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Effect of Initial Planting Density on the Moisture Content and Chemical Composition of the Triploid Chinese White Poplar (*Populus × tomentosa* Carrière) Plantation

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Abstract: The triploid Chinese white poplar (*Populus × tomentosa* Carrière) features desirable growth traits and wood properties, making it the preferred species in the pulp and paper industries and the sawn timber industry. In this study, we characterized the effects of initial planting densities on the moisture content (MC) and four chemical components (benzene-alcohol (BA), holocellulose (HC), alpha-cellulose (AC), and klason lignin (KL)) of the triploid Chinese white poplar. In this study, 11-year-old Chinese white poplars with three triploid clones (S86, B331, and B301) and one diploid clone (1316) that were planted using seven levels of planting densities (2490, 1665, 1110, 832, 624, 499 and 416 trees/hm^2) were examined in the Huabei Great Plain in China. The MC was observed to initially decrease and then subsequently increase with decreasing planting density, and exhibited significant differences under different initial planting densities ($0.001 < p < 0.01$). In terms of the chemical composition, the BA content of the triploid hybrid clones presented with much higher phenotypic variation (CV_p = 17.11%–32.45%) at each planting density compared to either the MC (CV_p = 3.73%–11.21%) or the other three chemical composition variations (CV_p = 1.16%–11.46%). Substantial differences were observed in the chemical composition of the triploid hybrid clones ($p < 0.05$), while no differences were found in the chemical composition within the initial planting density categories. The correlation between the chemical composition of wood (BA, HC, AC, and KL) and growth traits was generally weak. These results demonstrate that compared with the MC, the chemical composition of the triploid Chinese white poplar was primarily controlled by its own genetic background and was almost unaffected by the initial planting density. Thus, it is important to select a suitable clone and initial planting density to ensure the full growth of these trees and to improve the quality of pulping in the construction of pulp timber forests.

Keywords: planting density; triploid hybrid clones; wood properties; phenotypic correlations

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1. Introduction

The Chinese white poplar (*Populus × tomentosa* Carrière, 2n = 2x = 38) is a native tree species in China that is fast growing and easy to cultivate. In 1992, Zhu [1] was the first to discover a natural triploid Chinese white poplar (2n = 3x = 57), which was considered to originate from a natural 2n pollen crossing a normal (1n) egg. Compared with the diploid Chinese white poplar, the triploid Chinese white poplar exhibits a faster growth rate, longer fiber length, higher holocellulose content, and improved pulp properties [2,3], making it suitable for a variety of pulping regimes. As a fast-growing and high-quality tree, Chinese white poplar triploid hybrid clones have become the preferred species for the pulp and research industries in northern China [4]. At present, triploid hybrid poplar clones are widely planted in Hebei, Henan, Shandong, and Shanxi provinces to obtain high-yield fiber production.

Density management focuses on the number of trees and their allocation per unit of area, which determines the resource utilization of the trees in terms of nutrients, water, and light energy [5]. Under high plantation density conditions, intraspecific competition is intense, which results in the slow growth or death of individual plants [6,7]. A greater amount of ecological resources, such as light, water, and nutrients, can be obtained per plant at low densities [8], which consequently increases the average tree growth. Numerous recent studies have reported the effect of planting density on trees. Xu et al. demonstrated significant differences in the tree height (H), diameter at breast height (DBH), and stem volume (SV) of *Pinus elliottii* in stands among different initial densities [9]. The authors also identified non-significant ($p < 0.05$) effects of the initial densities on the wood tracheid formal features, wood chemical constitute content, wood shrinkage properties under air-drying conditions, and wood mechanical properties. The DBH, cellulose content, and lignin content of 26-year-old *Eucalyptus urophylla* × *E. grandis* varied with changes in forestation density [10]. Liziniewicz et al. reported that increasing the initial planting density enhanced the H of 23-year-old *Pinus contorta Dougl.* var. *latifolia* [11]. Furthermore, lumber stiffness has been observed to increase with decreasing initial tree spacing in *Pinus patula* Schiede ex Schltdl. and Cham. [12]. Research on *Schizolobium parahyba* var. *amazonicum* also showed its planting density to significantly affect both its fiber length (FL) and fiber wall thickness [13].

