of the West. Dwarf mistletoes, in general, have recently been monographed by Hawksworth and Wiens (1972). Surveys in Colorado, Wyoming, central Idaho, and western Montana show that from one-third to one-half of the commercial lodgepole pine is affected to some degree (Gill and Hawksworth 1964). Colorado and Wyoming surveys indicate that in merchantable timber, dwarf mistletoe is responsible for about one-third reduction in growth and a marked increase in mortality (Gill and Hawksworth 1964; Kimmey and Graham 1960). In terms of general impact it has been stated that no extensive areas of coniferous forests in the Northern Rocky Mountain or Intermountain regions are completely free of one or more of the dwarf mistletoes (Kimmey and Graham 1960).

The most effective means of control is to remove infected trees from the stand

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(Childs and Wilcox 1966; Smith 1970). Often this leads to clearcutting an entire stand of trees (Heidmann 1968). The logs from this clearcutting operation are then sent to production centers to become lumber, paper, or some other type of wood product.

There has been relatively little research conducted to determine the effects of dwarf mistletoe on the wood properties of any particular tree species. Because lodgepole pine is one of the most severely attacked tree species in the Rocky Mountain region, a study was undertaken to investigate the effects of dwarf mistletoe on the anatomical, chemical, and mechanical properties of lodgepole pine wood.

MATERIALS AND METHODS

Selection of materials

Sample material was collected from a site located in the Roosevelt National Forest, one mile south of Glendevey, Colorado (SW¼, NW¼, Section 34, T1ON, R76W, 6th P.M.). The site was characteristic of a stand moderately to severely infected with dwarf mistletoe.[3] Bolts 48 inches long were collected from the bottom ten feet of each tree. Ten bolts came from noninfected trees. Twelve pairs of bolts containing infected and noninfected wood came from trees infected with dwarf mistletoe. All bolts came from a stand of trees of approximately the same age (80 to 100 years).

Two sets of test specimens ($2 \times 2 \times 14$ inches) were cut from the infected bolts. Forty-four test specimens were cut from the noninfected region of the bolts, and 43 test specimens were cut from the infected region (area of swelling) of the bolts. The test specimens were cut so as to end-match specimens from the infected region with specimens from the noninfected region. Infected bolts, however, were swollen to such an extent that end-matching of test specimens in relation to the radius of the tree was difficult. A third set containing 56 test specimens was obtained from the ten noninfected trees. All test specimens were cut from the outer 30 growth rings of the tree and consisted entirely of sapwood.

The test specimens were conditioned to 12% equilibrium moisture content. This material was used for the following tests: (1) bending strength, (2) specific gravity, (3) alcohol-benzene extractive content, (4) longitudinal shrinkage, (5) growth ring width, (6) percentage of latewood, (7) fibril angle, (8) tracheid length, and (9) tracheid orientation.

Three categories were established: (1) infected wood, (2) noninfected wood from infected trees, and (3) control wood (wood from noninfected trees). Comparisons were made using a one-way analysis of variance as the test of significance.

METHODS

Static bending. After the specimens had reached a constant moisture content (12%), they were cut to $0.5 \times 0.5 \times 8$ inches and tested for bending strength on an Instron testing machine. The $1 \times 1 \times 16$-inch ASTM standard bending specimens could not be obtained because of the limited occurrence of dwarf mistletoe in the test specimens, so specimen size was changed in order to insure infection throughout the static bending test specimen. ASTM's recommendation for a span-to-depth ratio of 1 to 14 was retained (ASTM 1970).

The radius of curvature of the bearing block was 0.75 inches. This size showed the least compression on the static bending test specimen. Two metal plates (0.5×3 inches) were placed at each of the supports to prevent compression from occurring at the supports as the load was being applied. The load was applied continuously at a rate of 0.05 inches per minute. Moisture content was determined for each test specimen after the test. Other procedures pertaining to static bending followed the ASTM Standards (1970).

The following strength properties were calculated upon completion of the static bending tests: modulus of rupture, modulus of elasticity, work to proportional limit, and

[3] Personal communication from F. G. Hawksworth 15 June 1971.

work to maximum load. Work to maximum load was determined with a polar planimeter. All strength values were corrected to 12% moisture content. The number of rings per inch was recorded for each test specimen.

