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COMPARATIVE STUDY ON PHYSICAL AND MECHANICAL PROPERTIES OF DIFFERENT FAST-GROWING CLONES OF CUNNINGHAMIA LANCEOLATA

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Abstract: The objective of the current study was to compare, the wood properties of different Chinese wood verities to provide information for the rational use of wood and the directional cultivation of high quality wood. For this purpose a total of 7 excellent clones of 30-years old Chinese fir wood that were 79172, 8219, 7962, 79182, 79173, 7922 and 7911, respectively were taken to compare with one control (CK) wood collected from Jindong Forest Farm in Hunan Province. The air-dry density, basic density, modulus of rupture (MOR), modulus of elasticity, compressive strength parallel to grain, tensile strength parallel to grain, compression resistance of all stripes to flat & radial and compression resistance of local to flat & radial were measured according to national standards. Air-dry density, basic density, chord-wise cross-grain compression, all radial cross-grain compression, chord cross-grain local compression, radial cross-grain local compression, along-grain bending strength, along-grain resistance The measured values of flexural modulus, compressive strength along the grain, and tensile strength along the grain are 0.376-0.438 g/cm3, 0.301-0.355 g/cm3,5.18-7.16Mpa,4.64-6.27Mpa, 9.68-10.99MPa, 9.18-10.66MPa, 64.34-79.38 Mpa,7.78-8.95Mpa,42.78-50.20MPa,93.72-114.69 MPa; the corresponding maximum values are 79173 (0.463 g/cm3),79182 (0.355 g/cm3),79172 (7.16Mpa),79172 (6.27 Mpa),7922 (10.99MPa),79172 (10.66 MPa),79182 (179.38 Mpa),79182 (8.95 Mpa), 79172 (50.20 MPa), 79172 (114.69 MPa). In the physical and mechanical properties of wood, the air-dry density, basic density, chordwise transverse grains are all compressive, radial transverse grains are all compressive, chord transverse grains are locally compressive, radial transverse grains are locally compressive, and along grains of flexural strength, along-grain flexural modulus, along-grain compression and along-grain tensile are significantly different among different strains and are closely related. Using 10 indicators of wood physical and mechanical properties for cluster analysis, the wood properties of 79172 and 7922 are generally better than other varieties.

Keywords： Cunninghamia lanceolata; Superior clones; Physical properties; Mechanical properties.

INTRODUCTION

The development of clonal plantation resources to provide raw materials for the wood industry and pulp and paper is the common trend of global forestry development in the 21st century (Hui et al., 2016). In recent years, many studies have been conducted on the physical and mechanical properties of the main timber species clones, providing a reliable basis for the directional cultivation of high-quality wood. For example, a recent study results on 10-year-old hybrid eucalyptus clones showed that the basic wood density range is mainly concentrated in 0.4745~0.6104 g·cm3 (Tao et al., 2019). Similarly, Yi *et al.* (2018) studied the southern type of poplar clones and found that there are very significant differences among wood basic density, flexural strength, flexural elastic modulus, grain compression strength, wood basic density and flexural elastic modulus. They further reported a significant positive correlation in compressive strengths along the grain, and a significant linear correlation in the various indicators of mechanical properties in wood. Moreover Deyu *et al.* (2010) found 22-year-old clones of 180 excellent masson pine trees in 9 producing areas and designed method to confirm the importance and potential of excellent provenance background selection of masson pine, and excellent tree selection from the best provenance origin. Furthermore, Junpei *et al.* (2016) worked on different strains of American black walnut clone and wood physical and mechanical properties found that the clones showed significant differences in several physical and mechanical properties. Similarly, Munir *et al.* (2020) also reported that different strains of wood had significant differences in several physical and mechanical properties. Moreover, Sparke and Wünsche (2020) also reported similar findings. Based on the above research studies, it could be hypothesized that there are significant differences in the physical and mechanical properties of clonal wood. Therefore, studying the physical and mechanical properties of different clonal wood is of great significance to the rational use of wood and the directional cultivation of high-quality wood.