Previous studies on the planting density of the triploid Chinese white poplar have reported its impact on growth traits and wood properties. Bo et al. demonstrated a significant effect of planting density on the DBH and H of triploid Chinese white poplars, and suggested that planting density should therefore be considered in cultivating fast-growing and high-yield plantations [14]. Furthermore, planting density has been observed to yield a highly significant effect on the bark thickness [15] and growth traits [16] of 11-year-old triploid Chinese white poplars. Wang et al. reported that planting density significantly affected DBH and SV in a 4-year-old triploid Chinese white poplar plantation [17]. Research on 3-year-old triploid Chinese white poplars revealed that planting density only significantly affected its growth traits [18], while no differences in the content of its chemical components were observed [19]. Sang et al. found that planting density exerted a significant effect on the growth traits of 11-year-old triploid Chinese white poplars, while no effects were observed on its basic wood density (BWD) or fiber length to width (FL/W) ratio [16]. Despite the great progress made by the aforementioned studies, the effects of planting density on the moisture content (MC) and chemical composition of the triploid Chinese white poplar for plantations older than 10 years remain to be elucidated.

In the current study, with a focus on large-scale poplar timber production, an 11-year planting density trial located in the central region of Huabei Plain, China, was selected to evaluate the effect of the initial planting density on the MC and the chemical composition of the Chinese white poplar. The objectives of the study were as follows: (1) to determine whether different initial planting densities exert different effects on the MC and chemical composition of the triploid Chinese white poplar; (2) to determine the clonal effects and the clone × initial planting density interactions on its MC and chemical composition; and (3) to examine the relationships between the growth traits, BWD, MC, and chemical composition of the plants based on their initial planting density.

2. Materials and Methods

2.1. Description of the Study Site

The research was carried out in the Huayang Forest Tree Nursery located in the central region of Huabei Great Plain (36°50′–37°47′ N, 113°52′–115°49′ E), China. The region belongs to the warm temperate continental semi-arid monsoon climate zone with four distinct seasons. The annual sunshine of this region is estimated to be 2574.8 h, with an average annual sunshine rate of 58%. The average annual temperature of the Huayang Forest Tree Nursery is 13.1 °C, and the frost-free period is approximately 183 days. The average annual rainfall in the region is approximately 497.7 mm, with 70% of the rainfall occurring between July and September.

2.2. Materials

The materials used in this study were obtained from a planting density trial established by Beijing Forestry University. At the time of the experiment, the trail had been running for more than 10 years in Wei County, Hebei Province, China. Seven initial planting densities were employed: 2 m × 2 m (2490 trees/hm^2), 2 m × 3 m (1665 trees/hm^2), 3 m × 3 m (1110 trees/hm^2), 3 m × 4 m (832 trees/hm^2), 4 m × 4 m (624 trees/hm^2), 4 m × 5 m (499 trees/hm^2), and 4 m × 6 m (416 trees/hm^2), using three triploid hybrid clones and one diploid clone. Table 1 reports the details of the four Chinese white poplar hybrid clones. The experiment was set up in a two-factor complete randomized block design under the same management conditions. Each of the seven planting densities had three replicates. Thinning and fertilization were not included in the experiment.

Table 1. Identity and origin of the hybrid clones.

No.	Clone Identity	Parents	Level of Ploidy	Sex
1	B301	(*P. tomentosa* × *P. bolleana*) × *P. tomentosa*	Triploid	♀
2	B331	(*P. alba* × *P. glandulosa*) × *P. tomentosa*	Triploid	♀
3	S86	(*P. tomentosa* × *P. bolleana*) × (*P. alba* × *P. glandulosa*)	Triploid	♂
4	1316	*P. tomentosa* × *P. tomentosa*	Diploid	♂

♀ stands for female; ♂ stands for male.

After leaf fall commenced in autumn 2018, the poplar improvement program of Beijing Forestry University measured the total H and DBH of the 11-year-old trees. The stem volume (SV) of each sample was calculated according to the volume function described in Chen [20]. A representative wood sample was then selected from each plot for sampling. A 10-cm-thick disk was taken from each representative sampled tree at breast height and shipped back to Beijing for further analysis.

2.3. Determination of Moisture Content and Chemical Composition of the Chinese White Poplar

In order to measure the MC of the wood, discs of each tree were cut and ground into wood dust. The sawdust was sieved using the British standard (BS) of a 40–60 mesh. The MC of wood was determined according to the national standard GB/T 2677.2-2011 and expressed as the weight loss (green weight minus the oven-dried weight) divided by the oven-dried weight.

The benzene alcohol extract content (BA) of the papermaking raw materials was estimated based on the national standard GB/T 2677-1994. More specifically, the samples were extracted using a mixture of benzene and 95% ethanol ($V_{benzene}$:$V_{95\%\ ethanol}$ = 2:1) in soxhlet extractor, followed by liquid evaporation, drying, and weighing to quantitatively determine the substance content extracted by the solvent.

The Klason lignin (KL) content was estimated using the sulfuric acid method following the national standard GB/T2007. Extracted sample was taken into a conical flask, and 15 mL of 72% sulfuric acid was added. The conical flask was sealed and placed in a water bath at 20 °C for 2 h. Deionized water was added to the flask and boiled on a hot plate for 4 h. The total volume of the content in the flask should be kept constant at 560 mL during boiling. The flask was allowed to stand to deposit KL the flask. The final suspension was filtered through a porous glass filter. Solids were dried at 105 ± 1 °C to constant weight and used to determine KL.

