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著者名	田邊,純 成松,翔太 石栗,太 飯塚,和也 増山,知央 横田,信三 吉澤,伸夫
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Evaluation of wood properties in 4-year-old seedlings of two families from less pollen varieties of *Cryptomeria japonica* D. Don

4年生少花粉スギ苗木2家系における木材性質の評価

Jun TANABE[1], Shouta NARIMATSU[1], Futoshi ISHIGURI[1], Kazuya IIZUKA[1], Tomoo MASUYAMA[2], Shinso YOKOTA[1], Nobuo YOSHIZAWA[1]
田邊　純[1]、成松翔太[1]、石栗　太[1]、飯塚和也[1]、
増山知央[2]、横田信三[1]、吉澤伸夫[1]

[1] Faculty of Agriculture, Utsunomiya University, Utsunomiya 321-8505, Japan
[1] 宇都宮大学農学部 〒321-8505 宇都宮市峰町350
[2] Tochigi Prefectural Forestry Research Center, Utsunomiya 321-2105, Japan
[2] 栃木県林業センター 〒321-2105 宇都宮市下小池町280

和文要約

林木育種において，苗木の木材性質及び曲げ性能の評価は，材質優良家系の早期選抜のために重要である。本研究では，4年生少花粉品種由来のスギ2家系（南会津4及び東白川9）を用いて，木材性質及び曲げ性能を評価し，材質の早期選抜の可能性を検討した。成長形質，木材性質及び曲げ性能に関して，使用した2家系間に有意な差が認められた。容積密度及び晩材仮道管S_2層ミクロフィブリル傾角（MFA）は，スギ未成熟材における過去に報告された値とほぼ同様の値（30°）を示した。苗木の曲げヤング率（MOE）は，気乾密度及びMFAと関係があったことから，MFA及び気乾密度によって，MOEを早期推定できることが示唆された。しかしながら，供試した材料のほとんどに圧縮あて材が存在していた。そのため，苗木を用いてMFAを指標として材質を早期評価するためには，圧縮あて材の存在に注意すべきであることが明らかとなった。

キーワード：スギ，晩材仮道管S_2層ミクロフィブリル傾角，ヤング率，早期選抜

Summary

Evaluation of bending properties and other wood properties in seedlings is one of the important tree breeding program for early selection of families with desirable wood quality. In the present study, bending properties and other wood properties were examined for two families from less pollen varieties (Minamiaizu 4 and Higashishirakawa 9) of four-year-old *Cryptomeria japonica* D. Don to evaluate the possibility of selection of desirable wood properties at early stage of growth. Significant differences in growth characteristic, wood properties, and bending properties were found between two families. Basic density and microfibril angle (MFA) in latewood tracheid showed almost similar values (about 30 °) compared to those of juvenile wood in *C. japonica*. Modulus of elasticity (MOE) of seedlings was related to MFA and air-dry density, suggesting that MOE of seedlings could be estimated by MFA and air-dry density. However, compression wood existed in xylem of the many sample seedlings. Therefore, when the MFA is used as an indicator of evaluation of wood properties for early selection in a tree breeding program, existence of compression wood should be considered.

Key words: Cryptomeria japonica D. Don, MFA, Young's modulus, early selection

1. Introduction

Up to date, many researchers have been investigating the relationship between wood properties and strength properties in *Cryptomeria japonica* D. Don. [1,3,7,9,15] It is known that modulus of elasticity (MOE) is an important factor for construction lumbers. However, *C. japonica* wood shows relatively low MOE. It has been also reported that MOE negatively correlates with microfibril angle (MFA) of S2 layer in latewood tracheid[1,12]. In tree breeding programs, MFA has been considered as one of the predictors evaluating strength properties such as MOE. [2,5,10,15] There are some reports predicting MOE of mature wood using the MFA at early stage of growth. [2,10] Nakada *et al.*[10] investigated relationships between the dynamic Young's modulus of logs and MFA of latewood tracheid in plus tree clones of *C. japonica*. They concluded that the MFA at the 2nd annual ring from the pith can be used as an indicator for evaluating Young's modulus of log. Ishido *et al.*[2] also reported that MOE of mature wood determined by small-clear specimen can be predicted by using the MFA at the 3rd ring from the pith.

