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Article

Variation in the Growth Traits and Wood Properties of Hybrid White Poplar Clones

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Abstract: The physical and chemical properties of poplar clones largely determine their suitability for different applications. The main objective of this study was to investigate clonal variation in four hybrid poplar clones grown at three sites in North China and identify the superior clone. Study materials were collected from four clones of hybrid white poplar: *Populus tomentosa* "LM50", used as the control; two clones (Yiyang-1 and Yiyang-2), new hybrids of (*P. tomentosa* × *P. bolleana*) × *P. tomentosa* "Truncata"; and Yiyang-3, a new hybrid of (*P. tomentosa* × *P. bolleana*) × *P. tomentosa* "LM50". In total, 192 individuals from four hybrid clones were randomly chosen for sampling. The growth traits of four 7-year-old clones were examined at three sites. We also measured the wood properties of four 6-year-old clones at the Fengfeng nursery. Variation in the growth traits and the ranking of stem volumes differed among sites. Fiber traits and wood chemical components showed significant interclonal variation. With regard to the comprehensive growth rate, cellulose content, holocellulose content, and fiber traits, Yiyang-1 exhibited the best performance among the four hybrid poplar clones, indicating its utility as a raw material for pulp and papermaking.

Keywords: hybrid poplar clones; clonal variation; growth traits; physical properties; chemical properties

1. Introduction

The goal of tree breeding and seed source selection is to increase the quantity and quality of wood timber from plantations. Poplars have received much attention due to their shorter rotation times compared to other hardwood species grown in similar environments [1]. One of the fastest growing tree species, poplars are broadly used for construction, furniture, and as a potential energy resource. Poplar hybrids, in particular, are in demand because of their high productivity, and have been planted throughout North America; the maximum hybrid poplar yield reaches 40 m^3 (ha year)$^{-1}$ in southern Quebec, Canada [2].

With substantial increases in poplar afforestation worldwide, several poplar clones were introduced to China in the 1970s. Since then, poplars have become the major tree species in plantation and agroforestry systems throughout much of China. For example, *Leuce Duby* and *Aigeiros Duby* are very important in urban and rural greening projects.

The Chinese paper industry has grown rapidly since the 1990s, and China is now ranked second in the world in both paper and board production and consumption. Equally important, about 90% of the world's new paper machines are being built in China [3]. To meet increasing demand for raw materials, much effort has been put into improving tree quality and growth rates through breeding, particularly in poplar species. Chinese white poplar (*Populus tomentosa*) and its hybrids have developed into valuable species for various industries, and they are a sustainable part of forests [4,5].

Wood performance is closely related to the complex developmental process of wood formation, including the differentiation of cambial initials into various xylem tissues, cell elongation, and secondary cell wall synthesis. As the fiber and vessel cells undergo massive thickening, mature xylem cells form and accumulate, greatly increasing the quantity and quality of the timber. In general, wood properties can vary in their physical and chemical properties (e.g., fiber, lignin, and cellulose properties, and basic density). Wood density, mainly influenced by genotype [6], is considered the most important representative property of lignocellulosic materials. Additionally, fiber length (FL) determines whether the raw material is suitable for use in the paper industry [7]. The higher the density of the wood, the higher the pulp rate and paper tear strength at the expense of tensile strength, bursting strength, and elongation rate [8–10]. Fiber length impacts paper characteristics such as strength, optical properties, and surface quality. The microfibril angle (MFA), one of the main factors used to determine wood mechanical properties, provides a correlation between wood density and FL, affecting the elastic modulus of the wood, as well as anisotropic shrinkage, and low MFA can result in wood with high stiffness and strength [11]. In addition, crystallinity and water absorption are closely tied to the multifaceted performance of wood [12,13].

It is generally accepted that rapid growth results in less-than-desirable wood properties, especially with respect to density and mechanical properties [2]. Wood quality impacts the economic and commercial value of trees directly. Hybrid poplar wood is particularly well suited to current uses [14].