Holocellulose (HC) refers to all cellulose and hemicellulose in plant fiber raw materials. It was necessary to ensure that the cellulose and hemicellulose were not damaged and the lignin was completely removed when determining the HC content. The sodium chlorite method was used to determine the HC content followed the national standard GB/T 2677.10-1995. Samples of 2 g were accurately weighed, extracted with a benzene-ethanol mixture, and then air dried. In a 250 mL conical flask, extractives-free milled wood was added, along with 65 mL deionized water, 0.5 mL glacial acetic acid, and 0.6 g 100% sodium chlorite. The flask was sealed with a glass cap and placed in a 75 °C water bath for 1 h. After this time, 0.5 mL of glacial acetic acid and 0.6 g of 100% sodium chlorite were added to the flask, and the reaction continued at 75 °C for another hour. The reaction is stopped by soaking the flask in ice water. The solids were filtered through a porous glass filter, washed first with 500 mL deionized water, then with acetone, and finally dried at 105 ± 1 °C until a constant weight was obtained and determined to be HC.

Alpha-cellulose (AC) was prepared by weighting 2 g lignin-free wood in a 150 mL beaker. Then, 30 mL of 17.5% sodium hydroxide (*w/v*) were added; the slurry was homogenized and allowed to react for 45 min at room temperature. Finally, 30 mL of deionized water was added and mixed for 1–2 min. Solids were filtered using a porous glass filter, washed with 25 mL of 9.5% sodium hydroxide (repeated 3 times), followed by washing with 400 mL of deionized water and acetic acid 2.0 M. The neutralized sample was washed with 300 mL of deionized water. The final insoluble residue (AC) was dried at 105 ± 1 °C to constant weight. The difference between the initial and final weight was used to calculate the AC content followed the national standard GB/T 2677.10-1995.

2.4. Statistical Analysis

Diploid clone 1316 (control) was excluded from the main statistical analysis. Variation among the ramets of the sample clones was analyzed using analysis of variance based on the linear model in Equation (1) under the initial planting density:

$$X_{jk} = \mu + C_j + \varepsilon_{jk}, \tag{1}$$

where X_{jk} is the observation for the *k*th ramet from the *j*th clone; μ is the general mean; C_j is the effect due to the *i*th clone; and ε_{jk} is a random error. Equation (1) does not consider the clone–replicate effects, as the three trees per clone were chosen randomly.

The linear model in Equation (2) was used for the joint analyses of the seven planting densities:

$$Y_{ijkl} = \mu + B_i + C_j + S_k + C_{jSk} + \varepsilon_{ijkl} \tag{2}$$

where Y_{ijkl} is the observation of the *l*th tree from the *j*th clone in the *k*th planting density at the *i*th block; μ is the overall mean; B_i is the effect due to the *i*th block; C_j is the effect due to the *i*th clone; S_k is the effect due to the *k*th spacing; C_{jSk} is the interaction between the *j*th clone and *k*th planting density; and ε_{ijkl} is random error. All terms were considered randomly, with the exception of the block, which was considered as a fixed effect.

The UNIVARIATE procedure in SPSS (SPSS for Windows, version 20, SPSS, Chicago, IL, USA) was adopted to conduct the analyses of variance, multiple comparisons, and phenotypic correlations of the obtained clonal means for each pair of traits under the initial planting density. Excel (version 2206 Build 16.0.15330.20260, Microsoft Co., Washington, DC, USA) was also used to aid the statistical analysis and drawing.

3. Results

3.1. Effect of Initial Planting Density on the Moisture Content and Chemical Composition of the Triploid Chinese White Poplar

Timber strength, processing, and utilization are known to be affected by the wood MC and the percentage of wood chemical components. Table 2 reports the mean values, variation ranges, and phenotypic variation coefficients for the MC and four chemical components of four hybrid clones of the Chinese white poplar under the seven investigated planting densities. The HC and AC content of the triploid hybrid clones were higher than those of the diploid hybrid clone under the seven planting densities. In contrast, the MC and KL content of the diploid hybrid clone were higher than those of the triploid. The triploid hybrid clones had a higher BA content than the diploid clone at higher planting densities (2490 trees/hm^2 and 1665 trees/hm^2), while the opposite trend occurred at lower planting densities (1110 trees/hm^2, 832 trees/hm^2, 624 trees/hm^{2,} 499 trees/hm^2, and 416 trees/hm^2).

