SPECIFIC GRAVITY, FIBER LENGTH, AND EXTRACTIVE CONTENT OF YOUNG PAULOWNIA

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ABSTRACT

The potential of using paulownia (*Paulownia tomentosa*) as a pulpwood species was assessed by evaluating the within-tree variation in specific gravity, fiber length, and extractive content of young trees growing on surface-mined land. Stem-wood fiber length and extractive-free specific gravity averaged 0.79 mm and 0.249, respectively. Total average extractive content approached 13%. Compared with other fast-growing hardwoods, paulownia has a lower specific gravity, shorter fiber length, and higher extractive content. All of these factors make paulownia a poor pulpwood species for most types of paper. Its fast growth rate may, however, favor the species as a valuable fiber source for some specialty-type papers where strength is not important.

Keywords: Within-tree variation, wood properties, specific gravity, fiber length, extractive content, growth rate, pulpwood, *Paulownia tomentosa.*

INTRODUCTION

Paulownia (*Paulownia tomentosa*) is a valuable wood species that has been shown to have very fast growth, even on the harsh microclimates of surface-mined sites (Carpenter and Graves 1979; Tang et al. 1980). Rotation ages from 10 to 14 years have been recommended (Stearns 1944). Currently the demand for paulownia is high, as much of the better quality wood is exported to Japan.

Paulownia has been used in Japan for centuries, primarily as a furniture wood that utilizes 75% of all the logs exported to Japan (Larson 1981). Other Japanese traditional uses for the wood include boxes, bowls, toys, clogs, and carvings. Log prices quoted in the United States rival or exceed those paid for black walnut (*Juglans nigra*), according to Beckjord and McIntosh (1983).

As planting practices improve, more and more private landowners are growing paulownia so they can take advantage of its rising demand, value, and fast growth. However, along with its increased frequency of planting have arisen questions regarding its value should the future supply become overabundant, or should the overseas market be lost. Are there any substitute uses for paulownia in the U.S.?

Paulownia is one of the fastest growing species used for reforestation in China. The genus *Paulownia* contains nine species and two varieties in China. The average width of its annual rings normally is 2 cm and the widest over 4 cm. The average diameter of Chinese-grown paulownia at 10 years is 40 cm, with mean volumes

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TABLE 1. *Average property values for different* Paulownia *species growing in China (Jun-qing et al. 1983).*

Property	*P. tomentosa* average	7 *Paulownia* species	
		Average	Range
Specific gravity[1]	0.267	0.248	0.217–0.274
Fiber length (mm)	0.94	1.12	0.96–1.19
Extractive content (%)			
Cold water	7.6	6.7	4.2–8.7
Hot water	10.8	9.1	6.2–11.3
Alcohol	9.7	7.6	4.4–10.0
Cell composition (%)			
Fibers	52.3	54.5	50.1–56.7
Vessels	11.8	8.8	6.7–10.0
Axial parenchyma	28.1	27.9	25.2–31.2
Ray parenchyma	7.9	8.9	6.0–9.9
Alpha-cellulose (%)	40.72	40.10	38.50–41.46
Lignin (%)	20.87	23.00	21.24–24.28
Pentosan (%)	24.78	23.31	20.56–25.35
Ash (%)	0.19	0.46	0.21–0.74

[1] Converted to an oven-dry weight, green volume basis.

approaching 0.5 cubic meters (Zhao-hua 1983). Paulownia is a very light and soft wood and is easily sawn and planed, nailed, peeled, sliced, dried, and glued. It normally does not warp or check (Jun-qing et al. 1983).

The wood properties of eight of these native Chinese species were investigated in a recent study by Jun-qing et al. (1983). Three trees, each less than 30 cm in diameter, were examined for each species. The trees for *P. fargesii* and *P. kawakamii* were 30 and less than 10 years old, respectively. All others were between 10 and 20 years of age. Samples were taken at breast height. Selected wood property values for *P. tomentosa,* as well as the averages and ranges for the other seven species studied, are shown in Table 1. *Paulownia tomentosa* had the lowest fiber length, but its specific gravity and extractive contents were both one of the highest of the species investigated.

Other characteristics examined included acoustical, thermal, electrical, and mechanical properties. Their purpose in making these tests was to verify or clarify some doubtful or mistaken popular traditions or incorrect records of the wood properties or uses of paulownia. In some cases experimental evidence with opposite results was obtained from these tests. For example, it was earlier believed that paulownia was decay- and insect-resistant. However, these researchers found that the woods of three of the species examined, including *P. tomentosa,* were only slightly resistant to decay. All others were not decay-resistant. Moreover, five of the species, including *P. tomentosa,* were not resistant to termite attack. One other disagreement found with earlier studies showed that paulownia has a high, not a low, permeability.