Hybridization, selection, and crossbreeding have been used to improve the growth rate, stem form, disease resistance, and broad adaptability of poplar hybrids. Studies of wood properties with respect to clonal variation and their end-use potential have generated interest in breeding programs. For example, genetic improvements to *Leuce Duby* have contributed to its afforestation in China, as the genetically improved trees grow more rapidly and are better able to meet current economic and construction needs. However, to date, few reports have focused on variation in multiple traits of poplar clones [5,15,16].

Wood quality and growth must be assessed to facilitate the use and development of new clones. The correlations between growth and wood property traits investigated in many previous reports indicate that it is desirable to include only a few traits in selective breeding [17]. For solid pulpwood production, the superiority of clones was best evaluated by stem volume, which revealed higher yields at higher growth rates. For the pulp and paper industry, research is focused on wood fiber morphology and wood chemical components that determine key paper attributes.

This study provides a comprehensive assessment of growth and wood property traits in four Chinese white poplar clones. Specifically, we investigate clonal variation in growth traits and wood properties and identify the clone with superior wood quality among the four hybrids tested. Our results will provide insight into the potential future generation and application of these new varieties in North China and abroad.

2. Experimental Section

2.1. Sampling

Materials were collected from four hybrid clones, growing in three clonal trials established by Beijing Forestry University (Beijing, China) in the spring of 2006. One trial took place at the Guanxian state-owned nursery in Shandong Province, North China, while the other two trials were located at the Fengfeng and Weixian nursery fields, respectively, in Hebei Province, North China (Table 1). All plantation trials had a randomized block design with four blocks, four to six ramets in every block, and a spacing of 2 m × 3 m. No thinning was applied during the trial period until measurements were taken.

The four hybrid clones were as follows: clone LM50 was used as the control, and the other three clones (Yiyang-1, Yiyang-2, and Yiyang-3) were licensed as new varieties by the State Forestry Administration Office for the Protection of New Varieties of Plants in 2012 (Table 2). The natural hybrid white poplar LM50 is considered a superior clone of *Populus tomentosa* Carr.

Sixteen ramets per clone were randomly sampled at each site, for a total of 192 trees, in 2012. We measured the total tree height (H) and diameter at breast height (DBH) of all sampled trees. To reduce costs, three ramets per clone from Fengfeng nursery were selected for sampling based on a preliminary investigation of the growth characteristics of 29 6-year-old clones from the three sites; this was done to examine the physical and chemical properties of the wood. We avoided trees growing near roads or big gaps and inclined trees. All sample trees at each site had straight boles, were free from defects, and were growing on land with relatively uniform topography.

Table 1. Geographical and meteorological parameters of three sites in this study.

Parameters	Fengfeng Nursery	Weixian Nursery	Guanxian Nursery
Latitude (°N)	36°25′	36°58′	36°30′
Longitude (°E)	114°13′	115°15′	115°21′
Frost-free period (d)	200	198	210
Annual precipitation (mm)	627	584	500
Annual average temperature (°C)	14.1	13	13.6
Landform	Basin, plain	Plain	Plain
Climate	Sub-humid warm temperate continental monsoon climate	Semi-arid warm temperate continental monsoon climate	Semi-arid temperate continental monsoon climate
Soil type	Loam	Loam	Sandy loam

Table 2. Identity and origin of the hybrid clones.

Clone Identity	Scientific Name	Parents	Sex
LM50	*P. tomentosa* 'LM50'		♂
Yiyang-1	*Populus* × 'Yiyang-1'	(*P. tomentosa* × *P. bolleana*) × *P. tomentosa* 'Truncata'	♂
Yiyang-2	*Populus* × 'Yiyang-2'	(*P. tomentosa* × *P. bolleana*) × *P. tomentosa* 'Truncata'	♀
Yiyang-3	*Populus* × 'Yiyang-3'	(*P. tomentosa* × *P. bolleana*) × *P. tomentosa* 'LM50'	♂

2.2. Growth and Testing of Wood Properties

The stem volume (V) was calculated for each sample based on the volume function of DBH and H used by Chen [18]:

$$V = 0.51340\ H^{0.828956}\ DBH^{1.996375} \quad (1)$$

where V is the stem volume (m^3), H is the tree height (m), and DBH is the diameter at breast height (cm).