Table 2. Clone means (±SE), variation range, and phenotypic variation coefficients (CV*p*%) of moisture content and chemical compositions at seven initial planting densities.

Planting Density (Trees/hm^2)	Trait	Triploid Clones			Diploid Clone	
		Mean ± SE	Range	CV*p* (%)	Mean ± SE	Range
2490	MC (%)	7.70 ± 0.86	6.68–8.98	11.21	8.44 ± 0.64	7.70–8.85
	BA (%)	1.61 ± 0.47	1.27–2.70	29.21	1.48 ± 0.27	1.32–1.79
	HC (%)	82.84 ± 1.73	79.93–85.33	2.09	79.67 ± 1.23	78.37–80.81
	AC (%)	50.86 ± 1.65	48.42–53.40	3.25	46.00 ± 2.05	43.78–47.81
	KL (%)	19.64 ± 1.80	17.17–21.32	9.17	24.31 ± 0.18	24.10–24.43
1665	MC (%)	7.11 ± 0.26	6.74–7.51	3.73	7.54 ± 0.18	7.33–7.66
	BA (%)	1.44 ± 0.42	0.99–2.23	29.16	1.42 ±0.28	1.16–1.72
	HC (%)	81.32 ± 1.98	78.41–84.10	2.44	78.20 ± 0.94	77.22–79.10
	AC (%)	50.83 ± 2.02	47.62–53.45	3.98	47.56 ± 1.09	46.33–48.40
	KL (%)	19.39 ± 2.22	16.26–22.26	11.46	24.30 ± 0.74	23.45–24.79
1110	MC (%)	6.89 ± 0.73	5.66–7.68	10.56	7.30 ± 0.88	6.42–8.18
	BA (%)	1.40 ± 0.28	1.06–1.95	19.94	1.59 ± 0.12	1.48–1.71
	HC (%)	81.98 ± 0.95	80.69–83.28	1.16	79.98 ± 1.07	79.06–81.15
	AC (%)	51.70 ± 1.87	48.32–54.37	3.62	48.22 ± 0.74	47.58–49.03
	KL (%)	19.94 ± 1.46	17.69–21.31	7.34	24.25 ± 0.23	24.01–24.46
832	MC (%)	6.40 ± 0.56	5.64–7.20	8.79	6.84 ± 0.34	6.60–7.23
	BA (%)	1.46 ± 0.31	1.09–2.09	21.14	1.53 ± 0.02	1.51–1.55
	HC (%)	82.00 ± 1.36	80.53–84.32	1.66	80.16 ± 0.84	79.38–81.05
	AC (%)	52.15 ± 1.68	49.35–54.32	3.23	48.86 ± 0.41	48.48–49.30
	KL (%)	20.03 ± 1.84	17.48–21.88	9.19	24.62 ± 0.45	24.16–25.05
624	MC (%)	6.88 ± 0.66	6.23–8.29	9.55	7.13 ± 0.73	6.60–7.96
	BA (%)	1.33 ± 0.31	0.97–1.92	23.50	1.45 ± 0.14	1.36–1.62
	HC (%)	81.98 ± 1.63	78.92–84.13	1.99	80.31 ± 0.73	79.56–81.02
	AC (%)	52.01 ± 2.57	46.76–55.29	4.94	48.97 ± 1.18	48.00–50.28
	KL (%)	19.84 ± 1.84	17.31–21.64	9.29	24.66 ± 0.14	24.50–24.77
499	MC (%)	7.34 ± 0.47	7.05–8.53	6.37	7.65 ± 0.22	7.42–7.85
	BA (%)	1.51 ± 0.49	1.10–2.39	32.45	1.53 ± 0.09	1.43–1.60
	HC (%)	81.70 ± 1.49	80.23–84.26	1.82	80.15 ± 0.09	80.09–80.25
	AC (%)	51.68 ± 2.61	48.07–55.57	5.06	49.12 ± 0.42	48.63–49.38
	KL (%)	20.09 ± 2.14	16.84–22.02	10.66	24.95 ± 0.10	24.89–25.07
416	MC (%)	7.36 ± 0.32	6.88–7.82	4.34	7.48 ± 0.11	7.35–7.55
	BA (%)	1.47 ± 0.25	1.19–2.03	17.11	1.61 ± 0.06	1.55–1.66
	HC (%)	82.07 ± 1.27	79.50–83.96	1.54	80.21 ± 0.78	79.35–80.88
	AC (%)	51.39 ± 1.38	49.41–53.28	2.69	49.65 ± 0.36	49.31–50.02
	KL (%)	20.11 ± 1.44	17.39–21.33	7.16	24.41 ± 0.15	24.24–24.52

The MC ranged from 6.40 to 7.70% across the seven planting densities, with the maximum and minimum being 2490 trees/hm^2 and 832 trees/hm^2, respectively. Its trend initially decreased and subsequently increased with decreasing planting density. The BA content of the triploid hybrid clones ranged from 1.33 to 1.61%, with an average of 1.46%. Furthermore, a substantially higher phenotypic variation (CV*p* = 17.11%–32.45%) was observed at each planting density compared to either the MC (CV*p* = 3.73%–11.21%) or the other three chemical composition variations (CV*p* = 1.16%–11.46%). After 11 years, the content of HC, AC, and KL in triploid Chinese white poplars fluctuated with the change of planting density, exhibiting no regular trends, and differences between the lowest and highest means were determined to be 1.87%, 2.60%, and 3.71%, respectively.

