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Primary Selection of Excellent *Catalpa fargesii* Clones Based on Growth and Wood Properties

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Abstract: To select excellent clones characterized by fast growth and high-quality wood of *Catalpa fargesii* Bur., growth traits, including height and diameter at breast height (DBH) at 1, 9, 11 and 13 years old, were collected and wood properties, including the Pilodyn value and elastic modulus at age 13 of 200 clones of *C. fargesii* from different ecological areas (four provinces), were measured. Genetic variation analysis and repeatability estimation were carried out. The correlation between the characteristics and the correlation between the characteristics and the geographical and climatic factors were analyzed. Excellent clones were selected by a comprehensive evaluation method combined with breeding values. The traits of *C. fargesii* were significantly different among the clones. The coefficient of variation (*CV*) ranged from 12.12% to 26.17%, and the repeatability (*R*) ranged from 0.79 to 0.97. The growth traits among ages of 9, 11 and 13 were significantly correlated, and the growth traits at ages of 9, 11 and 13 and Pilodyn values at the age of 13 were positively correlated with altitude and negatively correlated with longitude. Tree growth at ages of 11 and 13 showed a high negative correlation with wood properties. The suitable tree age for the early selection of clones with excellent growth and wood properties is 11 years old. Nine clones with excellent growth, six clones with high-quality wood and three clones with great growth and wood properties were selected, which laid a foundation for further optimization of *C. fargesii* clones. Additionally, *C. fargesii* clones in the western and high-altitude areas featured fast growth, while those in the eastern and low-altitude areas had better wood properties. This study serves as a reference for the selection of *C. fargesii* clones in different ecological areas.

Keywords: *Catalpa fargesii*; genetic variation; comprehensive evaluation method; breeding value; excellent clone breeding

Citation: Yu, X.; Li, F.; Zhao, Q.; Wang, J.; Liu, Y.; Yi, F.; Guo, X.; Zhang, P.; Ma, W. Primary Selection of Excellent *Catalpa fargesii* Clones Based on Growth and Wood Properties. *Forests* **2022**, *13*, 1659. https://doi.org/10.3390/f13101659

Academic Editors: Chenghao Li, Jingli Yang and Yuhan Sun

Received: 14 September 2022
Accepted: 3 October 2022
Published: 10 October 2022

1. Introduction

Trees harbor an abundance of genetic diversity arising from both genetic and environmental factors [1]. These genetic variations can be utilized by selectively breeding to genetically improve trees. Owing to the high genetic correlation between tree traits at early and late ages, the mature-stage traits can be predicted according to the young-stage traits. This makes early selection an effective breeding strategy, which can greatly shorten the breeding cycle [2]. Li et al. [3] selected 77 excellent *Populus deltoides* clones through the growth parameters, which could be used for regional test. Shu et al. [4] measured the DBH, tree height and volume of 170 *Liriodendron sino-americanum* clones aged 1–8 years, and determined that the 3-year-old trees could be used for early selection, thus eight fast-growing clones were selected. Environmental diversity will result in differences in tree growth and wood properties. Therefore, analyzing the correlation between target traits and the geographical and climatic factors of provenance can provide basis for germplasm selection and improve selection efficiency. For example, Zhang et al. [5] analyzed the growth differences among 17 *Phoebe bournei* provenances, and identified that Lishui provenance had elite growth performance among all the provenances. By dissecting the variation of photosynthetic parameters of Rhododendron simsii among three provenances and the correlation between photosynthetic parameters and environmental factors, Zhang et al. [6] determined that Anhui provenance was an excellent growth adaptability resource.

Catalpa fargesii Bur. is a tree of the genus *Catalpa* in the Bignoniaceae family that has excellent wood properties, developed roots, and a strong capacity to consolidate soil, resist wind, and endure drought as well as cold. *C. fargesii* is mainly distributed in Gansu, Shaanxi, Shanxi, Hebei, and Henan Provinces, among others [7]. It has high genetic variation due to its wide ecological distribution range [8], and the potential for excellent clone breeding is substantial. Zhao [7] et al. conducted diversity analysis on 137 germplasm resources based on the growth and leaf traits of 2-year-old *C. fargesii* and revealed that the differences in phenotypic traits were mainly caused by genetic factors. Ling [9] et al. conducted genetic variation analysis on 33 5-year-old *C. fargesii* clones and preliminarily screened 6 fast-growing and high-yielding varieties and 4 excellent timber varieties for directional cultivation. Due to the increasing demand for excellent wood, it is very urgent and necessary to select fast-growing and high-quality *C. fargesii* clone for subsequent plantation construction.