Wood quality attributes were quantified by examining wood density, fiber length (FL), fiber width (FW), microfibril angle (MFA), volume drying shrinkage (VDS), and lignocellulosic content. We drilled a 10-cm-thick duramen in the north-south direction from bark to pith from the main stem at breast height (130 cm) for each tree, and sealed it immediately in a plastic bag to prevent moisture content loss. The basic wood density (BWD) was calculated as the oven-dry mass to green volume ratio following sample preparation [2,19], using the maximum moisture content method described by Smith [20]. Wood samples underwent natural drying and were processed in accordance with various specifications. Through natural drying, the water content of the specimens was measured. Three pieces of wood (20 mm × 20 mm × 20 mm) were prepared longitudinally for physical property measurements: FL, FW, BWD, MFA, VDS, and crystallinity. FL was measured from maceration using an L&W Fiber Tester (AB Lorentzen and Wettre, Kista, Sweden) for image analysis [21]. The MFA was determined by X-ray diffraction (XRD 6000 Diffractrometer, Shimadzu, Japan). For chemical property measurements, sawdust powder was used to test for cellulose, holocellulose, and lignin using near-infrared reflectance spectroscopy (NIRS). Wood quality evaluations were performed at Beijing Forestry University based on national measurement standards. The chips were stored in polyethylene bags throughout the study.

2.3. Data Analysis

SPSS v. 17.0 (SPSS for Windows) was used to perform a statistical analysis. The normality and homogeneity of variance for residuals were tested using the UNIVARIATE procedure. An analysis of variance (ANOVA) was used to detect differences within and among the poplar clones. A type III (partial sums of squares) estimation was used to assess the relative magnitude of each variation source. Variation among the clones for individual components is presented.

3. Results and Discussion

3.1. Within- and Among-Site Variation

The mean values of all studied growth traits for 7-year-old clones of hybrid white poplar in each trial are presented in Table 3. On average, the greatest DBH, H, and V were found at Fengfeng nursery, and the lowest were observed at Guanxian nursery, with 21.80%, 23%, and 75.25% differences, respectively. Clearly, growth was fastest at Fengfeng and slowest at Guanxian. The ANOVA for the three sites in Table 4 revealed a significant effect of growth site on the growth characteristics studied. Tables 3 and 4 show that Fengfeng differed significantly (α = 0.05) in all growth traits from the other sites.

Table 3. Mean growth traits of four clones from three sites.

Trait and Geographical Origin (Site)	Mean ± SE				Mean	Significance
	Yiyang-1	Yiyang-2	Yiyang-3	LM50		
Fengfeng Nursery						
DBH (cm)	20.4 ± 0.1 a	20.9 ± 0.1 a	16.5 ± 0.2 c	18.3 ± 0.3 b	19.0	**
H (m)	15.1 ± 0.1 ab	14.4 ± 0.2 b	15.5 ± 0.4 a	14.9 ± 0.2 ab	15.0	*
V (m^3)	0.2043 ± 0.0296 a	0.2058 ± 0.0137 a	0.1374 ± 0.0336 c	0.1633 ± 0.0854 b	0.1777	**
Guanxian Nursery						
DBH (cm)	14.9 ± 0.2 b	17.7 ± 0.1 a	15.1 ± 0.1 b	14.7 ± 0.1 b	15.6	**
H (m)	11.9 ± 0.1 b	11.9 ± 0.1 b	13.2 ± 0.1 a	12.1 ± 0.2 b	12.2	*
V (m^3)	0.0892 ± 0.0230 b	0.1303 ± 0.0080 a	0.0983 ± 0.0194 b	0.0878 ± 0.0211 b	0.1014	**
Weixian Nursery						
DBH (cm)	18.9 ± 0.2 a	15.5 ± 0.2 b	13.7 ± 0.2 c	17.7 ± 0.2 a	16.5	**
H (m)	14.9 ± 0.2 a	14.5 ± 0.1 a	15.0 ± 0.1 a	15.6 ± 0.0 a	15.0	NS
V (m^3)	0.1758 ± 0.0408 a	0.1161 ± 0.0251 b	0.0931 ± 0.0119 c	0.1605 ± 0.0309 a	0.1364	**

Note: (1) SE: standard error; DBH: diameter at breast height; H: tree height; V: stem volume; (2) Different lowercase letters correspond to significant differences ($p < 0.05$) among the clones. (3) NS: not significant; * Significant at $\alpha = 0.05$; ** Significant at $\alpha = 0.01$.