Table 3 reports the analysis of variance results for the combined seven planting densities. The initial planting density exerted significant effects solely on the MC ($p < 0.05$).

Figure 1 depicts the effect of the initial planting density on the MC of 11-year-old triploid Chinese white poplars. The MC of the triploid hybrid clones planted at 832 trees/hm^2 were significantly lower than those of the triploid planted at 416 trees/hm^2, 499 trees/hm^2, 1110 trees/hm^2, 1665 trees/hm^2, and 2490 trees/hm^2.

Table 3. Analyses of variance of the moisture content and chemical compositions of 11-year-old triploid Chinese white poplars for the combined seven planting densities.

Trait	Planting Density (Trees/hm^2)		Clone		Planting Density × Clone	
	F	*p*	F	*p*	F	*p*
MC	4.351	0.002	0.795	0.459	0.522	0.888
BA	0.536	0.777	4.171	0.023	0.694	0.748
HC	1.123	0.367	14.811	<0.001	0.304	0.985
AC	1.076	0.393	23.405	<0.001	0.740	0.705
KL	0.755	0.609	90.017	<0.001	0.450	0.932

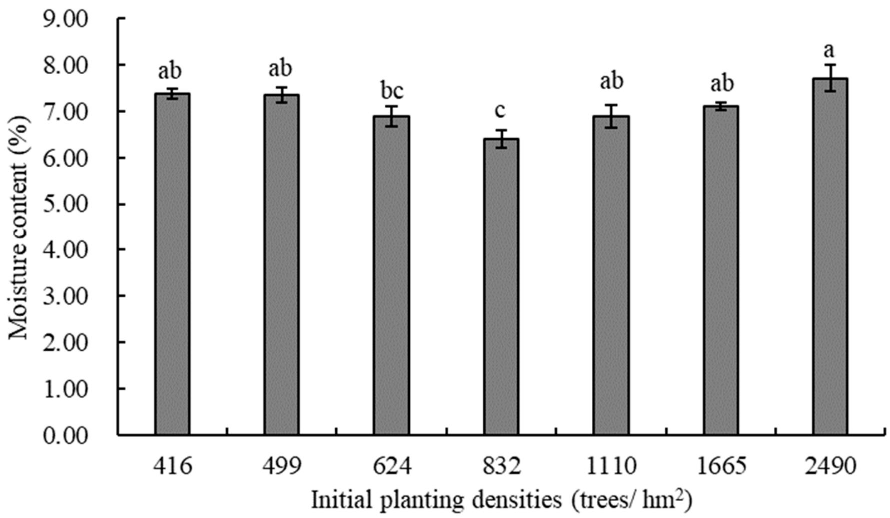

Figure 1. Effects of initial planting density on the moisture content of triploid Chinese white poplars. Different letters indicate a significant difference under different planting densities ($p < 0.05$).

3.2. Effect of Clonal and Initial Planting Density × Clone Interaction on the Moisture Content and Chemical Compositions of the Triploid Chinese White Poplar

The analysis of variance for the MC at the seven planting densities combined (Table 3) was consistent with that within each initial planting density (Table 4). This demonstrates that the clonal effects were not significant on the MC of the triploid Chinese white poplar. In addition, Table 3 reveals the significant clonal effects ($p < 0.05$) on all of the chemical components. These are further compared in Figure 2, indicating the following key results: (1) compared with the triploid hybrid clones B331 and B301, triploid S86 exhibited the lowest BA (Figure 2a); (2) the HC content of triploid hybrid clone S86 exceeded that of clones B301 and B331 (Figure 2b); (3) the order of the AC content was S86 > B301 > B331 (Figure 2c); and (4) triploid S86 exhibited the lowest KL when compared to the triploid hybrid clones B331 and B301 (Figure 2d). With the exception of the initial planting density of 1665 trees/hm^2, the clonal effect of planting density on KL was considerable at all planting densities (Table 4). Moreover, the clonal effects of BA and HC were not significant for the majority of the tested planting densities. Therefore, the selection of a suitable clone is key to improving the pulping process to maximize economic outputs and decrease environmental pollution.