In this study, 200 *C. fargesii* clones from Gansu, Shaanxi, Shanxi and Henan Provinces were used. (i) The variation level was revealed by measuring and analyzing the growth traits of 1-, 9-, 11-, and 13-year-old *C. fargesii* and the wood properties of 13-year-old *C. fargesii*. (ii) The appropriate tree age and province for selecting *C. fargesii* clones were determined by analyzing the correlation between the traits of different tree ages, as well as the correlation between each trait and the geographical and climatic factors of the province. (iii) Based on growth, wood properties and breeding values, excellent clones of *C. fargesii* were selected to further evaluate the productivity and stability of different ecological zones.

2. Materials and Methods

2.1. Material Source

In 2007, a comprehensive investigation and collection of *C. fargesii* germplasm resources were carried out in Gansu, Shaanxi, Shanxi and Henan Provinces. One-year-old twigs were collected, and a total of 267 germplasms were collected. In 2008, the clones were grafted in Qinzhou District, Tianshui city, Gansu Province, and each plant was grafted and propagated into 36 plants. The growth and phenotypic traits of 200 clones were measured in the same year. In 2009, a comparative experimental forest of germplasm resources was built in the Shaba experimental area of the Forestry Science Research Institute of Xiaolongshan Forestry Experimental Bureau in Gansu Province. A randomized complete block design was adopted, with 4 repetitions, and 200 clones were tested. The specific source information of the tested clones is shown in Figure 1 and Table 1.

2.2. Experimental Site

The site is located in the western Qinling Mountains, with loess soil. The annual average temperature is 10.7 °C, the accumulated temperature $\geq$ 10 °C is 3359 °C, the extreme high temperature is 39 °C, the extreme low temperature is $-$19.2 °C, the frost-free period is approximately 190 days, and the annual precipitation is more than 600 mm.

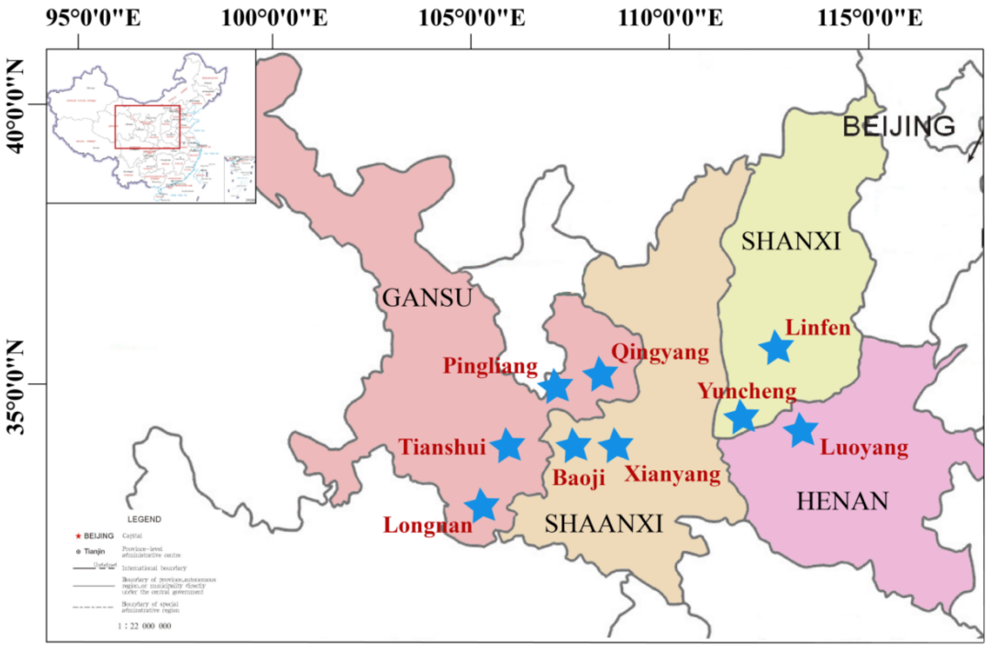

Figure 1. Distribution map of tested clones. A total of 200 clones were sampled across the 9 Provenance (asterisk) from Gansu ( ), Shaanxi ( ), Shanxi ( ) and Henan Province ( ).

Table 1. Source of tested clones.