In the current research project, 7 fast-growing Chinese fir clones in the 30-year period of the Jindong Forest Farm in Hunan Province was used to fetch the excellent materials. This study will provide the base for future studies to construct the fast-growing high-quality industrial timber forests of Chinese fir.

MATERIALS AND METHODS

Overview of the test site: The experimental site is located in the Jindong Forest Farm in Yongzhou City of China. The geographical coordinates were E110º53´43” and N26º21´37” and it belongs to the mid subtropical southeast monsoon humid climate, with an average annual temperature of 18℃, an average annual rainfall of 1000~1800mm, and an average annual evaporation of 1225mm. The effective sunshine hours are 1617h, and the relative humidity is 75~82%. The soil belongs to forest yellow soil, with a thickness of 30~60cm and a pH of 4.5~5.5.

Experiment material: Fast-growing clones and control CK samples were selected from the 30a clone field trial forest in October 2016. According to the criteria of H>CK5%, D1.3>CK10% and V>CK20% among the 131 clones tested, 7 fast-growing clones were selected from the tested clones, and each clone was selected separately. There were 3 representative and normal samples for each variety and the control also contained 3 representative and normal samples. The felling was carried out in November 2016, and samples were cut according to relevant national technical regulations. The basic situation of the sample wood is shown in Table 1. It can be seen from Table 1, that the diameter at breast height of the 7 clones in descending order was 79172>7911>7922>8219>7962>79173>7918>CK; the order of tree height was 79173> 7922>79182>79172>7962>7911>8219>CK; the order of volume from largest to smallest was 7922>79172>7911>8219>79173>7962>79182>CK. In terms of diameter at breast height, tree height and volume values, were 79172 and 7922 and showed better growth.

Material index and measurement method: The physical and mechanical properties included air-dry density, basic density, compression resistance of all stripes to flat, compression resistance of all stripes to radial, compression resistance of local to flat, compression resistance of local with tot radial, bending strength to grain, flexural modulus to grain, tensile strength parallel to grain, compressive strength parallel to grain. The performance test was in accordance with China’s National Standards. The performance test was in accordance with GB/T1933-2009 "Wood Density Determination Method", GB/T1938-2009 "Wood Grain Tensile Strength Test Method", GB/T1938-2009 T1935-2009 "Test Method for Timber Compressive Strength along Grain", GB/T1936.1-2009 "Test Method for Timber Flexural Strength", GB/T1936.2-2009 "Determination of Timber Flexural Modulus of Elasticity", GB/T1936.1-2009 T1939-2009 "Test Method for Compressive Strength of Wood Horizontal Grain".

Table 1. Basic information of selected wood sample

Clone	Mean		
	DBH	Height	Volume
7911	27.50	18.55	0.5507
7922	27.40	18.90	0.5553
7962	26.30	18.60	0.5046
79172	27.73	18.83	0.5825
79173	26.17	19.20	0.5135
79182	25.87	18.90	0.4950
8219	26.80	18.47	0.5208
CK	23.57	17.30	0.3809

Statistical method: One-way analysis of variance (one-way ANOVA) and Duncan method were used for analysis of variance and multiple comparisons (P=0.05) by using SPSS 25.0 (Jiande *et al.*, 2016); Euclidean distance was used for cluster analysis of the tested germplasms (Dacai *et al.*, 2019). Pearson correlation coefficient was used to measures the correlation between two variables (Liming *et al.*, 2019).

RESULTS

Wood density of fast-growing clones: The comparison and variation analysis results of the air-dry density and basic

Table 2. Comparison and variation of wood density of fast-growing clones.