Table 4. Genetic stability of four clones at three sites.

Clones	ΔV (%)	CV (%)	Ci	$p < 0.01$
Yiyang-1	14.0	35.66	0.0179	A
Yiyang-2	9.8	31.87	0.0122	B
LM50	0.0	33.58	–0.0013	C
Yiyang-3	–20.1	24.34	–0.0289	D
Mean	–	31.36	0.0000	

Note: (1) ΔV (%): Percentage of V increment of the three new varieties, compared with LM50. CV (%): coefficient of variation in the site × clone interaction. Ci: clonal effect. (2) Different lowercase letters correspond to significant differences among the clones at α = 0.05. Different capital letters correspond to significant differences among the clones at α = 0.01.

The significant site effect was consistent with previous reports [5,15,16,21–23]. Site effects reflect the reaction of trees to the combined effects of edaphic and climatic conditions [2,16,21]. With the exception of cultivation and the management of irrigation and drainage, variation in growth rate in this study is attributable in part to geography, soil quality, annual precipitation, etc. Individuals from Fengfeng nursery show characteristics superior to those from Weixian or Guanxian: all clones planted at Fengfeng exceeded the productivity of the other sites in terms of stem volume. Fengfeng has high annual precipitation compared to the other two sites, and more fertile soil than Guanxian, which may explain these differences in wood quantity and quality.

3.2. Clonal Variation in Growth Traits

The variation in growth traits at each site differed in significance (with the exception of H at Weixian) among the four hybrid clones (Table 3). At α = 0.05, the V ranking for the hybrid clones at each site varied.

For the Fengfeng nursery, Yiyang-1 and Yiyang-2 had greater V values than did LM50 or Yiyang-3, with Yiyang-3 having the lowest value. Specifically, the V of Yiyang-1 and Yiyang-2 were greater than that of LM50 (the control) by 25.1%, 26.0%, and −15.9%, respectively. However, we found no significant differences between Yiyang-1 and Yiyang-2. For the Guanxian nursery, Yiyang-1 had a V similar to that of LM50, and the percentage of excesses V in Yiyang-2 and Yiyang-3 reached 48.4% and 12.0%, respectively. Yiyang-2 had the greatest V and differed significantly from Yiyang-1, LM50, and Yiyang-3, respectively, whereas no significant differences were observed among the three clones. For the Weixian nursery, the V of Yiyang-1 was similar to that of LM50 and greater than those of Yiyang-2 and Yiyang-3, with the lowest V observed for Yiyang-3.

Yiyang-3 displayed notably lower growth performance than the other three clones, except at Guanxian nursery where it was similar to that of LM50 (Table 3; Figure 1). However, Yiyang-1 and Yiyang-2 exhibited faster growth than Yiyang-3 and LM50 at Fengfeng and Guanxian. Although significant differences between Yiyang-1 and Yiayng-2 were minor or inconsistent, Yiyang-1 had the greatest total mean volume and the largest percentage-of-volume increment *vs.* LM50 across all three sites (Table 4). Among all clones, Yiyang-1 was ranked first, followed by Yiyang-2, LM50, and Yiyang-3. In this case, Yiyang-1 grew faster than LM50 and the other two new hybrid clones.