No significant interactions were observed between the clones × initial planting densities on the MC and chemical compositions, as shown in Table 3. In particular, we gather that the effect of clones × initial planting densities on the MC and chemical compositions may be neglected in the planning of plantation rotations longer than 11 years involving triploid Chinese white poplars.

Table 4. Analysis of variance results for the moisture content and four chemical components of the 11-year-old triploid Chinese white poplar plantation within each initial planting density group.

Planting Density (Trees/hm^2)	*p*				
	MC	**BA**	**HC**	**AC**	**KL**
2490	0.189	0.514	0.067	0.668	<0.001
1665	0.660	0.737	0.512	0.264	0.287
1110	0.233	0.043	0.091	0.071	0.008
832	0.651	0.407	0.356	0.020	<0.001
624	0.438	0.116	0.044	0.020	<0.001
499	0.250	0.357	0.039	0.026	<0.001
416	0.671	0.280	0.152	0.083	0.024

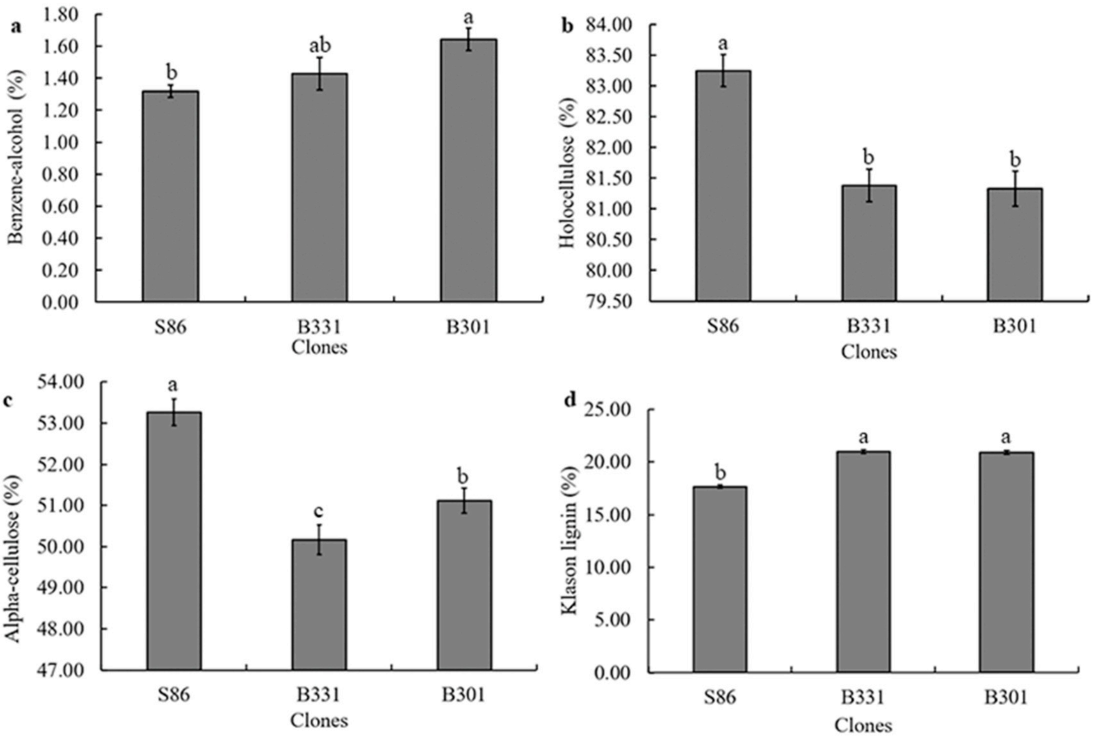

Figure 2. Effects of the clones on the content of four chemical components of the triploid Chinese white poplar: (**a**) clonal effects on the BA content of the triploid Chinese white poplar; (**b**) clonal effects on the HC content of the triploid Chinese white poplar; (**c**) clonal effects on the AC content of the triploid Chinese white poplar; (**d**) clonal effects on the KL content of the triploid Chinese white poplar. Different letters indicate significant differences ($p < 0.05$).

3.3. Phenotypic Correlations between the Growth Traits, Basic Wood Density, Moisture Content, and Chemical Compositions within the Initial Planting Density Groups

In addition to the genetic variation of a single trait, the correlation between different traits should also be examined in genetic analyses. Table 5 reports the phenotypic correlations between the growth traits, BWD, MC, and four chemical components of the three triploid hybrid clones at seven planting densities. The correlation coefficient of all the traits varied from 0.004 (DBH with HC at 416 trees/hm^2) to 0.997 (DBH with SV at 624 trees/hm^2), while those among the growth traits ranged from 0.627 to 0.997. All correlations were significant and positive (with the exception of H with DBH at 1665 trees/hm^2). The AC and HC contents were positively correlated with both the growth traits and BWD. With the exception of BA and the MC, negative correlations were observed between KL and the traits at the seven studied planting densities. In addition, the correlation coefficients between HC and AC exceeded 0.5 for all seven planting densities (except for 2490 trees/hm^2).