Province	City	Number of Clones	Altitude /m	Longitude (E)/°	Latitude (N)/°	Annual Mean Temperature/°C	Annual Precipitation/mm
Gansu	Tianshui	97	1509.48	105.72	34.57	10.93	592.98
	Longnan	22	1295.68	105.61	33.80	11.22	716.33
	Qingyang	36	1417.50	106.84	35.19	9.56	542.58
	Pingliang	8	1318.19	107.39	35.42	9.65	556.61
Shaanxi	Xianyang	3	1084.00	107.51	35.12	9.10	584.00
	Baoji	1	910.00	107.06	34.36	9.10	584.00
Shanxi	Linfen	17	790.35	111.16	35.86	10.47	556.71
	Yuncheng	5	447.20	110.42	34.97	14.10	530.00
Henan	Luoyang	11	395.00	112.45	34.62	14.34	565.27

2.3. Measurement Index

The growth traits of the 1-, 9- and 11-year-old *C. fargesii* clones were measured in 2008, 2016 and 2018, respectively, and the growth and wood properties of the 13-year-old *C. fargesii* were measured in 2020. The specific measurement method involved randomly selecting 3 normal trees from each clone, and the measurement accuracies of tree height and diameter at breast height (DBH) were 0.01 M and 0.01 cm, respectively. A Pilodyn wood tester (6J, Proceq, Switzerland) was used to measure the Pilodyn values to the north and south of where the DBH was measured three times [10,11], and the average of these values was taken as the Pilodyn value (0.01 mm). A director ST300 wood mechanical property tester (Fibre-gen, New Zealand) was used to measure the elastic modulus (MOE) at the DBH three times, and the average value was taken as the MOE (0.01 GPa) [12,13].

2.4. Data Analysis

Excel 2013 was used to organize and analyze the data. SPSS 16.0 was used for one-way ANOVA and correlation analysis, and the breeding value was calculated by ASReml according to Gilmour [14]. RStudio was used to calculate the genetic diversity index (H'), $H'=-\sum PiLnPi$, where Pi is the probability of occurrence of the i-th code of a certain trait [15]. GraphPad and TBtool were used to draw figures.

Coefficient of variation (*CV*):

$$CV = SD/X \tag{1}$$

where *CV* is the coefficient of variation, *SD* is the standard deviation, and *X* is the mean of the clones.

Clone repeatability was estimated by the method of Xu [16]:

$$R = 1 - 1/F \tag{2}$$

where *R* is the repeatability and *F* is the *F* value in the analysis of variance.

The clones were comprehensively evaluated by the Brounnstrom comprehensive evaluation method [17], and the calculation formula is:

$$Qi = \sqrt{\sum_{j=1}^{n} ai}, ai = Xij/Xj\max \tag{3}$$

where *Qi* is the comprehensive evaluation value, *Xij* is the value of a trait of the i-th clone, *Xjmax* is the optimal value of a trait, and *n* is the number of evaluation indicators. In this study, clones with small Pilodyn values need to be selected, so the formula is adjusted when calculating the ai value of Pilodyn values, $ai = -Xij/Xjmax$. The formula for calculating the genetic gain estimation is [18]:

$$\triangle G = RW/X \tag{4}$$

where *W* is the poor selection, *R* is the repeatability of the trait, and *X* is the average value of a trait.

3. Results

3.1. Overall Variation Analysis of Growth and Wood Properties of C. fargesii Clones

The results of the variance analysis for each trait of the 200 *C. fargesii* clones at 1, 9, 11 and 13 years showed (Table 2) that there were highly significant differences in tree height, DBH, Pilodyn value and MOE among the clones ($p < 0.01$). The mean values of the tree height and DBH of the 1-year-old *C. fargesii* clones were 1.65 m and 16.70 mm, respectively, and the variation ranges were 1.07–2.32 m and 7.60–21.94 mm. The mean values of the tree height and DBH of 13-year-old clones were 6.31 m and 92.91 mm, respectively, and the variation ranges were 3.60–8.00 m and 43.00–152.00 mm. The *CV*s of the tree height and DBH of the 1-, 9-, 11- and 13-year-old *C. fargesii* clones ranged from 13.71% to 26.17% (Table 2), and the *CV*s of the Pilodyn value and MOE were 12.12% and 15.59%, respectively. The height H' values of the 1-, 9-, 11- and 13-year-old trees were 2.083, 2.043, 1.939 and 1.898, respectively, which gradually decreased with increasing tree age. The DBH H' of the four tree ages were between 1.830 and 2.042. The H' values of the Pilodyn value and MOE were 1.825 and 1.854, respectively. Therefore, there was substantial genetic variation in the growth and wood properties of the *C. fargesii* germplasm. The repeatability values of the height and DBH of the 1-year-old *C. fargesii* clones were the highest, which were 0.97 and 0.84, respectively. The repeatability values of the height and DBH of the 9-, 11- and 13-year-old trees were slightly lower than those of the 1-year-old trees; however, the tree height was still between 0.87 and 0.90, and the DBH was between 0.79 and 0.84. The repeatability values of the Pilodyn value and MOE of 13-year-old clones were 0.88 and 0.75, respectively.

Table 2. Variance analysis and repeatability estimation of the growth and wood characteristics of the *C. fargesii* clones. *CV*, coefficient of variation; *H′*, genetic diversity index **, $p < 0.01$.