Specific gravity. Blocks, $0.5 \times 0.5 \times 2$ inches, were cut from the ends of the static bending test specimens. These specimens were utilized to determine both moisture content and specific gravity. The displacement method (ASTM 1971) was utilized in determining specific gravity, based on green volume and oven-dry weight. Specific gravity measurements were also made on the longitudinal shrinkage test specimens ($0.5 \times 0.5 \times 6$ inches).

Alcohol-benzene extractive content. Alcohol-benzene solubility content of wood is a measure of the waxes, fats, resins, and certain other ether-insoluble components. Alcohol-benzene extractive content was determined by combining each of the specific gravity specimens from each bolt and using this as the source material for the Tappi Standard (1959) extraction procedure. Consequently, a value for the bolt was obtained rather than a value for each test specimen. Ten grams of wood ground to a 40/60 mesh were then placed into a Soxhlet extractor and extracted successively with ethanol-benzene for 18 h and 95% ethanol for 16 h.

Longitudinal shrinkage. Longitudinal shrinkage measurements were made on 20 test specimens ($0.5 \times 0.5 \times 6$ inches) for each category. These test specimens were taken from the same area of the tree as were the static bending test specimens. Measurements were made with the specimen green, oven-dry, and at equilibrium moisture contents of 15, 12, and 6%. Shrinkage is expressed as a percentage of green length.

Anatomical structure. Five static bending test specimens were selected from each of the categories: infected, noninfected, and control. Anatomical test specimens ($0.25 \times 0.25 \times 0.50$ inches) were cut from the static bending test specimens. Cross sections 30 to 35 μm thick were cut on a sliding microtome, stained with Heidenhain's iron haematoxylin-bismarck brown staining schedule and permanently mounted (Jensen 1962). Growth ring width and percentage of latewood were studied with a Reichert Visopan microscope at 100×.

After these measurements had been made, each specimen was split radially along the same line where the ring width measurements had been made. Latewood was separated from one of the split halves and macerated in a warm mixture (1:1 by volume) of glacial acetic acid and 30% hydrogen peroxide (Tsoumis 1968; Wilson 1954). Tracheid length was measured microscopically (35×) on 10 cells mounted in water from each latewood portion of the growth increments from each specimen. Five growth increments were studied from each specimen.

Radial sections (five from each category) were taken from the same line where the ring width measurements had been made using the other half of each split anatomical specimen. The sections, 25 μm thick, were stained in safranin for five minutes and permanently mounted. Within the latewood zones of each radial section, fibril inclination was determined by measuring the angle between the longitudinal axis of the tracheids and the slit-like pit apertures in the cross fields (Hiller 1964; Shumway et al. 1971). The restriction to latewood tracheids was due to the relative ease of measuring the microfibril angle. Measurements were made on a Reichert Visopan microscope at 340×.

RESULTS AND DISCUSSION

The presence of dwarf mistletoe on lodgepole pine results in definite changes in the growth patterns of the tree. These changes are reflected in the anatomy and chemistry of the wood cells, which together affect the strength and shrinkage properties of the wood. These changes in strength, chemistry, shrinkage, and anatomy of wood are quantified and discussed below.

Static bending

In three of the four strength properties measured, a significant difference was

TABLE 1. *Statistical summary of static bending data*

Property	Mean	Standard Deviation	Standard Error of the mean	Range
MOE ($X10^6$psi)				
X_1	0.836	0.247	0.038	1.033
X_2	1.154	0.233	0.035	1.131
X_3	1.366	0.133	0.018	0.496
X_4	1.340	--	--	--
MOR ($X10^3$psi)				
X_1	9.022	1.826	0.278	7.040
X_2	10.562	1.502	0.226	7.073
X_3	11.192	0.990	0.132	3.842
X_4	9.400	--	--	--
W_{pl}(inlb/in^3)				
X_1	1.256	0.424	0.065	1.660
X_2	1.351	0.258	0.039	0.137
X_3	1.499	0.208	0.028	0.870
X_4	1.970	--	--	--
W_{max}(inlb/in^3)				
X_1	11.224	3.515	0.536	16.610
X_2	12.044	2.446	0.369	10.260
X_3	10.870	2.703	0.361	10.980
X_4	6.800	--	--	--

where:

X_1 = Infected (sample size 43)
X_2 = Non-infected (sample size 44)
X_3 = Control (sample size 56)
X_4 = Published values taken from Wood Handbook (USDA 1955)

observed between infected wood and control wood. A significant difference was also observed in each of the four strength properties between noninfected wood from an infected tree and control wood (see Tables 1 and 2). Thirty-nine percent lower values for modules of elasticity were found in mistletoe-infected wood when compared to control wood, with 16% lower values for noninfected wood. Nineteen percent lower values for modulus of rupture occurred in mistletoe-infected wood compared to con-

TABLE 2. *Summary of "F" values for analysis of variance (Static bending)*

Source of Variation	MOE	MOR	W_{pl}	W_{max}
Infected vs. non-infected	38.11**	18.48**	1.86NS	1.28NS
Infected vs. Control	187.63**	57.30**	14.05**	0.34NS
Non-Infected vs. Control	32.73**	6.36*	8.75**	4.54*

NS = Not Significant
**Significant at 0.01 level
*Significant at 0.05 level

TABLE 3. *Statistical summary of specific gravity and alcohol-benzene extractive content*

Property	Sample Size	Mean	Standard Deviation	Standard Error of the Mean	Range
Specific gravity #1 (static bending specimens)					
X_1	43	0.405	0.069	0.010	0.334
X_2	44	0.380	0.034	0.005	0.136
X_3	56	0.371	0.029	0.004	0.109
X_4	--	0.380	--	--	--
Corrected Specific Gravity #1 (static bending specimens)[a]					
X_1	43	0.378	0.054	--	--
X_2	44	0.372	0.033	--	--
X_3	56	0.364	0.028	--	--
X_4	--	0.380	--	--	--
Specific gravity #2 (Longitudinal shrinkage specimens)					
X_1	20	0.412	0.060	0.013	0.267
X_2	20	0.391	0.036	0.008	0.136
X_3	20	0.373	0.032	0.007	0.121
X_4	--	0.380	--	--	--
Alcohol-benzene extractive content (%)					
X_1	12	7.617	4.918	1.420	14.300
X_2	12	1.983	0.822	0.237	3.500
X_3	10	1.940	1.112	0.352	3.300

Where:
X_1 = infected
X_2 = Non-infected
X_3 = Control
X_4 = Published values taken from Wood Handbook (USDA 1955).

[a] individual specific gravity values corrected utilizing the equation

$$\text{Sp. Gr.}_{corr} = \frac{\text{Sp. Gr.}}{1+EC}$$

where:
EC = extractive content of each bolt
Sp. Gr. = specific gravity

trol wood, with 6% lower values for noninfected wood. Sixteen percent lower values for work to proportional limit were found in mistletoe-infected wood when compared to control wood, with 10% lower values in noninfected wood. No significant difference occurred in work to proportional limit between infected and noninfected wood from the same tree. Eleven percent lower values for work to maximum load were seen in noninfected wood as compared to control wood. However, no significant difference was seen in work to maximum load, between infected and noninfected wood and between infected and control wood. The reason for this may lie in the shape of the stress-strain curves. The curves in the infected category increased slowly and flattened out beyond the proportional limit, while the curves in the control category increased rapidly. A balancing effect resulted in comparable total areas beneath the curves of the different categories because of this difference in curve shape.

Specific gravity

Results from both specific gravity trials are shown in Tables 3 and 4. Nearly 10% greater values for specific gravity were seen in infected wood as compared to control wood. In both trials there was no significant difference in specific gravity between the noninfected and control categories. However, a discrepancy existed between the

TABLE 4. *Summary of "F" values for analysis of variance (specific gravity and alcohol-benzene extractive content)*

Source of Variation	Specific Gravity #1	Specific Gravity #2	Alcohol-Benzene Extractives
Infected vs. Non-Infected	4.65*	1.64NS	15.32**
Infected vs. Control	10.73**	6.49*	12.68**
Non-Infected vs. Control	1.72NS	2.94NS	0.01NS

NS = Not significant
** = Significant at 0.01 level
* = Significant at 0.05 level

two trials when infected wood and non-infected wood from the same tree were compared.

Another discrepancy existed between the static bending results and specific gravity results. Specific gravity was greatest in infected wood. This suggests that infected wood should have higher clear-wood strength values than control wood. This was not the case, however, as the static bending results indicated weaker wood in the infected category.