Clones	Air-dry density(g/cm3)		Basic density(g/cm3)	
	mean(g/cm3)	Coefficient of variation (%)	mean(g/cm3)	Coefficient of variation (%)
79172	0.4125±0.0098[b]	2.38	0.3347±0.0078[a]	2.33
8219	0.3877±0.0040[c]	1.03	0.3148±0.0034[d]	1.08
7962	0.3832±0.0058[d]	1.51	0.3110±0.0048[d]	1.54
79182	0.4201±0.0091[a]	2.17	0.3405±0.0075[a]	2.20
79173	0.4266±0.0095[a]	2.23	0.3399±0.0062[a]	1.82
7922	0.4203±0.0091[a]	2.17	0.3408±0.0072[a]	2.11
7911	0.4107±0.0018[b]	0.44	0.3330±0.0015[b]	0.45
CK	0.4017±0.0152[c]	3.78	0.3270±0.0102[c]	3.12

Different lowercase letters in the same column indicated significant difference (P<0.05) density of the 7 fast-growing clones are shown in Table 2. The result of variance analysis and multiple comparisons showed that the air-dry density and basic density of the 7 fast-growing clones were significantly different *(P<0.05)*. Results showed that the air-dry density range of fast-growing clones was 0.372~0.438g/cm^3, and 79173 variety showed the highest air-dry density which was 7.3% larger than CK, The basic density range was 0.301~0.355 g/cm^3, The highest basic density was observed in 79182 variety, which was 5.5% larger than CK. Coefficient of variation results indicated that the CK coefficient of variation for the air-dry density and the basic density were higher, which were 3.78% and 3.12% respectively; the coefficient of variation of the test samples of wood density of all clones is less than 10% , Which showed that the degree of wood dispersion was relatively uniform among all the varieties.

In general, the air-drying density of the 7 fast-growing clones was positively correlated with the basic density, that was, the greater the air-drying density which can provide a basis for the directional selection of superior Chinese fir clones.

Mechanical properties of fast-growing clones: The comparison and variation analysis results of the wood mechanical properties of 7 fast-growing clones are shown in Table 3. The results of analysis of variance and multiple comparisons show that there were significantly different *(P<0.05)* in the mechanical properties among the 7 fast-growing clones. The compressive range of the fast-growing clone chord wise transverse grain was 5.18~7.16MPa, the largest was observed in 79172 variety, which was 14.7%, greater than CK. The radial transverse grain has a total compressive range of 4.64~6.27MPa, and the largest radial transverse grain was observed in 79172 variety, which was 14.4%, larger than CK. The local compressive range of chordwise transverse grain was 9.68~10.99MPa, the largest was observed in 7922 variety, which was 5.8%, larger than CK. The local compressive range of radial transverse grain was 9.86~10.66MPa, and the largest was observed in 79172 variety, which was 5.9%, greater than CK. The flexural strength range along the grain was 64.34~79.38MPa, the largest was observed in 79182 variety, which was 12.1%, greater than CK; The flexural modulus along the grain was 7.78-8.95MPa, and the maximum bending strength was observed in 79182. which was 8.4%, larger than CK. The compressive range along the grain was 42.78~50.20MPa, the maximum bending strength was observed in 79172 variety, which was 5.5%, larger than CK. The tensile range along the grain was93.72~114.69MPa, the largest was observed in 79172 variety, which was larger than CK 7.7%, larger than CK. The coefficient of variation results showed that, The coefficient of variation of the test samples for mechanical traits of 7 fast-growing clones were all lower than 10%, which shows that wood properties have great room for improvement and optimization at the clonal level

***The relationship between the Physical and mechanical properties*:** The correlation analysis results of the physical properties and mechanical properties of the 7 fast-growing clones are shown in Table 4. It can be seen from Table 4 that the air-dry density and basic density of wood were positively correlated with the along-grain flexural modulus without significant difference. They are all compression-resistant to the chordal transverse grains, all compressive to the radial transverse grains, and chordal transverse grains.

Table 3. Comparison and variation analysis on mechanical properties of fast-growing clones.