Age	1 a		9 a		11 a		13 a			
Characters	Height /m	Diameter /mm	Height /m	Diameter /mm	Height /m	Diameter /mm	Height /m	Diameter /mm	Pilodyn value/mm	MOE /GPa
Mean ± SD	1.65 ± 0.23	16.70 ± 2.60	5.15 ± 0.92	60.22 ± 13.15	6.28 ± 0.98	76.85 ± 14.45	6.31 ± 0.86	92.91 ± 23.59	14.01 ± 1.70	9.22 ± 1.44
Amplitude	1.07–2.32	7.60–21.94	2.45–7.18	23.09–94.77	3.20–9.20	29.84–133.08	3.60–8.00	43.00–152.00	8.92–25.00	4.76–15.45
CV/%	13.73	15.59	17.81	21.84	15.60	18.80	13.71	26.17	12.12	15.59
F Value	29.12 **	6.35 **	7.58 **	6.13 **	8.62 **	4.77 **	10.12 **	5.08 **	8.27 **	3.92 **
Repeatability	0.97	0.84	0.87	0.84	0.88	0.79	0.90	0.80	0.88	0.75
H′	2.083	2.040	2.043	1.830	1.939	1.983	1.898	2.042	1.825	1.854

3.2. Correlation Analysis of Growth Characteristics, Wood Properties and Geographical and Climatic Factors of C. fargesii Clones

3.2.1. Correlation of Growth Traits of *C. fargesii* Clones

Correlation analysis was carried out on the height and DBH of the 1-, 9-, 11- and 13-year-old *C. fargesii* clones (Figure 2). There were no significant correlations between the height and DBH of 1-year-old clones and those of the 9-, 11- and 13-year-old clones ($p > 0.05$). The growth traits among the 9-, 11- and 13-year-olds were highly significantly positively correlated ($p < 0.01$). The height and DBH were significantly positively correlated at each age. Therefore, the height and DBH of the 1-year-old *C. fargesii* clones could not fully reflect the growth level of middle-aged forests, and the growth tended to be stable after 9 years of age.

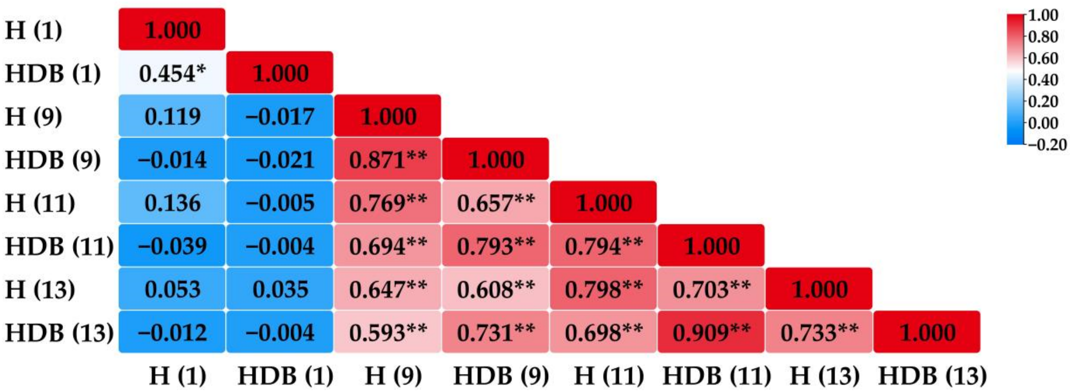

Figure 2. Correlation analysis of the growth characteristics of *C. fargesii* clones at 1, 9, 11 and 13 years. H, height; DBH, diameter. The numbers in brackets indicate the age of the tree. * Represents correlation is significant at the 0.05 level, and ** represents correlation is significant at the 0.01 level.

3.2.2. Correlation between Growth Traits and Wood Properties of *C. fargesii* Clones

The correlation analysis between the growth traits of the 1-, 9-, 11-, and 13-year-old *C. fargesii* clones with the wood traits of the 13-year-olds clones showed that (Figure 3) non-significant correlation between the growth traits and wood traits of the 1-year-old clones. After 9 years of age, DBH and MOE were significantly or extremely significantly negatively correlated, and the correlation increased with increasing age; however, the correlation between height and MOE did not reach a significant level. There was a positive correlation between the Pilodyn value and height, which was only extremely significant at 11 years old. The DBHs of the 11- and 13-year-olds were significantly positively correlated with the Pilodyn value. The growth traits of the *C. fargesii* clones showed a significant correlation with the wood properties after 11 years of age, and the correlation between the DBH and the wood properties increased with age. In general, the better the growth was, the larger the Pilodyn value, and the smaller the MOE.