This shows that care should be given to accepting as factual evidence earlier studies, and that analysis of the properties of paulownia should be made in the United States to insure that proper assessment of its properties is determined prior to suggesting end uses. In addition, paulownia growing here may possess different properties than that of the Far East.

Suggested uses for paulownia include veneer or plywood, furniture, handicrafts, tools, musical instruments, and charcoal (Jun-qing et al. 1983). It was also stated that paulownia would make a good raw material for paper manufacture. The paper type, quality and yield were not evaluated.

Romeka (1951) reported that paulownia pulp was fairly strong for a short-fibered material. Tests showed that it produced a fair pulp, the yield of which was believed too low to be economically feasible at that time. Comparable species were not given, which makes it difficult to ascertain the value of paulownia as a pulpwood. Paulownia, however, has been determined to be suitable for particleboard manufacture (Vital et al. 1974; Chad and Pommer 1980).

The objective of this study was to analyze the potential of utilizing paulownia as a pulpwood species in the United States by evaluating its extractive content, specific gravity, and fiber length.

MATERIALS AND METHODS

Three young-growth paulownia trees, healthy and free from defects, were selected on different sites in southeastern Kentucky. The sites had earlier been surface mined, and the trees are believed to have grown naturally. The diameter at breast height (dbh) and the height of each were measured. After felling at 10 cm from ground level, the age, number of rings of sapwood (as indicated by color differences), and growth rate (cm/yr) were determined. The trees were then sampled at the base and at nine points along the stem at 10% intervals of total-tree height. A 20-cm longitudinal sample was removed at each sampling point, and oriented to denote the north cardinal direction.

In the laboratory, three 2.5-cm thick, matched discs were removed from each sample for specific gravity, extractive content, and fiber length measurements. Unextracted specific gravity was determined for one matched disc at each height for each tree by the water immersion method. Bark was removed prior to measurement. Unextracted specific gravity was calculated on a green volume, oven-dry mass basis. The green diameter, age, and number of rings of sapwood were also determined at each height.

Fiber length samples were removed from the second matched disc. A debarked 0.3-cm wide slice from the pith to the orientation mark inside the bark was taken from each. The growth rings were separated into two-year increments starting at the pith and working outward toward the bark. Samples were macerated in a 1:1 solution of 30% hydrogen peroxide and glacial acetic acid, stained with basic fuschin, temporarily mounted in glycerin, and measured on a microprojector. The magnification used was 52×. Three horizontal lines were drawn on the screen. The distance between each corresponded to the length of the longest fiber encountered in a preliminary analysis. Fifty fibers were measured for each two-year increment using an electronic ruler that employed a digital map wheel capable of measuring straight or curved fibers.

Depending upon the sample diameter, extractive content samples were taken opposite the fiber length sample. If greater than 7.5 cm in diameter, a 30-degree wedge was used; if between 4 and 7.5 cm, a 90-degree wedge was taken; if less than 4 cm, the entire remaining sample was used. Debarked extraction samples were prepared according to TAPPI standards (TAPPI 1978). Extraction times were 8, 8, and 4 hours for benzene-EtOH, 95% EtOH, and hot water, respectively.

TABLE 2. *Growth characteristics of the paulownia study trees.*

Tree no.	Age (yr)	Sapwood (no. of rings)	dbh (cm)	Height (m)	Growth rate (cm/yr)
1	12	1	18.6	12.7	1.55
2	7	1	13.8	10.3	1.97
3	7	1	16.0	10.6	2.29
Avg.	8.7	1	16.1	11.5	1.85

The samples were oven-dried to constant mass at 103 C and weighed after each successive solvent extraction. Extractive contents were determined based upon initial oven-dry mass. Individual extractive isolation and identification within each extractive grouping were not made.

Trends in the radial variation of extractive content were examined in the third set of matched discs. The disc located at the base of each tree was divided into four sections: 1) sapwood, 2) sap-heartwood transition, 3) outer heartwood, and 4) inner heartwood. Samples were prepared and extracted as above. Successive extractive contents were determined and compared with that obtained from the whole disc.