Clones	Compression resistance of all stripes to flat		Compression resistance of all stripes to radial		Compression resistance of local to flat		Compression resistance of local with tot radial	
	Mean (Mpa)	Coefficient of variation(%)	Mean (Mpa)	Coefficient of variation (%)	Mean (Mpa)	Coefficient of variation (%)	Mean (Mpa)	Coefficient of variation (%)
79172	7.16±0.123^a	1.72	6.27±0.169^a	2.69	10.75±0.205^b	1.91	10.66±0.222^a	2.08
8219	5.64±0.164^d	2.91	4.89±0.214^e	4.38	10.44±0.224^{bc}	2.15	9.77±0.247^d	2.53
7962	5.18±0.109^e	2.10	4.64±0.106^e	2.28	9.68±0.419^d	4.33	9.18±0.204^e	2.22
79182	6.15±0.310^c	5.04	6.14±0.293^{ab}	4.77	10.39±0.226^{bc}	2.18	10.43±0.302^{ab}	2.89
79173	6.28±0.231^{bc}	3.68	5.91±0.407^{bc}	6.88	10.43±0.381^{bc}	3.65	10.02±0.485^{cd}	4.84
7922	6.43±0.284^b	4.42	5.89±0.189^{bc}	3.21	10.98±0.593^a	5.40	10.16±0.232^{bc}	2.22
7911	6.08±0.331^c	5.44	5.62±0.286^{cd}	5.09	10.02±0.497^{cd}	4.96	9.86±0.328^{cd}	3.33
CK	6.24±0.228^{bc}	3.65	5.48±0.266^d	4.85	10.39±0.226^{bc}	2.18	10.06±0.198^{cd}	1.97

Clones	Bending strength to grain		Flexural modulus to grain		Tensile strength parallel to grain		Compressive strength parallel to grain	
	Mean (Mpa)	Coefficient of variation (%)	Mean (Gpa)	Coefficient of variation (%)	Mean (Mpa)	Coefficient of variation (%)	Mean (Mpa)	Coefficient of variation (%)
79172	75.20±0.853^b	1.13	8.58±0.353^b	4.11	50.20±1.251^a	2.49	114.69±2.538^a	2.21
8219	64.64±2.215^d	3.43	8.42±0.407^{bc}	4.83	43.98±1.414^d	3.22	95.15±1.790^d	1.88
7962	64.54±1.985^d	3.08	7.78±0.097^e	1.25	42.78±1.098^d	2.57	93.72±3.300^d	3.52
79182	79.38±2.013^a	2.54	8.95±0.233^a	2.60	46.59±0.992^c	2.13	101.54±3.986^c	3.93
79173	75.29±2.818^b	3.74	8.28±0.256^{cd}	3.09	46.09±1.395^c	3.02	106.91±3.037^b	2.84
7922	72.87±3.265^{bc}	4.48	7.83±0.175^e	2.23	49.09±1.655^{ab}	3.37	111.14±5.373^{ab}	4.83
7911	64.34±0.497^d	0.77	8.21±0.145^{cd}	1.77	47.34±2.400^{bc}	5.07	107.09±5.257^b	4.91
CK	70.83±1.742^c	2.46	8.06±0.186^{de}	2.31	47.58±1.768^{bc}	3.72	106.50±2.459^b	2.31

Local compression, radial transverse grain local compression, along-grain bending strength, along-grain compression, and along-grain tensile had a significant positive correlation, which indicates that the air-dry density and basic density of wood have different mechanical properties. There was also a very significant correlation between the chordwise transverse grain compression, the radial transverse grain compression, the chord transverse grain partial compression, the radial transverse grain partial compression, the parallel grain compression, and the parallel grain tension.