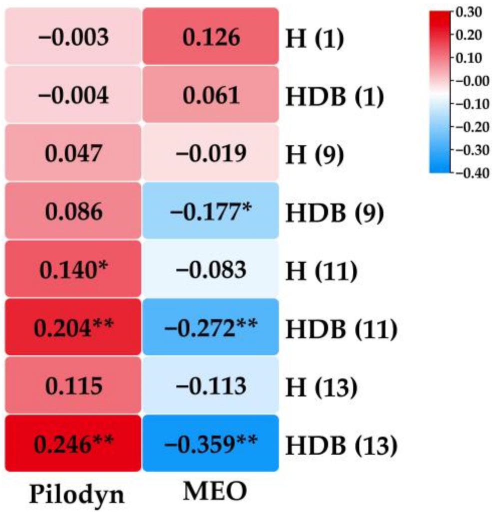

Figure 3. Correlation analysis between growth characteristics and wood properties of *C. fargesii* clones. Pilodyn, Pilodyn value; MEO, elastic modulus. * Represents correlation is significant at the 0.05 level, and ** represents correlation is significant at the 0.01 level.

3.2.3. Correlation between the Growth and Wood Properties of *C. fargesii* Clones and Geographical and Climatic Factors

A correlation analysis was carried out between the growth and wood properties of the 13-year-old *C. fargesii* and the main geographical and climatic factors of the province (Figure 4). Both height and DBH were significantly positively correlated with altitude and negatively correlated with longitude and annual mean temperature. The Pilodyn value was significantly positively correlated with altitude and annual rainfall and extremely significantly negatively correlated with longitude. Therefore, in comparison to other clones, the clones in provinces at higher altitudes, near western geographical locations and with lower annual average temperatures grew better. The Pilodyn values of clones in provinces in eastern areas at low altitudes were lower. The lower the annual rainfall was the lower the Pilodyn value was, and the higher the MOE was.

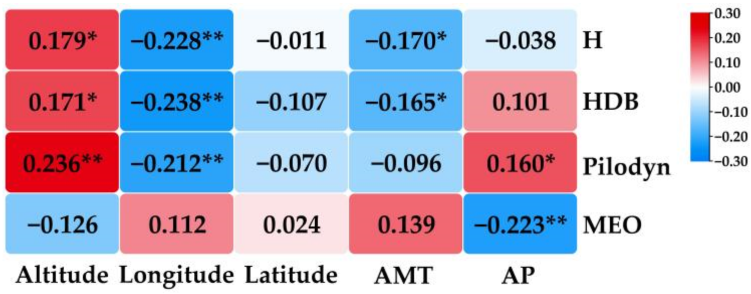

Figure 4. Correlation analysis between growth and wood properties with geographical and climatic characteristics of the 13-year-old *C. fargesii* clones. AMT, annual mean temperature; AP, annual precipitation. * Represents correlation is significant at the 0.05 level, the same below, and ** represents correlation is significant at the 0.01 level.

3.3. Comprehensive Evaluation of C. fargesii Clones

3.3.1. Clonal Evaluation Based on Growth Traits

The growth of the *C. fargesii* clones was comprehensively evaluated by using the height and DBH of 9- (Q_{i9}), 11 (Q_{i11}) and 13-year-old (Q_{i13}) clones, and the clones were selected with a selection rate of 10% (Figure 5a–c). The selection results of the three tree ages are shown in Figure 6. The average values of height and DBH of the 20 clones selected at 9 years old were 6.48 m and 80.93 mm, which were 20.52% and 25.59% higher than the overall average, and the genetic gains were 22.51% and 28.89%, respectively. The average values of height and DBH of the 20 clones selected at 11 years old were 7.67 m and 99.62 mm, which were 18.12% and 22.86% higher than the overall average, and the genetic gains were 19.44% and 23.41%, respectively. The average values of height and DBH of the 20 clones selected at 13 years old were 7.44 m and 122.89 mm, which were 15.19% and 24.40% higher than the overall average, and the genetic gains were 16.17% and 25.82%, respectively. The results showed that the average values of the height and DBH of the selected excellent clones were 15%–25% higher than the overall average, the genetic gains of height were between 19.44% and 22.51%, and the genetic gains of DBH were between 22.86% and 28.89%, respectively. There were 11 clones selected for all three tree ages (Figure 6), which were 21626-076, 11213-232, 11212-129, 11522-074, 11216-206, 11213-194, 11213-240, 11521-225, 11212-130, 11522-067 and 11215-020. Their growth traits were stable and good. Two clones, 11317-012 and 11521-044, were not selected at the age of 9 but were selected at the ages of 11 and 13. In particular, 11317-012 ranked first, indicating that it had great growth potential. The breeding values of height and DBH of the 200 clones were calculated and comprehensively evaluated ($Q_{i\mathrm{B}}$). Nine of the above twelve clones had better growth scores than the overall average value (0.994), and these values were 11212-129 (1.287), 11215-020 (1.240), 11213-194 (1.237), 11521-225 (1.277), 11522-067 (1.260), 21626-076 (1.377), 11213-240 (1.290), 11213-232 (1.263) and 11521-044 (1.258).