Both of these discrepancies can be explained by the higher percentage of alcohol-benzene extractives in infected wood (Tables 3 and 4) and their irregular distribution throughout the infected wood. When the effect of extractive content is removed (corrected specific gravity), very little difference between the mean specific

TABLE 5. *Statistical summary of longitudinal shrinkage (percent)*

Moisture Content	Mean	Standard Deviation	Standard Error of the Mean	Range
15%				
X_1	0.076	0.070	0.016	0.249
X_2	0.078	0.054	0.012	0.183
X_3	0.025	0.026	0.006	0.083
12%				
X_1	0.120	0.092	0.021	0.315
X_2	0.097	0.058	0.013	0.200
X_3	0.049	0.032	0.007	0.133
6%				
X_1	0.150	0.096	0.022	0.332
X_2	0.121	0.065	0.014	0.232
X_3	0.071	0.037	0.008	0.150
Ovendry				
X_1	0.326	0.135	0.030	0.431
X_2	0.276	0.078	0.017	0.310
X_3	0.228	0.041	0.009	0.183

Where:
X_1 = Infected (sample size 20)
X_2 = Non-infected (sample size 20)
X_3 = Control (sample size 20)

TABLE 6. *Summary of "F" values for analysis of variance (longitudinal shrinkage)*

Source of Variation	Moisture Content			
	15%	12%	6%	Ovendry
Infected vs. Non-Infected	0.01NS	0.87NS	1.22NS	2.04NS
Infected vs. Control	9.44**	10.68**	11.54**	9.54**
Non-Infected vs. Control	15.52**	10.62**	8.87**	5.85*

NS = Not significant
** = Significant at 0.01 level
* = Significant at 0.05 level

gravity of the three groups is seen, as illustrated in Table 3. Such a masking of true specific gravity has been alluded to by Panshin and de Zeeuw (1970). These results suggest that specific gravity may not be a good indicator of strength loss in wood infected with dwarf mistletoe.

Alcohol-benzene extractive content

Mistletoe-infected wood contained three times the quantity of extractives as both the control and noninfected wood (see Tables 3 and 4). No significant difference existed between noninfected wood and control wood with respect to extractive content.

The presence of dwarf mistletoe appears to stimulate increased resin accumulation in the wood. The quantity of resin, a major constituent of the alcohol-benzene extractives in lodgepole pine wood, often bears a direct relationship to strength. Experiments conducted on southern pine indicated that the endwise compressive strength, bending strength, and shock resistance of these woods were somewhat increased by the presence of resin (Wangaard 1950). However, it must be borne in mind that a high resin content may be the result of injuries which themselves reduce strength of wood (Wangaard 1950).

Longitudinal shrinkage

Values for longitudinal shrinkage are shown in Tables 5 and 6. There was no significant difference in shrinkage between infected and noninfected wood at any moisture content, but values were higher for infected and for noninfected wood than for control wood. Increased longitudinal shrinkage of dwarf mistletoe infected wood is most likely the result of a decrease in tracheid length, and an increase in microfibril angle; however, other anatomical characteristics such as increased volume of ray parenchyma and nonaxial alignment of tracheids may be important.

Anatomical properties

Data for the rate of growth are shown in Tables 7 and 8. The greatest number of growth rings per inch occurred in the noninfected category, and the least in the control trees. No significant difference was found when ring widths were compared between infected and control wood (see Tables 7 and 8). The greater rate of radial growth found in the infected region of the tree appeared to be coupled with slower rate of growth in the noninfected regions of the tree. Forty-eight percent lower growth ring width values were observed in noninfected wood as compared to control wood.

Data for percentage of latewood are also shown in Tables 7 and 8. No significant difference in latewood percent occurred between infected and noninfected wood; however, control wood contained a significantly higher percentage of latewood than both categories of wood from infected trees.

Growth ring width and percentage of latewood bear a direct relationship to the specific gravity of wood. Discrepancies

TABLE 7. *Statistical summary of anatomical properties*

Property	Sample Size	Mean	Standard Deviation	Standard Error of the Mean	Range
Rings/inch					
X_1	43	35.84	19.08	2.91	82.00
X_2	44	45.09	15.12	2.28	68.00
X_3	56	27.18	7.82	1.04	42.00
Growth ring width (mm)					
X_1	24	0.74	0.38	0.08	1.15
X_2	25	0.46	0.15	0.03	0.56
X_3	24	0.89	0.25	0.05	1.01
Percentage of latewood (%)					
X_1	24	11.56	2.50	0.51	9.15
X_2	25	10.73	2.30	0.46	9.78
X_3	24	15.70	3.73	0.76	14.42
Tracheid length (mm)					
X_1	250	2.09	0.46	0.03	2.43
X_2	250	2.24	0.43	0.03	2.16
X_3	250	2.97	0.42	0.03	2.34
X_4	---	3.22	0.44	--	--
Microfibril angle (degrees)					
X_1	50	25.78	10.28	1.45	56.00
X_2	50	21.98	7.45	1.05	33.00
X_3	50	11.92	6.86	0.97	30.00