Oven-dry mass of the specific gravity sample was adjusted using the matched total extractive content values. Extractive-free specific gravity was calculated and compared to unextracted specific gravity.

Using the truncated-cone method of Wahlgren and Yandle (1970), stem-wood specific gravity, fiber length, and extractive contents were determined for each tree. The sample diameter at each height was employed in the truncated-cone weighting procedure.

An analysis of variance was performed on all data to determine the significance of variation in specific gravity, fiber length, and extractive content between trees as well as between locations within the tree.

RESULTS AND DISCUSSION

The age, number of rings of sapwood, dbh, height, and growth rate are given in Table 2 for each of the study trees. Both predicted stem-wood property values and those obtained at breast height are shown in Table 3. Average values are also given. Average unextracted stem-wood specific gravity was very low, 0.285, while the average value at breast height, 0.274, was lower than all native commercial species given in the Wood Handbook (USDA For. Serv. For. Prod. Lab. 1974).

The average stem-wood extractive content was high, 12.7%, which is exceeded

TABLE 3. *Stem-wood properties of the paulownia study trees (values at breast height in parentheses).*

Tree no.	Specific gravity		Fiber length (mm)	Percent extractive content			
	Unextracted	Extracted		Benzene-EtOH	EtOH	Hot water	Total
1	0.269 (0.236)	0.239 (0.212)	0.80 (0.83)	7.2 (7.1)	1.2 (0.9)	2.8 (2.4)	11.2 (10.4)
2	0.291 (0.290)	0.257 (0.257)	0.79 (0.80)	7.0 (7.1)	2.0 (1.8)	2.8 (2.4)	11.8 (11.3)
3	0.296 (0.295)	0.252 (0.246)	0.79 (0.81)	9.7 (11.5)	1.8 (2.2)	3.4 (3.0)	14.9 (16.7)
Avg.	0.285 (0.274)	0.249 (0.238)	0.79 (0.81)	8.0 (8.6)	1.7 (1.6)	3.0 (2.6)	12.7 (12.8)

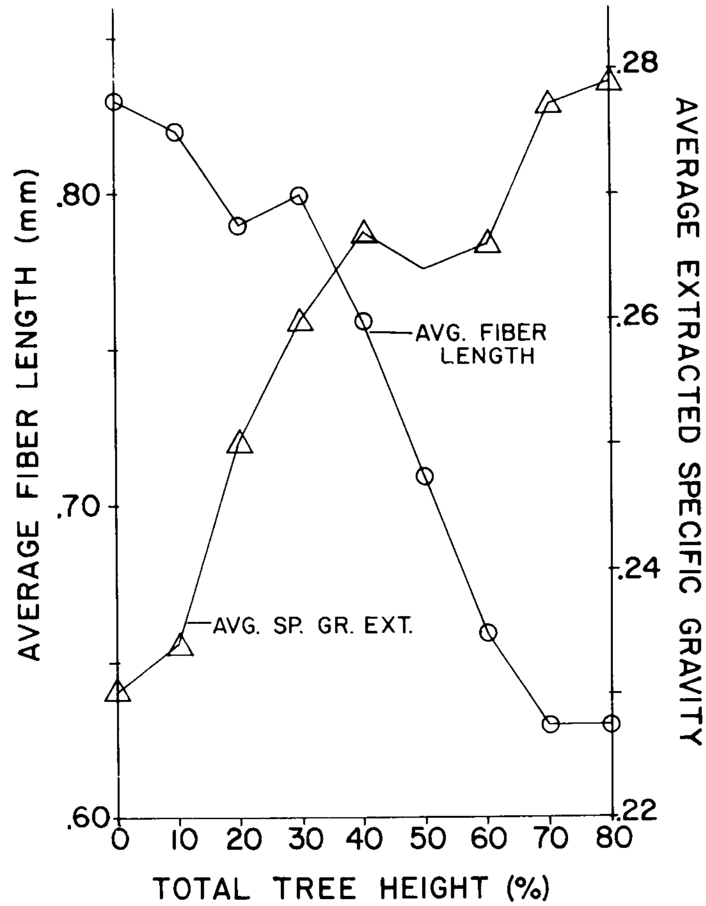

FIG. 1. Relationship between percent total-tree height and average fiber length and extractive-free specific gravity.

only by a few other species (Fengel and Grosser 1975). The *successive* extraction sequence resulted in average stem-wood values of 8.0, 1.7, and 3.0% extractive content for benzene-EtOH, EtOH, and hot water extractions, respectively. If the specific gravity is adjusted for the large amount of extractives present, the average stem-wood specific gravity is decreased 12.6% to 0.249.