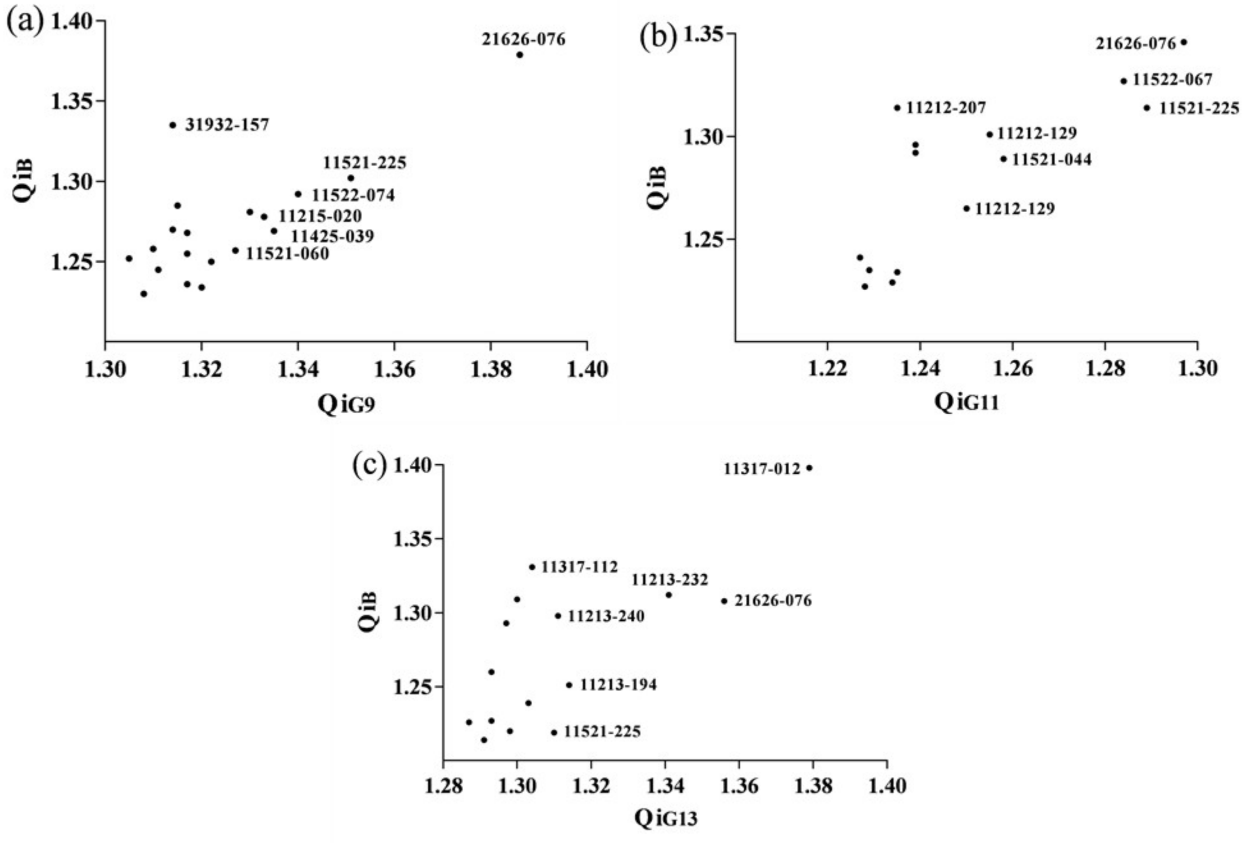

Figure 5. *Qi* values of 200 *C. fargesii* clones based on growth traits by comprehensive evaluation methods. Q_{iB}, Comprehensive evaluation index of breeding value of tree height and diameter. $Q_{i\mathrm{G}9}$ (**a**), $Q_{i\mathrm{G}11}$ (**b**) and Q_{iG11} (**c**) represent the comprehensive evaluation indexes of height and DBH of 9-, 11- and 13-year-old trees, respectively.