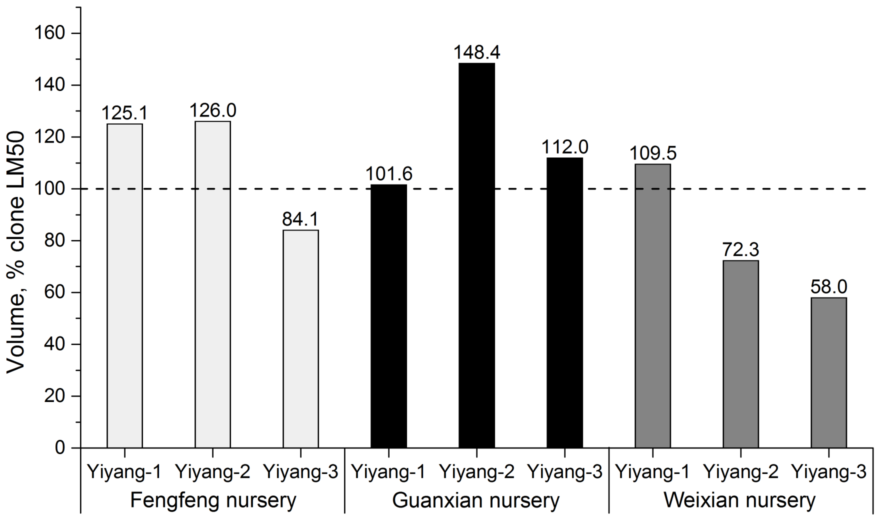

Figure 1. Individual clone mean as a percentage of the LM50 clone mean (dashed line) at each site.

The site × clone interactions of all studied properties were significant (Table 5), which demonstrated that the clones performed differently among the three locations. Overall, these differences demonstrate that the clonal effect on wood growth traits was considerable, suggesting that the properties of the hybrids were mainly correlated with those of their parents. Pairwise comparisons of the samples from each clone at each site showed no statistically significant differences ($\alpha = 0.05$), indicating potential genetic stability for each clone.

Table 5 focuses on the genetic stability and growth adaptability of the four clones. V and clonal effect values (Ci) reflect yield levels. Genetic stability refers to the stability of traits controlled by genetics in different environments. The coefficient of variation (CV) in the site × clone interaction was applied for this test. The comprehensive ranking of the hybrid poplar clones was Yiyang-1 > Yiyang-2 > LM50 > Yiyang-3, with high significance ($p < 0.01$). Theoretically, the smaller the CV value, the more stable the growth will be. We found a negative correlation between the CV and clonal growth stability. All clones exhibited strong stability, with CV values ranging from 24.34% to 35.66%. The CV was greatest for Yiyang-1 and lowest for Yiyang-3, inferring that Yiyang-1 exhibits better growth under better cultivation practices, that Yiyang-2 has no special cultivation requirements, and that Yiyang-3 is adapted to relatively poor environmental conditions.

Table 5. Summary of the ANOVA results for tree growth at the three sites combined.

		DBH (cm)			**H (m)**			**V (m^3)**		
	DF	MS	F	*P*	MS	F	*P*	MS	F	*P*
Sites	2	50.80	1636.05	< 0.001	40.54	1356.78	< 0.001	0.023	1960.45	< 0.001
Clones	3	23.88	769.20	< 0.001	1.85	61.76	< 0.001	0.005	439.55	< 0.001
Site × Clone	6	11.27	363.06	< 0.001	0.61	20.36	< 0.001	0.003	280.25	< 0.001
Error	36	0.03			0.03				1.191×10^{-5}	

Note: DBH: diameter at breast height; H: tree height; V: stem volume.

3.3. Clonal Variation in Wood Properties

BWD is an indicator of the degree of wood compactness, and is positively associated with dry air density, mechanical strength, and hardness. The mean and standard error and pairwise comparisons of several physical properties at breast height from four clones at Fengfeng are presented in Table 6. The overall mean BWD of the four hybrid clones was 0.324 g cm^{-3}. Yiyang-3 displayed the greatest BWD of the hybrids, but BWD did not differ significantly among clones. Notably, the differences in fiber traits among the four clones were statistically significant. The mean FLs ranged from 872.90 to 1062.61 μm for all hybrids (Figure 2). Yiyang-3 had the lowest average FL, at 17.85%, 17.60%, and 17.58% shorter than those of LM50, Yiyang-1, and Yiyang-2, respectively. Yiyang-1 and Yiyang-2 both had slightly shorter FLs, but were statistically similar to those of LM50. The mean FWs ranged from 23.13 to 27.69 μm for all hybrids (Figure 2). Yiyang-2 had the largest average FW, while Yiyang-3 had the smallest. Yiyang-2 displayed markedly higher FW than the other clones, whereas Yiyang-1 did not differ significantly from Yiyang-3. LM50 displayed 6.9% and 9.2% higher FW than Yiyang-1 and Yiyang-3, respectively. The mean FL:FW of the four hybrids ranged from 37.74 to 44.83 (Figure 2). Yiyang-1 had the greatest average FL:FW, while Yiyang-3 had the lowest. The FL:FW for LM50 was 10.0% and 11.6% greater than those of Yiyang-2 and Yiyang-3, respectively, while that for Yiyang-1 was 6.5% greater than that for LM50. The greatest difference in FL:FW occurred between Yiyang-1 and Yiyang-3, but there was no significant difference between Yiyang-2 and Yiyang-3. Variation in VDS, crystallinity, and MFA, which are related to wood mechanical properties, was not significant among the four clones.