There are several researches estimating strength properties of seedlings at early stage of growth. [4,11] Nakamura[11] examined static Young's modulus of seedlings of plantation species (*Abies sachalinesis* Masters, *Larix kaempferi* (Lamb.) Carr., *L. kaempferi* × *L. gmelini, Picea glehnii* Mast., and *P. jezoensis* Carr.) in Hokkaido, Japan. Kasal *et al.*[4] also examined compression, tensile, and bending strength using 1-year-old quaking aspen (*Populus tremuloieds*). They reported that failure was difficult due to the large sample deflection, leading to the relatively high strength value. However, only a few reports are available for clarifying the relationship between bending properties and other wood properties in seedlings.[13] In tree breeding program, it is a subject that evaluation of wood properties in mature wood needs a long time. However, to reduce the time for breeding, estimating wood properties of mature wood by some properties in early stage of growth is important.

In the present study, the relationship between bending and other wood properties were investigated using 4-year-old seedlings of two families from less pollen varieties of *C. japonica* using to evaluate wood properties at early stage of growth.

2. Materials and Methods

Materials

Seedlings of two open pollinated families from less pollen varieties (Minamiaizu 4 and Higashishirakawa 9 of *Cryptomeria japonica* D. Don were used in this study. The seedlings were provided from Tochigi Prefectural Forestry Research Center, Tochigi, Japan. Minamiaizu 4 and Higashishirakawa 9 were selected as less pollen varieties of *C. japonica* by Forestry and Forest Products Research Institute, Tsukuba, Japan. The seedlings were grown at nursery of Tochigi Prefectural Forestry Research Center, from which 4-year-old seedlings of both families were obtained. Seedlings used in the present study were 18 and 10 for Minamiaizu 4 and Higashishirakawa 9, respectively. Only the seedlings with straight stem were selected to avoid the presence of compression wood. Stem diameter at 3 cm above the ground and height of seedlings were measured in all seedlings

Basic density and microfibril angle (MFA) of the S2 layer in latewood tracheid

To measure basic density and MFA, two disks (1 cm in thickness) were collected at about 90 cm above the ground.

Basic density was calculated by green volume measured dividing by water displacement method by oven-dried weight. A whole disk without bark collected from each seedlings was used as the specimen for measuring basic density.

The MFA was measured at the 3rd annual ring from the pith by iodine method.[6] The radial-longitudinal sections (20 μm in thickness) were prepared by using a sliding microtome (Yamato, Rom380). These sections were soaked in Schultze's solution (100 ml 35% nitric acid containing 6 g potassium chlorate), and then dehydrated with graded ethanol series (50 to 100%). Dehydrated sections were treated with one drop of mixture solution of 3% potassium iodine and iodine solutions and then treated with one drop of 60% nitric acid. Ten microphotographs were taken using a system-microscope (Nikon, ECLIPSE E600) equipped with a digital camera (Nikon, E4500). Mean value of MFA was calculated by averaging the values of 30 latewood tracheids in each seedling.

Static bending property

A specimen (30 cm in length) without the bark was obtained at 60 to 90 cm above the ground to determine static bending properties for each seedling. Dimension and weight of the specimen were measured to calculate air-dry density of specimens.

Static bending test was conducted using an universal testing machine (Tokyo Testing Machine, MSC-5/500-2). The span and cross head speed were 280 mm and 10 mm/min, respectively. Mean moisture content of specimen was 109.8% at bending testing. Modulus of elasticity (MOE) and Modulus of rupture (MOR) were calculated by the following equations:

$$\text{MOE (MPa)} = \Delta PL^3 / 48Iy$$

$$\text{MOR (MPa)} = PL / 4Z$$

, where ΔP (N) is the proportional limit load, L (mm) is the span, I (mm^4) is the moment of inertia of the specimen, y (mm) is the deflection corresponding to ΔP, P (N) is the maximum load, and Z (mm^3) is the modulus of section of the specimen.

Statistical analysis

Statistical differences between two families in bending properties and other wood properties were evaluated by *t*-test.

3. Results and discussion

Wood property

Table 1 shows wood properties of seedlings in two families. Mean values of diameter and tree height in Minamiaizu 4 family were significantly larger than those of Higashishirakawa 9 family. These results suggest that Minamiaizu 4 family has superior growth characteristic at the early stage of growth compared to Higashishirakawa 9 family.