Average stem-wood fiber length was short, 0.79 mm. The fiber length at breast height, 0.81 mm, is exceeded by 95% of the native hardwoods reported by Panshin and de Zeeuw (1980).

These data were obtained for trees from 7 to 12 years of age, possessing primarily juvenile wood. Within-tree data should indicate whether the properties will change appreciably as the trees get older. Only one ring of sapwood was found on each of the study trees.

Fiber length and specific gravity

Fiber length and both extracted and extractive-free specific gravity were found to be correlated with percent stem-wood height. A negative correlation (r = −0.945)

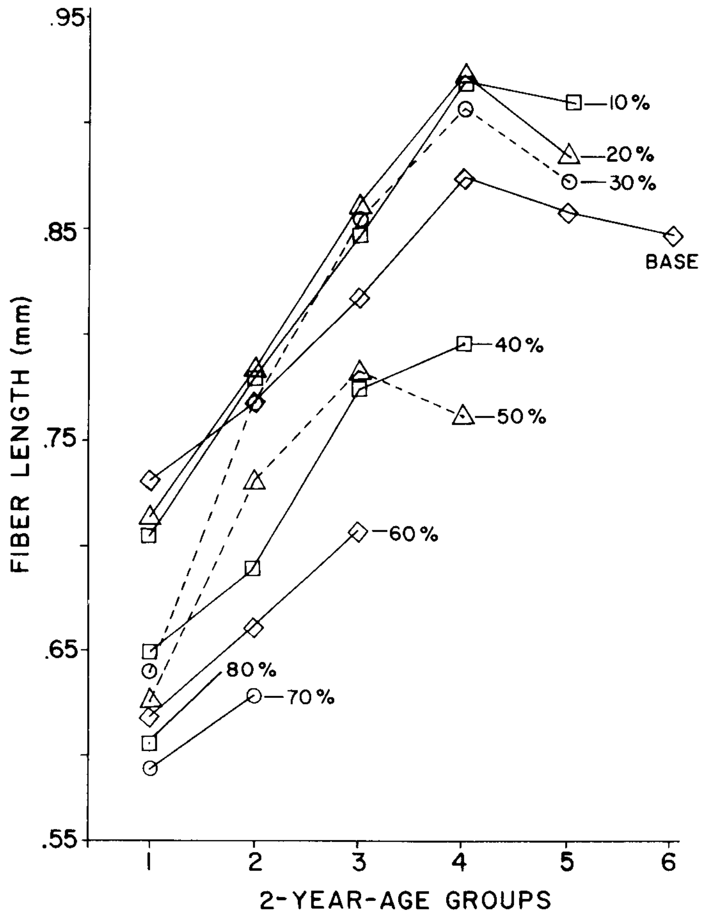

FIG. 2. Effect of radial position, as measured at two-year-age groups from pith to bark, on fiber length at different percents of total-tree height for tree 1.

was determined for fiber length and percent total-tree height, while a positive relationship was obtained for both unextracted (r = 0.696) and extracted (r = 0.616) specific gravity. Each was significant at the 1% level. By analysis of variance, the three trees, if sampled at different percent total-tree heights, were found to be similar at the 5% level of significance with respect to fiber length and unextracted and extracted specific gravity. If the data at each height are averaged for the three trees, within-tree variation in fiber length and extracted specific gravity with respect to percent total-tree height can be represented as shown in Fig. 1.

The effect of radial position on fiber length can also be determined since the wood at each height was separated into 2-year-age groups from the pith to the bark. An analysis of variance indicated the absence of variation in average fiber length between the three trees. A representation of the fiber length of 2-year-age groups at the different heights is given in Fig. 2 for tree 1. Fiber length for a given tree was affected by radial position and was significant at the 1% level, increasing from the pith to the bark. At the base of the tree, fiber length begins to drop at 8 years of age with a length of between 0.85 and 0.90 mm. If rotation ages are