Based on our results, the fiber traits (FL and FW) of Yiyang-1, Yiyang-2, and Yiyang-3 are consistent with the ranges reported for several FL and FW values in various species or hybrids obtained from the literature [5]. Additionally, the FL values of Yiyang-1 and Yiyang-2 were > 1000 μm, which corresponds to an intermediate wood FL of 0.9–1.6 mm according to the International Wood Anatomical Society [24]. Fiber properties have a major effect on the quality of pulp and paper products. Greater fiber lengths and narrower fiber widths (with a length to width ratio of > 30) are preferred for pulp and paper production, and result in higher-density paper sheets, smoother paper, more uniform formation, *etc.* [25,26]. In this study, Yiyang-1 and LM50 both showed similarly high fiber lengths but different fiber widths than Yiyang-2, and the FL: FW ratio of Yiyang-1 was the greatest among clones. With respect to fiber traits, Yiyang-1 would be particularly promising for pulp and paper manufacturing applications, followed by LM50, Yiyang-2, and Yiyang-3. The cellulose contents of Yiyang-2, Yiyang-1, LM50, and Yiyang-3 were 49.52%, 49.14%, 49.07%, and 48.36%, respectively (Figure 2). The holocellulose and lignin contents ranged from 75.81% to 77.35% and from 19.72% to 21.06%, respectively (Figure 2). Yiyang-2 had the highest average cellulose content and Yiyang-3 had the lowest; Yiyang-3 was markedly lower than Yiyang-2, Yiyang-1, and LM50, while there were no significant differences among Yiyang-2, Yiyang-1, and LM50. The mean holocellulose content ranged from 75.81% to 77.35%. Yiyang-1 was 0.8%, 1.4%, and 2.0% greater than LM50, Yiyang-2, and Yiyang-3, respectively. Mean lignin content varied in a range from 19.72% to 21.06%. Similar results among different poplar clones were reported previously [27,28]: Yiyang-1 was the lowest, 2.8%, 3.7%, and 6.4% lower than LM50, Yiyang-2, and Yiyang-3, respectively. However, there was a small but significant difference among LM50, Yiyang-2, and Yiyang-3.

Table 6. Mean values and standard error of the wood quality at the Fengfeng nursery.

Clone Identity	BWD ($g\ cm^{-3}$)	FL (μm)	FW (μm)	FL:FW	VDS (%)	MFA	C (%)	Water (%)	Cellulose (%)	Holocellulose (%)	Lignin (%)
LM50	0.326 ± 0.005	1062.61 ± 8.06	25.26 ± 0.75	42.10 ± 1.44	6.75 ± 1.02	31.00 ± 0.49	44.30 ± 1.02	90.4 ± 0.20	49.07 ± 0.15	76.7 ± 0.52	20.28 ± 0.16
Yiyang-1	0.318 ± 0.006	1059.34 ± 28.25	23.63 ± 0.25	44.83 ± 1.07	8.00 ± 3.98	31.13 ± 0.29	45.32 ± 0.75	91.26 ± 0.54	49.14 ± 0.52	77.35 ± 0.50	19.72 ± 0.67
Yiyang-2	0.325 ± 0.005	1059.10 ± 11.70	27.69 ± 0.59	38.26 ± 1.07	12.80 ± 1.88	31.38 ± 0.54	44.18 ± 1.57	92.72 ± 0.24	49.52 ± 0.25	76.29 ± 0.28	20.48 ± 0.41
Yiyang-3	0.326 ± 0.010	872.90 ±9.71	23.13 ± 0.30	37.74 ± 0.35	10.02 ± 2.48	31.21 ± 0.35	44.20 ± 1.12	91.92 ± 0.79	48.36 ± 0.06	75.81 ± 0.27	21.06 ± 0.80
Mean	0.324	1013.49	24.83	40.73	9.39	31.18	44.50	91.58	49.02	76.54	20.39
F-value	1.076	77.264	66.407	27.376	3.009	0.554	0.868	10.541	15.547	7.383	3.957
p-value	0.427	<0.001	<0.001	0.001	0.116	0.602	0.467	0.008	0.003	0.019	0.072