Moisture content of Minamiaizu 4 and Higashishirakawa 9 families were 115.5 ± 21.5% and 99.6 ± 31.1%, respectively (Table 1). Basic density of Higashishirakawa 9 family (0.43 ± 0.05 g/cm^3) showed higher value than that of Minamiaizu 4 family (0.41 ± 0.04 g/cm^3) (Table 1). There was no significant difference (5% level) in moisture content and basic density between two families. It has been reported that basic density near the pith of *C. japonica* shows about 0.3 to 0.4 g/cm^3.[3,7] Our results were similar to those reported by other researchers.

MFA of Minamiaizu 4 family showed significantly higher value (26.2 ± 2.2 °) than that (23.2 ± 1.4 °) of Higashishirakawa 9 family (Table 1). Hirakawa and

Table 1 Comparison of wood properties of seedlings between two families

Property	Family: Minamiaizu 4 (n=18)				Higashishirakawa 9 (n=10)				Difference
	Avg.	SD	Maximum	Minimum	Avg.	SD	Maximum	Minimum	
Diameter (mm)	34.9	6.7	45.3	23.4	29.3	4.3	36.2	21.8	*
Tree height (cm)	205.8	30.2	251.0	161.0	180.0	19.3	212.0	147.0	*
MC (%)	115.5	21.5	147.7	74.0	99.6	31.1	157.3	60.4	ns
BD (g/cm^3)	0.41	0.04	0.50	0.37	0.43	0.05	0.50	0.36	ns
MFA (degree)	26.2	2.2	29.3	22.7	23.2	1.4	25.1	21.1	**
ρ (g/cm^3)	0.48	0.07	0.66	0.41	0.50	0.03	0.55	0.45	ns
MOE (GPa)	2.43	0.68	3.95	1.47	3.10	0.65	4.05	2.15	*
MOR (MPa)	58.7	11.2	81.9	40.7	59.5	5.6	68.1	50.1	ns
E/ρ	4.61	1.10	6.90	2.80	5.78	1.22	7.53	4.42	*

Notes: Diameter, diameter at 3 cm above the ground; MC, moisture content; BD, basic density; MFA, microfibril angle of S_2 layer in latewood tracheid; ρ, density of specimen using for bending test; MOE, modulus of elasticity; MOR, modulus of rupture; E/ρ, specific MOE; SD, standard deviation; *, **, and ns shows significance at 5% level, at 1% level, and no significant differences between families.

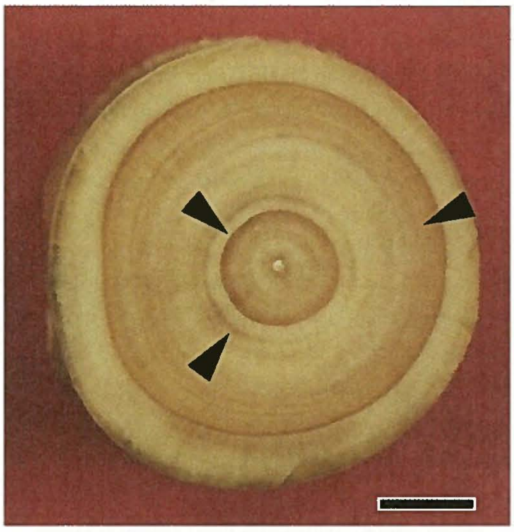

Fig. 1 A disk of Minamiaizu 4 collected from 90 cm above the ground.

Notes: Arrowheads indicate compression wood; bar, 0.5 cm.

Fujisawa[1)] reported that MFA of *C. japonica* plus tree clone was about 20 to 40 ° at the 2nd annual ring from the pith. Our results obtained were similar to those obtained by Hirakawa and Fujisawa.[1)] In the present study, on the other hand, the presence of compression wood was confirmed in many parts of xylem (Fig. 1). In general, compression wood is characterized by eccentricity of stem cross section on the under side of included stems or branches, circular tracheid in cross section, and large MFA of about 45 °.[8)] Although significant difference in MFA between two families was found, the difference might be caused by the existence of compression wood. We would have to pay attention to the existence of compression wood in selection of family with good wood quality at the early stage of growth in tree breeding.