3.3.2. Clonal Evaluation Based on Wood Traits

The Pilodyn value and MOE of the 13-year-old *C. fargesii* clones were used to comprehensively evaluate the wood properties (Q_{iw}), and the clones were selected with a selection rate of 10%. The 20 selected clones are shown in Figure 7. The average values of the Pilodyn value and MOE were 11.83 mm and 12.00 GPA, respectively. The Pilodyn value was 18.43% lower than the overall mean, the MOE was 23.17% higher than the overall mean, and the genetic gains for the Pilodyn value and MOE were 13.70% and 22.62%, respectively. There was no overlap between the 20 clones selected based on wood traits and those selected based on growth traits (Figure 8). The breeding values of the Pilodyn value and MOE of these 20 clones were calculated and comprehensively evaluated (Q_{iB}). Six of the above twenty clones had better wood scores than the overall average value (1.019), and these clones were 11213-238 (1.237), 42034-211 (1.235), 42034-175 (1.262), 11213-236 (1.159), 11213-089 (1.184) and 11213-081 (1.156); in addition, they could be used for the breeding of clones with excellent wood properties.

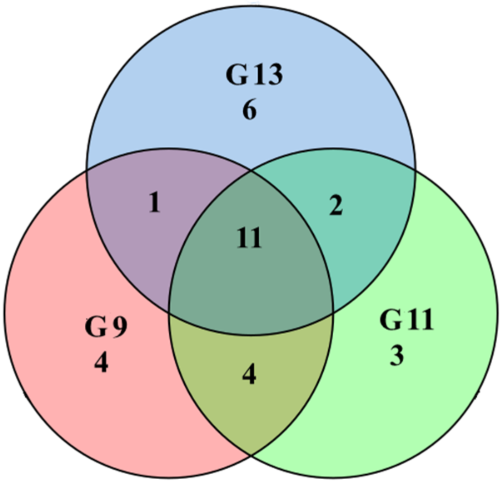

Figure 6. Wayne diagram of excellent growth clones selected at the ages of 9, 11 and 13. G9 ( ), G11 ( ) and G13 ( ) represent 20 excellent clones selected according to the comprehensive evaluation of growth traits at the ages of 9, 11 and 13, respectively.

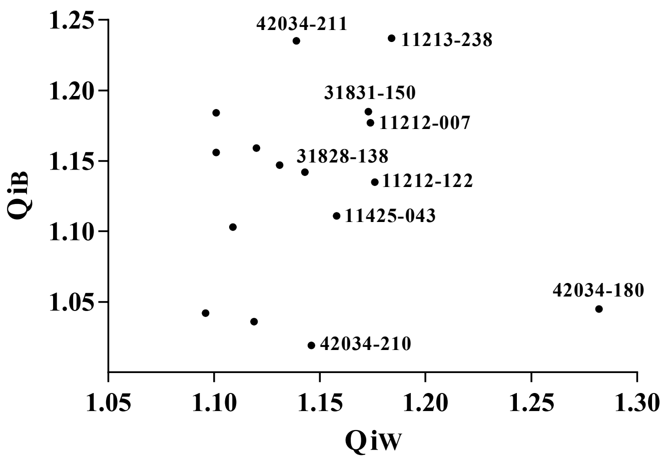

Figure 7. Q_i values of 200 *C. fargesii* clones based on wood traits by comprehensive evaluation methods. Q_{iB}, Comprehensive evaluation of the breeding values of the Pilodyn value and MOE; Q_{iW}, comprehensive evaluation of the Pilodyn value and MOE.

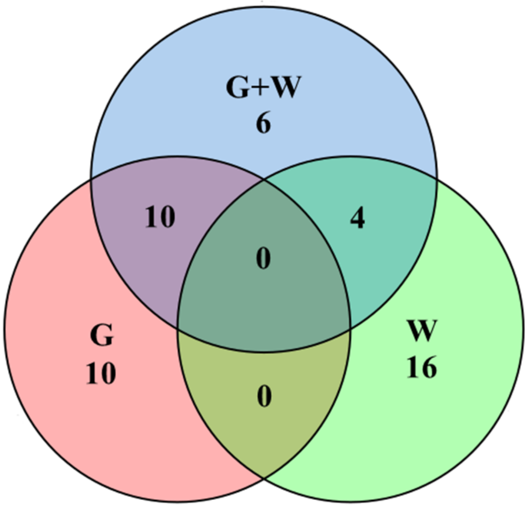

Figure 8. Wayne diagram of excellent clones selected for growth, wood and growth and wood properties. G ( ), 20 excellent clones selected according to the comprehensive evaluation of growth charac-teristics; W ( ), 20 excellent clones selected according to the comprehensive evaluation of wood properties; G + W ( ), 20 excellent clones selected according to the comprehensive evaluation of growth and wood properties.