Significant negative correlations between HC and BA were observed under the initial planting densities of 2490 trees/hm^2 and 499 trees/hm^2.

Table 5. Estimated phenotypic correlations between the growth traits, wood basic density, moisture content, and four chemical components of the three triploid hybrid clones under the seven planting densities.

Planting Density (Trees/hm^2)	Traits	H	SV	BWD	MC	BA	HC	AC	KL
2490	DBH	0.836 **	0.984 **	−0.307	0.671 *	0.014	0.258	0.280	−0.291
	H		0.891 **	−0.025	0.571	−0.055	0.494	0.465	−0.481
	SV			−0.281	0.704 *	−0.012	0.324	0.289	−0.309
	BWD				−0.451	0.231	0.225	0.466	−0.459
	MC					−0.225	0.295	−0.178	−0.262
	BA						−0.758 *	0.282	0.530
	HC							0.266	−0.877 **
	AC								−0.394
1665	DBH	0.627	0.969 **	0.328	0.400	0.474	0.214	0.186	−0.448
	H		0.796 *	0.508	−0.232	−0.273	0.785 *	0.628	−0.117
	SV			0.401	0.251	0.271	0.399	0.324	−0.346
	BWD				−0.021	0.036	0.802 **	0.829 **	−0.215
	MC					0.642	−0.443	−0.335	−0.383
	BA						−0.463	−0.396	−0.540
	HC							0.936 **	−0.006
	AC								−0.098
1110	DBH	0.919 **	0.992 **	0.101	−0.042	0.535	0.222	0.569	−0.168
	H		0.934 **	0.213	−0.289	0.488	0.156	0.588	−0.271
	SV			0.111	−0.122	0.566	0.167	0.592	−0.161
	BWD				0.065	−0.158	0.567	0.556	−0.774 *
	MC					0.210	0.348	−0.026	−0.069
	BA						−0.376	0.154	0.201
	HC							0.630	−0.753 *
	AC								−0.723 *
832	DBH	0.900 **	0.995 **	0.305	0.502	0.532	0.203	0.582	−0.028
	H		0.909 **	0.507	0.681 *	0.186	0.283	0.656	−0.221
	SV			0.269	0.534	0.541	0.171	0.590	−0.016
	BWD				0.316	−0.440	0.633	0.585	−0.795 *
	MC					−0.138	0.490	0.558	−0.092
	BA						−0.452	−0.083	0.436
	HC							0.561	−0.405
	AC								−0.656
624	DBH	0.959 **	0.997 **	0.194	−0.239	0.310	0.366	0.441	−0.288
	H		0.951 **	0.217	−0.213	0.373	0.243	0.334	−0.352
	SV			0.179	−0.266	0.324	0.336	0.415	−0.273
	BWD				0.499	0.342	0.526	0.647	−0.778 *
	MC					0.523	0.064	0.056	0.082
	BA						−0.144	−0.087	0.106
	HC							0.971 **	−0.508
	AC								−0.640
499	DBH	0.841 **	0.987 **	0.562	−0.033	−0.190	0.544	0.825 **	−0.718 *
	H		0.892 **	0.523	−0.097	0.178	0.365	0.605	−0.579
	SV			0.558	−0.097	−0.192	0.578	0.815 **	−0.743 *
	BWD				−0.172	−0.033	0.298	0.540	−0.664
	MC					0.325	−0.379	−0.278	0.238
	BA						−0.685 *	−0.474	0.483
	HC							0.877 **	−0.895 **
	AC								−0.922 **
416	DBH	0.943 **	0.994 **	0.410	−0.042	0.147	0.004	0.326	−0.373
	H		0.954 **	0.489	−0.017	0.060	0.283	0.455	−0.538
	SV			0.491	−0.122	0.131	0.057	0.348	−0.416
	BWD				−0.723 *	0.111	0.384	0.460	−0.534
	MC					−0.378	−0.096	−0.159	0.104
	BA						−0.305	0.306	0.215
	HC							0.634	−0.719 *
	AC								−0.768 *