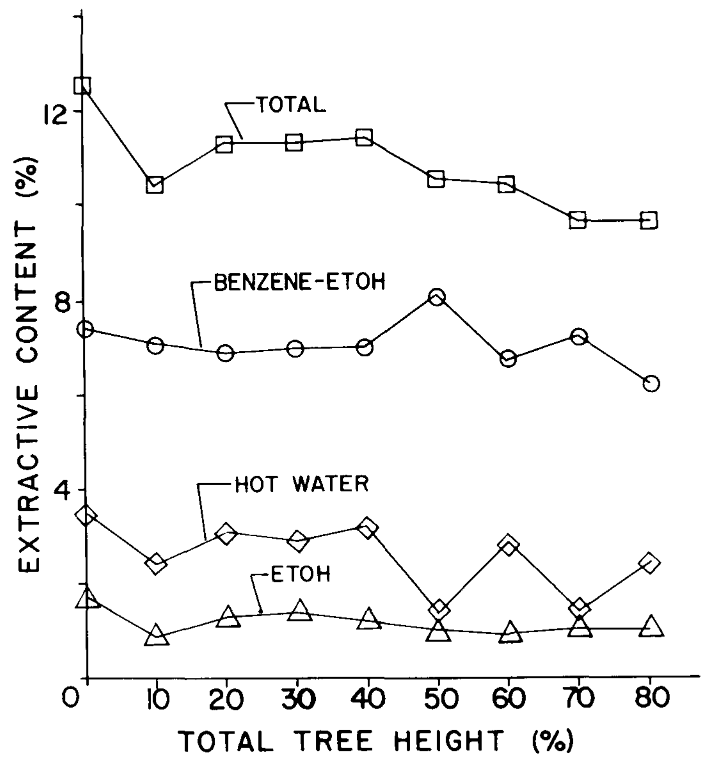

FIG. 3. Relationship between extractive content and percent total-tree height for tree 1.

extended past ten years, it is expected that fiber length, based upon the results of this study, will average less than 1 mm.

Extractive content

A representation of benzene-EtOH, EtOH, hot water, and total percent extractive content with percent total-tree height for tree 1 is given in Fig. 3. No correlation was found between percent total-tree height and extractive content. In all cases the relationship was nonsignificant at the 5% level.

Radial variation in extractive content was determined on samples taken at the base of the tree. An analysis of variance indicated that all trees had similar extractive values when tested at the 5% level of significance. Thus, the results were averaged for the three trees and are presented in Fig. 4.

In another analysis of variance, all extractive contents were shown to vary with radial position at the base of the tree at the 5% level of significance. The results of Duncan's multiple range test ($P = 0.05$) indicate that sapwood is significantly different from the heartwood in benzene-EtOH, EtOH, and total extractives. Only the hot water extractive components of both sapwood and inner heartwood were similar, and, in general, more than twice as many total extractives were found in the sapwood as in the heartwood.

An analysis of the sapwood extractives was not made. However, a possible explanation for the higher sapwood extractive content can be attributed to extraction of soluble sugars from the hemicellulose fraction of wood. The most

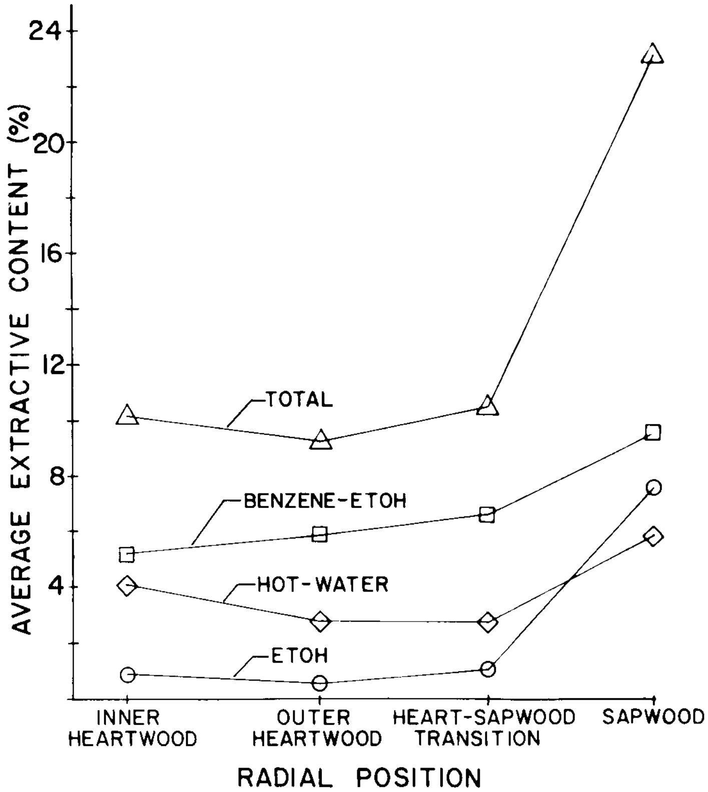

FIG. 4. Effect of radial position on average extractive content.

soluble fractions include some portion of all the sugars that are present and practically all the total amount of those minor sugars found in quantities less than 1 or 2% (Schuerch 1963). Sucrose, glucose, and fructose are common in the sapwood of hardwoods (Buchannan 1963). However, since the sapwood consisted of only one growth ring in each of the study trees, its contribution to the total extractive content is limited.