WHERE:

X_1 = Infected
X_2 = Non-infected
X_3 = Control
X_4 = Published values taken from Panshin and de Zeeuw (1970)

exist in the literature, however, as to the exact effect of ring width on specific gravity. Because of these discrepancies, no attempt was made to correlate ring width data with specific gravity values. A direct relationship between wood specific gravity and latewood percentage has been reported in conifers (Panshin and de Zeeuw 1970), that is to say, a high percentage of latewood is associated with high specific gravity. The results of this study, however, are contrary to this assumption in that infected wood had a low percentage of latewood and high specific gravity.

TABLE 8. *Summary of "F" values for analysis of variance (anatomical properties)*

Source of Variation	Rings/ inch	Growth Ring Width	Percentage of Latewood	Tracheid Length	Fibril Angle
Infected vs. Non-Infected	6.30*	11.63**	1.46NS	13.98**	4.48*
Infected vs. Control	9.48**	2.56NS	20.39**	501.29**	62.87**
Non-Infected vs. Control	58.71**	52.47**	31.77**	373.35**	49.31**

NS = Not Significant
** = Significant at the 0.01 level
* = Significant at the 0.05 level

Infected wood had the shortest tracheid lengths and largest microfibril angle measurements of any of the categories. Thirty percent lower values for tracheid length and 116% higher values for microfibril angle were found in infected wood as compared to control wood. Comparable values for noninfected wood were 25% lower for tracheid length and 84% higher for microfibril angle.

The orientation of the tracheids was also affected by dwarf mistletoe. The accelerated growth and the invading sinkers caused a definite distortion in the tracheids and ray parenchyma cells. Ray aggregates were seen in infected wood, as has previously been reported (Piirto 1971; Srivastava and Esau 1961).

SUMMARY AND CONCLUSIONS

Dwarf mistletoe has a pronounced effect on the wood properties of lodgepole pine. A large variation exists in these effects, however, as indicated by the high standard deviation values for infected wood displayed in each of the tests except percentage of latewood. This variation was attributed to differences in the degree of infection within infected trees.

Previous investigations have shown for infected lodgepole pine a decreased tracheid length (Smythe 1967; Srivastava and Esau 1961), distorted tracheids (Smythe 1967), and an increase in ray parenchyma cells (Smythe 1967). The results from this study confirm these changes in the wood properties of lodgepole pine. Similar effects have been shown for other conifers (Srivastava and Esau 1961).

Further, this study has shown when comparing wood from infected trees to that from control trees: (1) lower values for percentage of latewood in infected and noninfected wood from the same tree; (2) 48% lower values for growth ring width in the noninfected regions of an infected tree; (3) 30% lower values for tracheid length in infected wood and 25% lower in noninfected wood from the same tree; (4) 116% greater values for microfibril angle in infected wood and 84% higher in noninfected wood from the same tree; (5) threefold greater values for alcohol-benzene extractive content in infected wood; (6) 39% lower values for modulus of elasticity in infected wood and 16% lower in noninfected wood from the same tree; (7) 19% lower values for modulus of rupture in infected wood and 6% lower in noninfected wood from the same tree; (8) 16% lower values for work to proportional limit in infected wood and 10% lower in noninfected wood from the same tree; and (9) greater longitudinal shrinkage of both infected and noninfected wood from the same tree.

The occurrence of dwarf mistletoe in the tree, whether the infection is in a limb or the trunk or both, affects the entire tree system. This was confirmed by the differences that existed between noninfected wood and control wood in every property studied except specific gravity and alcohol-benzene extractive content.

Although the effects of dwarf mistletoe on the wood properties of lodgepole pine are relatively large, it is possible that they might go undetected at the sawmill as shown for white fir by Wilcox et al. (1973). The combination of this work and that of Wilcox et al. (1973) suggest a definite need for improved detection methods.

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