Static bending property

The results of static bending test are shown in Table 1. Almost the same mean values in MOR were obtained in both families. On the other hand, MOE and E/ρ showed significant higher values in Higashishirakawa 9 than in Minamiaizu 4 family. It has been reported that, in *C. japonica*, MOE in juvenile wood is lower than that in mature wood.[2,3,9,16)] The MOE in juvenile wood shows about 3 to 5 GPa.[2,3,9)] In the present study, MOE showed 2.43 ± 0.68 and 3.10 ± 0.65 GPa in Minamiaizu 4 and Higashishirakawa 9 families, respectively. Our results obtained in the present study showed relatively smaller values than those obtained by other researchers.[2,3,9)] Zhu *et al.*[16)] examined radial variation of MOR in *C. japonica* at various tree heights. They reported that MOR in juvenile wood was similar or slightly smaller than that in mature wood, indicating that MOR showed almost the same value from the pith to bark. Thus, in Minamiaizu 4 and Higashishirakawa 9 families, MOR in mature wood might be similar to that in juvenile wood obtained in the present study (*ca.* 60 MPa). The results obtained suggested that MOR of seedlings can be used as one of the indicators for estimating that of mature wood in the early selection of good wood properties.

Figure 2 shows correlation coefficients among static bending properties in two families. In both families, significant correlation coefficients were recognized among

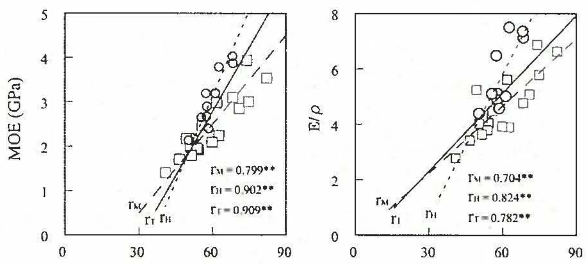

Fig. 2 Relationship between MOR and MOE or E/ρ in two families.

Notes: r_M, r_H, and r_T indicate correlation coefficient in Minamiaizu 4, Higashishirakawa 9, and all tree, respectively.

Table 2 Correlation coefficients among wood properties

	Family				All tree (n=28)	
	Minamiaizu 4 (n=18)		Higashishirakawa 9 (n=10)			
Factor	BD	MFA	BD	MFA	BD	MFA
MOE	0.118 ns	-0.378 ns	0.491 ns	-0.303 ns	0.348 ns	-0.524 **
MOR	0.149 ns	-0.233 ns	0.556 ns	-0.138 ns	0.233 ns	-0.199 ns
E/ρ	-0.005 ns	-0.426 ns	0.410 ns	-0.428 ns	0.272 ns	-0.571 **

Notes: Abbreviations refer to Table 1

static bending properties. It has been reported that MOE positively correlated to MOR.[9,14] Our results obtained were similar to those obtained by other researchers. It is concluded that MOE would be a powerful indicator to predict MOR in four-year-old seedlings of *C. japonica*.

Correlation between static bending properties and other wood properties

Table 2 shows correlation coefficients among wood properties in two families. Significant correlations among wood properties were not recognized in both Minamiaizu 4 and Higashishirakawa 9 families. On the other hand, significant negative correlation coefficients were obtained between MFA and MOE or E/ρ in all trees. Kijidani and Kitahara[5] reported that MOE obtained by compression test parallel to grain correlates with MFA in both juvenile and mature wood. Ishiguri *et al.*[3] also reported that high significant negative correlation coefficient ($r = -0.863$) was recognized between MOE by small clear specimen and MFA in juvenile wood of *C. japonica*. It has been reported that, in juvenile wood of *C. japonica*, MOE does not always correlate to density because MFA in juvenile wood considerably varied compared to mature wood.[1] On the other hand, E/ρ was reported to correlate with MFA in juvenile wood.[1,12] Our results obtained were similar to those by other researchers. Therefore, results obtained here suggest that MOE of seedlings might be estimated by using MFA and air-dried density.

4. Conclusion

In the present study, the relationship between bending properties and other wood properties was investigated in two families from less pollen varieties of *C. japonica*, Minamiaizu 4 and Higashishirakawa 9, to evaluate wood properties at the early stage of growth. The results obtained are as follows:

1) There was a significant difference in growth, static bending and other wood properties between Minamiaizu 4 and Higashishirakawa 9 families.
2) Wood properties such as basic density and MFA were almost similar compared to those reported previously in *C. japonica*, although compression wood was observed in xylem of many sample seedlings.
3) MOE of seedlings could be estimated by using MFA and air-dried density in four-year-old seedlings.

For early selection of good wood properties in tree breeding program, the existence of compression wood must be considered when the MFA is used as an indicator for predicting mechanical properties in mature wood.

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