Cluster analysis of physical and mechanical properties: The cluster analysis of 7 fast-growing clones based on Euclidean distance is shown in Figure 1. The Euclidean distance 6.0 of the 7 fast-growing clones were divided into 2 groups. Clones 79172 and 7922 were one type and excellent physical and mechanical properties were observed in them. After that the clones 7911, 79178, 79173, and CK showed physical and mechanical properties. Some of the individual clones have some indicators higher than the previous category, but their overall performance was slightly lower. For example, the

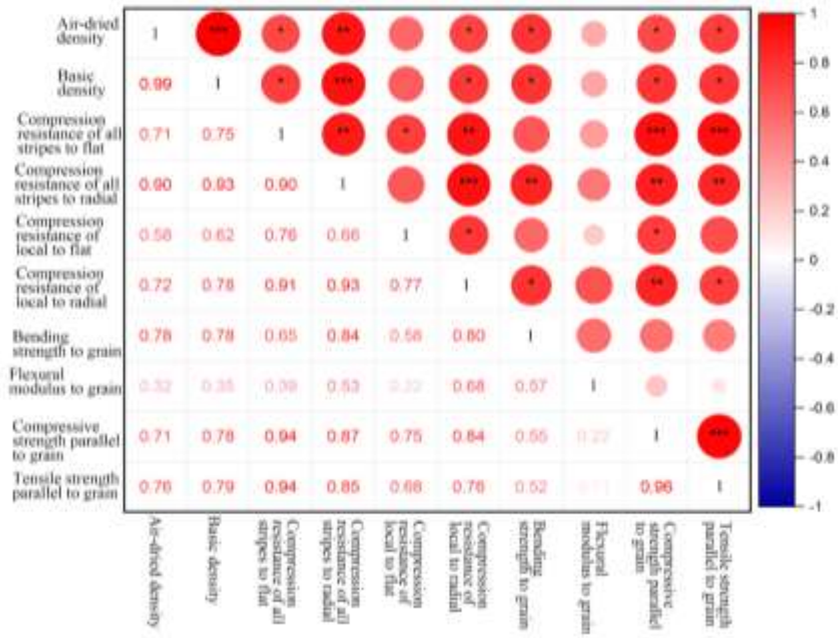

Figure 1. Correlation coefficient of physical and mechanical properties to fast-growing clones.
*.significant correlation (P<0.05),**.extremely significant correlation (P<0.01), ***.Very significant difference (P<0.001).

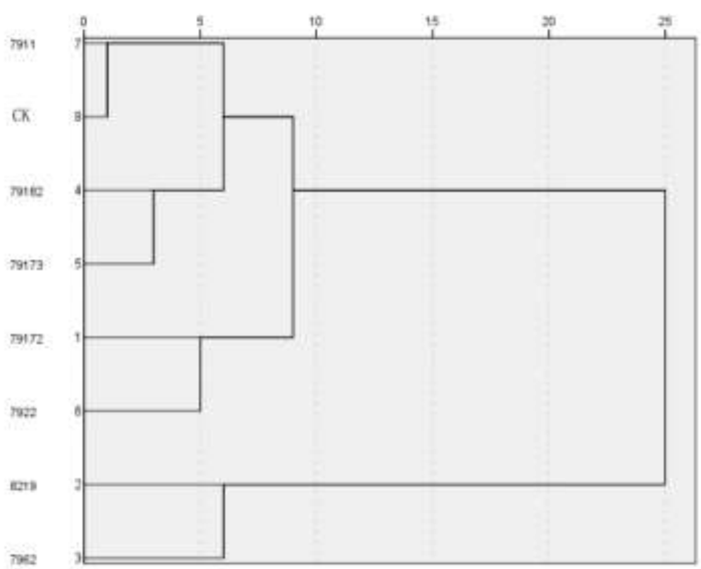

Figure 2. Cluster analysis of Chinese fir clones based on wood physical and mechanical properties.

clones 8219 and 7962 were categories as the first category and had the worst comprehensive performance.