Comparison with paulownia grown in China

The specific gravity, fiber length, and extractive content values of Table 1 for Chinese-grown *P. tomentosa* can be compared with data from this study (Table 3). While the paulownia growing in China was slightly older, the average specific gravity at breast height, 0.267, was very similar to that of the current study, 0.274. On the other hand, fiber length values were almost 15% shorter in this study, 0.81 mm, as compared with that obtained in China, 0.94 mm.

A comparison of extractive contents is more difficult. In the Chinese study, extractions, using only polar solvents, were made *separately* with different samples for each solvent. In this work, *successive* extractions, including both nonpolar and polar solvents, were performed. A cold water extraction was employed in the former analysis, but not in the latter. Comparing these extractions, therefore, involves some approximations.

TABLE 4. *Comparison of average properties of paulownia, sycamore and cottonwood.*

Species	Age (yr)	dbh (cm)	Growth rate (cm/yr)	Specific gravity	Fiber length (mm)	EtOH-benzene extractive content (%)	Reference
Paulownia tomentosa	8.7	16.1	1.85	0.274	0.81	8.6	—
Platanus occidentalis	10	—	—	0.46	1.78	—	Jett and Zobel (1975)
	11	16.5	1.50	0.43	—	1.1	Barker (1974)
	12	20.5	1.69	—	—	4.0[1]	Moore and Effland (1974)
Populus deltoides × *P. caudina*	13	13.5	1.03	0.402[2] 0.379[3]	1.30[2] 0.83[3]	2.8	Morton et al. (1968)
Populus deltoides	8–10	—	—	—	1.30	—	Wilcox and Farmer (1968)

[1] Outer rings 8–12.
[2] Outer rings 10–12.
[3] Inner rings 1–3.

A total extractive content at breast height of 12.8% was obtained in this study. It is expected that the polar solvents of the Chinese investigation would successively extract a total of approximately 12% extractives. An additional nonpolar solvent initially might add another 2 or 3%, giving a total of at least 14%. This is higher than that given in the current study.

Comparisons with cottonwood and sycamore

The results of this investigation are compared in Table 4 with corresponding data found in the literature for cottonwood (*Populus deltoides*) and sycamore (*Platanus occidentalis*). These are two fast-growing species that are currently being harvested for pulpwood at rotation ages similar to the age of the trees of this study. The studies from which these data were obtained were not exactly the same with respect to growing conditions, methods, etc., but the data should provide a suitable comparison of the three species.

Paulownia has a higher extractive content and lower specific gravity and fiber length. The cottonwood and sycamore were grown on better sites, whereas the paulownia obtained in this study was growing on a very poor site, reclaimed, surface-mined land. This should be a major advantage for utilizing this species. Once it is established on such marginal sites, then it generally will grow at a very fast rate.

SUMMARY AND CONCLUSIONS

Within-tree variation in specific gravity, fiber length, and extractive content was determined for three young paulownia trees, ranging in age from 7 to 12 years, growing on surface-mined land. The average stem-wood specific gravity was 0.285, unextracted, or 0.249, extractive-free, while fiber length averaged 0.79 mm. Specific gravity and fiber length both varied significantly with stem-wood height, but extractive content was not affected by height. Radial variation in extractive content was pronounced for total extractive content, being greatest in the sapwood (23.1%) to approximately 10% throughout the remainder of the wood inward to the pith. Similar trends were obtained for the individual types of extractives measured.

If compared with paulownia grown in China, that growing in the United States has a specific gravity that is about the same, while fiber length is shorter and total extractive content lower.

While young-growth paulownia's pulp yield would be lower than other commercial species because of its low density and high extractive content, if compared with other fast-growing hardwoods, its faster growth at shorter rotations may provide a valuable source of pulpwood. The fibers of paulownia are short, which will also influence the type of paper that can be produced from this wood. Additional testing of its papermaking characteristics is suggested.

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