** Significant correlation between traits at the 0.01 level; * significant correlation between traits at the 0.05 level.

4. Discussion

The MC of trees varies with different species, individual plants, trunk components, growing seasons, and site conditions [21]. The MC of *Pterocarya stenoptera* C. DC. has been observed to vary with flooding duration [22], while the environment is reported to have a strong effect on the wood MC of European beech (*Fagus longipetiolata*) in Ukrainian Carpathians [23]. Previous research had observed large variations in the MC of the *E. urophylia* clone 'u6′ planted on latosol, sedimentary sand soil, and coarse red soil [24]. Thus, the wood MC is affected by forest environments. In the current study, the initial planting density exerted a significant effect on the MC of 11-year-old triploid Chinese white poplars, and was observed to initially decrease and then subsequently increase with decreasing planting density. This is attributed to the different nutrient spaces occupied by trees at different initial planting densities, thus resulting in distinct wood MCs under varying planting densities. This is consistent with the conclusion that the forest site affects the wood MC. Therefore, to achieve the purpose of directional cultivation, an appropriate initial planting density must be selected and the nutrient space should be adjusted to optimize the growth and differentiation of forest trees.

Expanding awareness of the effect of raw-material qualities on pulp quality has resulted in increased research on wood quality metrics and their incorporation into improvement programs with selection traits [25]. Manipulating plantation density comprises one of the most prevalent silvicultural methods. Such measures have an impact on forest growth and quality [26,27] and play a key role in silvicultural breeding [28]. However, the combined literature of local and foreign studies on the impacts of planting density on chemical composition contains heterogeneous findings. Research on 9-year-old rubber trees (*Hevea brasiliensis Muell. Arg.*) planted in northeast Malaysia revealed the HC and BA levels to be significantly affected by planting density [29]. Zanuncio et al. found significant differences in the chemical composition of *Eucalyptus* wood under different plantation densities [30]. In a study by Rocha et al. [31], planting density significantly affected the KL and HC contents of *Eucalyptus grandis* × *E. camaldulensis*, while no effects were observed for extractives content and acid-soluble lignin. In contrast, studies on poplar [19,32,33] suggest that initial planting density does not exert a significant effect on the chemical composition of wood. In the current study, no significant effects were observed in the chemical composition content of wood under different initial planting densities (Table 3). As the experimental materials in the aforementioned studies were sourced from different countries and regions, it is speculated that the differences in the growth environment and tree species may be the sources of inconsistent research conclusions. Additional research conducted on the wood properties of triploid *Populus tomentosa* [34] and *Populus* × *Euramericana Guinier* 'I-214′ [35] revealed significant effects of various clones on their chemical composition. Similarly, our results on the chemical composition analysis of the 11-year-old triploid Chinese white poplar showed that there were substantial differences in the content of BA, HC, AC, and KL among the triploid hybrid clones, and the effects of the clones on the chemical composition were significant. Table 3 shows minimal variations in the average chemical composition of poplar with different initial planting densities, indicating that the chemical composition of poplar was not significantly affected by the planting density. This demonstrates unequivocally that the chemical composition of poplar is a biological characteristic of its species, and is primarily controlled by its own genetic background rather than forest management measures. As a result, clonal selection breeding can improve the chemical composition of wood to some extent.

The chemical compositions of triploid Chinese white poplars were observed to be determined by the variety of clone, but not by the initial planting density, nor the interaction of initial planting densities × clones (Table 3). These results are consistent with research on 3-year-old triploid Chinese white poplar plantations in Yanzhou conducted by Zhang et al. [19].

Correlation coefficients are important for breeding strategies [36] because they describe the degrees of correlation between different traits and characters [37]. In this study, the chemical composition of wood (BA, HC, AC, and KL) was found to generally exhibit a weak correlation with growth traits, which was consistent with previous research conducted on 38-year-old *Populus simonii* × *P. nigra* [33], *Larix olgensis* [38], and *Pinus massoniana* [39]. This suggests that wood growth traits and chemical composition may be genetically independent, which is advantageous for combination selection.

5. Conclusions

In summary, the results of the current study indicate that the MC displayed a firstly decreasing and then subsequently increasing correlation with decreasing planting density. The BA content of triploid hybrid clones exhibited a high phenotypic variation (CVp = 17.11%–32.45%) at each planting density, which was much higher than the MC (CVp = 3.73%–11.21%) and other three chemical composition variations (CVp = 1.16%–11.46%). The initial planting density exerted a significant effect on only the MC of 11-year-old triploid Chinese white poplars ($0.001 < p < 0.01$). Large effects ($p < 0.05$) were also observed for the chemical compositions of the clones. More specifically, compared with the wood MC, the chemical composition of the triploid Chinese white poplar was primarily controlled by its own genetic basis and was virtually unaffected by the initial planting density. Furthermore, the chemical composition of wood (BA, HC, AC, and KL) generally exhibited a weak correlation with its growth traits. Therefore, high biological yield should be considered in the determination of initial planting density in the construction of poplar pulp timber forests.

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