Note: BWD: basic wood density; FL: fiber length; FW: fiber width; VDS: volume drying shrinkage; MFA: microfibril angle; C: crystallinity.

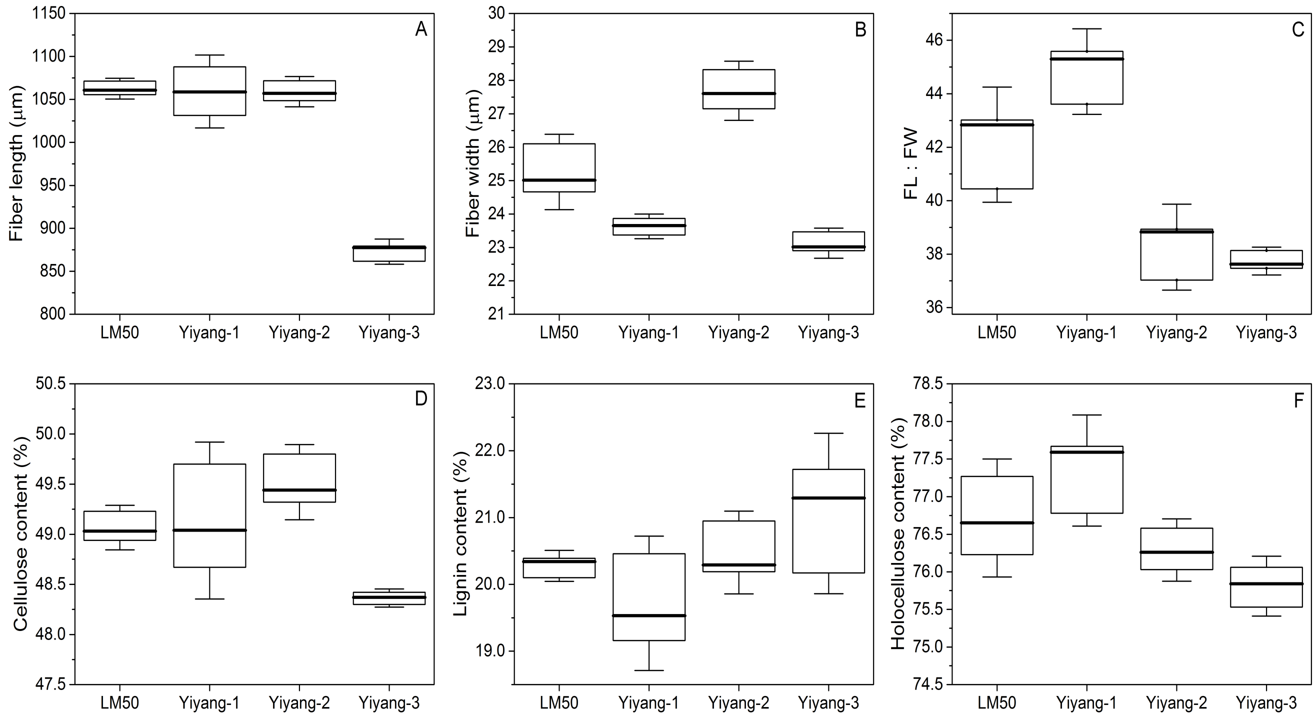

Figure 2. Boxplots of fiber traits and wood chemical components of four hybrids. (maximum-minimum values; the top and bottom of each box indicate the 75th and 25th percentiles, respectively. FL refers to fiber length; FW refers to fiber width.).