DISCUSSION

Wood density has an important relationship with the mechanical strength of wood, and it is an important index for judging the technological properties and physical and mechanical properties of wood (Yin *et al.*, 2019). The mechanical properties of wood refer to the ability of wood to resist external mechanical forces, and it is an important basis for the rational development and utilization of wood (Peng *et al.*, 2018). Density is closely related to many properties of wood, and it is also an important parameter affecting wood mechanical properties (Qingyun *et al.*, 2015). In the current study, the air-dry density of the tested fast-growing clones was in between 0.372~0.438 g/cm^3, and the basic density was in between 0.301-0.355 g/cm^3, which is higher than the average level of the air-dry density (0.279 g/cm^3) and basic density (0.301 g/cm^3) intensity of Chinese fir clone (Chenkaii *et al.*, 2006). The difference could be related to the test tree age. However, it is consistent with the findings of the Hongwei *et al.* (2006) and Ruping *et al.* (2006). Mechanical properties can measure the ability of wood to resist external force, which is the main index of structural timber and also an important basis for rational utilization of wood (Hui et al., 2016). There was a very significant correlation between the chordwise transverse grain compression, the radial transverse grain compression, the chord transverse grain partial compression, the radial transverse grain partial compression, the parallel grain compression, and the parallel grain tension in the current study. Findings of the current study explain that the mechanical properties of wood are interrelated (Wei et al., 2014). It also shows that as far as the selection of excellent Chinese fir clones is concerned, the physical and mechanical properties of wood can be screened simultaneously. Moreover, in the current study, it was also observed that selected Chinese fir clones in the current study were fully compression resistance of all stripes to flat, compression resistance of all stripes to radial,compression resistance of local to flat, compression resistance of local with tot radial, bending strength to grain, flexural modulus to grain,tensile strength parallel to grain,compressive strength parallel to grain. These findings are consistent with the research results of Hongwei *et al.* (2006) and Jianliang *et al.* (2006).

Analysis of variance is an important method to evaluate the degree of variation in breeding research (Safaci *et al.*, 2006). In this study,10 physical and mechanical indicators differ significantly, which was consistent with the findings of the previous researcher (Qinbing *et al.*, 2006). Results of the current study explored that there was great potential to improve the timber properties of Chinese fir clones, and good results could be obtained by using 10 physical and mechanical indicators as reference indexes for selection of cultivars of large diameter wood culture of Chinese fir clones. Coefficient of variation also shows the degree to which the trait is influenced by genetic control and environmental factors (Rongli *et al.*, 2020). In the current study, the variation coefficients of 10 physical and mechanical properties were ranged from 0.44% to 6.88%. The variation coefficients were all less than 10%, indicating that the antagonistic conditions of the traits were not high, and the variation mainly came from the difference of genotypes, but was less affected by the environment (Dehuo *et al*., 2004; Wu *et al.*, 2012). The results also showed that the ratio of the tested clones to inherit the excellent characters of the original strains was higher. The stability of the characters in the same clone was high, and it has a broad genetic basis, which can provide theoretical basis for different levels of genetic improvement research and the selection and breeding of new excellent varieties.

The correlation coefficient reflects the population level parameters, rather than referring to a particular individual. Even if there is a negative correlation between two traits on the whole, there may be a special case where the genetic values of both traits are positively correlated with a specific genotype (Jiaqi *et al.*, 2001). According to the results of correlation analysis, the air-dry density and basic density of Chinese fir were positively correlated. Meanwhile, the air-dry density and basic density were positively correlated with the 8 mechanical properties of wood, and were significantly different from the mechanical properties of transverse mechanics, except the Flexural modulus to grain (Zobel *et al.*, 2001).These results indicates that physical and mechanical properties of Chinese fir are closely related. In the process of genetic improvement, the correlation between wood physical and mechanical properties can be used as a comprehensive index to carry out genetic improvement of two favorable traits simultaneously.

***Conclusion*:** The physical and mechanical properties of the seven fast growing Chinese fir clones were significantly different in 10 traits, which indicated that the improvement of Chinese fir clones had great potential and high selection gain could be obtained in application. Wood properties of fast-growing clones of Chinese fir showed a very significant positive correlation with wood density. Among all of the selected Chinese fir clones wood properties of 79172 and 7922 were best. Furthermore, cluster analysis results revealed that 79172 and 7922 belong to the first class. 79172 and 7922 Chinese fir clones have excellent physical and mechanical properties and can be popularized as indigenous wood.

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