Chemical components have an important effect on pulping and papermaking. Lignin, a complex phenolic heteropolymer, represents an important fitness trait in tree adaptation to the environment. However, lignin content has adverse effects on the pulping process when lignin removal is accompanied by cellulose degradation [1,29]. According to Hart *et al.* [1], transgenic poplar trees with lowered lignin content showed as much as 15% improvement in their efficiency at converting cellulose to corresponding monomers. Therefore, higher pulp yield and quality are related to higher cellulose and lower lignin contents [30]. Our results showed that Yiyang-3 was markedly inferior in terms of wood chemical components than the other three clones studied, but that the differences among Yiyang-1, Yiyang-2, and LM50 were small. Nevertheless, minor changes will certainly affect the processing operations of large-scale pulp mills. In this case, with its slightly higher holocellulose and lower lignin content relative to Yiyang-2, Yiyang-1 would be superior in wood performance.

The differences in wood quantity and quality among the clones indicate heterosis and genetic control of properties (Tables 3–6). The hybrid poplar clones Yiyang-1, Yiyang-2, and Yiyang-3, selected as quality varieties, have a common female parent (*P. tomentosa* × *P. bolleana*) and a different male parent. *Populus tomentosa* "Truncata" was selected as the male parent of clones Yiyang-1 and Yiyang-2, while *P. tomentosa* "LM50" was selected as the male parent of clone Yiyang-3. *Populus tomentosa* × *P. bolleana*, *P. tomentosa* "Truncata", and *P. tomentosa* "LM50" were all excellent varieties, offering a straight stem, fast growth, strong resistance, and good wood properties. *Populus tomentosa* "Truncata" is a mutant variety of *P. tomentosa Carr.* (*P. tomentosa* × *P. bolleana*) hybridized by the Chinese Academy of Forestry in the 1950s as an improved variety. *Populus tomentosa* "LM50", bred in

Shandong Province, has been recognized as a superior clone. Numerous studies have shown both significant and stable heterosis in F1 hybrids of *Populus* spp. However, the genetic cause is not yet fully understood [31,32].

There is also some doubt as to whether breast height measurements provide an accurate projection of the economic and commercial value of trees [33]. Several investigations have attempted to determine a representative sampling height, and some authors concluded that sampling at heights other than breast height provided better predictions of the BWD and FL of the entire tree [34,35]. Therefore, additional research is needed to better evaluate performance in terms of tree applications and production.

4. Conclusions

In our study, growth site significantly impacted variation in growth traits. The growth of 7-year-old clones was fastest at the nursery in Fengfeng and slowest at the nursery in Guanxian. All clones planted at Fengfeng were the most productive in terms of stem volume, followed by those at Weixian and Guanxian nurseries. The site × clone interactions of all studied properties were significant, demonstrating that the clones performed differently at the three locations.

The stem volume ranking of the hybrid clones differed among sites, with Yiyang-1 and Yiyang-2 exhibiting faster growth than Yiyang-3 and LM50 at Fengfeng and Guanxian. Although significant differences between Yiyang-1 and Yiayng-2 were minor or inconsistent, Yiyang-1 had the greatest total mean volume and largest percentage-of-volume increment *vs.* LM50 across all three sites. Yiyang-1 was ranked first in average growth, followed by Yiyang-2, LM50, and Yiyang-3.

Fiber traits and chemical components were distinctly different among the clones, while the BWD and other properties related to wood mechanical strength were not. Yiyang-1 exhibited superior fiber traits, followed by LM50, Yiyang-2, and Yiyang-3. Regarding chemical properties, Yiyang-3 was inferior, while the differences among Yiyang-1, Yiyang-2, and LM50 were small. Combining fiber traits and wood chemical properties, Yiyang-1 would be the superior clone in wood performance.

Overall, Yiyang-1 exhibited the best performance of the four hybrid white poplar clones. The fast growth in Yiyang-1 does not negatively affect its wood quality characteristics, highlighting its advantages and suggesting the possibility of interspecific hybrid crossing.

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Author Contributions

Xinmin An designed the experiments, coordinated and supervised the research. Huandi Ma analyzed the data and drafted the manuscript. Youming Dong contributed analysis tools and manuscript reversion. Zhong Chen and Shanwen Li were responsible for the samples collection and data measurment. They also performed the experiments with help of Weihua Liao, Bingqi Lei, Kai Gao. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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