3.3.3. Clonal Combined Evaluation Based on Growth Wood Traits

The height, DBH, Pilodyn value and MOE of the 13-year-old *C. fargesii* clones were comprehensively evaluated (Q_{iB+W}). The clones were selected with a selection rate of 10%. The 20 selected clones are shown in Figure 9. The average values of the height, DBH, Pilodyn value and MOE were 7.24 m, 109.62 mm, 11.83 mm and 12.00 GPa, respectively. Heitht, DBH and MOE were 12.85%, 15.24% and 8.62% higher than the overall mean, respectively, and the Pilodyn value was 12.94% lower than the overall mean. The genetic gains of the height, DBH, MOE and Pilodyn value were 13.20%, 14.39%, 4.29% and 7.05%, respectively. The average values of the height, DBH, Pilodyn value and MOE of the 20 clones selected according to wood and growth traits were higher than the overall average value; however, the increases were less than those of the clones selected based only on growth or wood properties, and the same was true for genetic gain.

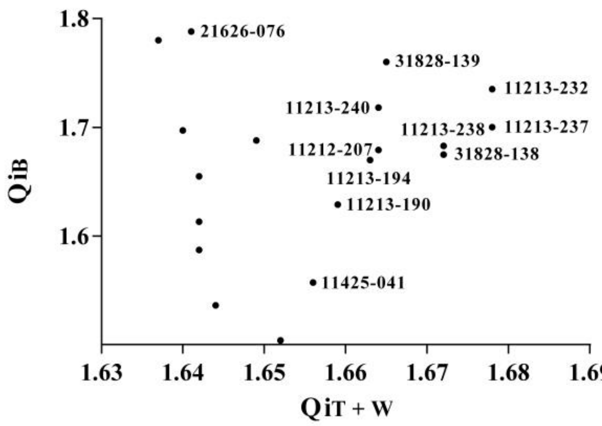

Figure 9. Q_i values of the 200 *C. fargesii* clones based on growth and wood traits by comprehensive evaluation. Q_{iB}, comprehensive evaluation index of breeding value of growth and wood properties; Q_{iT+W}, comprehensive evaluation index of growth and wood properties.

Among the 20 clones selected, 11216-206, 11213-232, 11213-237, 11213-240, 11213-194, 11213-006, 11212-130, 31829-145, 21626-076 and 11318-164 were the clones selected by using growth traits (Figure 9), indicating that the selection of these 10 clones was due to their good growth. However, 31828-138, 11213-238, 11425-041 and 42034-180 were the clones selected by using wood properties, and the selection was due to their superior wood properties. The six clones, including 31828-139, 11212-207, 11213-190, 11214-102, 11215-031 and 11213-242, were between 7.00 m and 7.67 m in height and 97.67 mm and 107.33 mm in DBH, the Pilodyn values ranged from 9.17 mm to 10.92 mm, and the MOE ranged from 9.16 GPa to 10.92 GPa. Because the growth traits and wood properties of the above six clones were relatively balanced and all at the middle and upper levels, they were selected. Although the growth or wood properties of these six clones were not optimal, they were fast-growing and high-quality clones. The breeding values of the growth and wood properties of these 20 clones were comprehensively evaluated (Q_{iB}). Seven of the above twenty clones, including 11213-232 (1.700), 11213-240 (1.718), 11212-207 (1.679), 11213-194 (1.670), 11213-190 (1.629), 11212-130 (1.688) and 11213-242 (1.697), had greater values than the average value of the two-hundred clones (1.624) and could be used for breeding clones with excellent growth and wood properties.

3.4. Analysis of the Environmental Factors of the Selected Clonal Provinces

The provinces with excellent clones selected at different ages are shown in Table 3. Based on Q_{iG}, the province with the highest clone selection rate was Tianshui (45%–60%), followed by Pingliang (20%–25%). According to Q_{iW}, the provinces with the highest selection rates of clones were Tianshui (55%), Luoyang (25%) and Linfen (10%). According to Q_{iG+W}, the province with the highest selection rates of clones was Tianshui (65%), followed by Linfen (15%), and the selection rates of Luoyang, Longnan, Qingyang and Xianyang were all 5%. Ninety-seven clones were collected in Tianshui city, Gansu Province, accounting for 48.5% of the total germplasms. Twelve clones were selected according to the growth traits of 9- and 11-year-old trees from Tianshui, with a selection rate of 60%. According to the wood property traits and joint evaluation of growth and wood properties of 13-year-old trees, the selection rates from Tianshui were 55% and 65%, respectively, which were greater than the percentage of Tianshui Province in the total germplasms. Eight germplasms were collected in Pingliang city, Gansu Province, accounting for 4% of the total germplasms. According to Q_{i9}, Q_{i11} and Q_{i13}, the selection rates were 20%, 25% and 25%, respectively, which were far greater than the proportion of those from Pingliang in the total clones. Seventeen germplasms were collected from Linfen city, Shanxi Province, accounting for 8.5% of the total germplasm, and the selection rates were 10% and 15% based on the Q_{iG+W}. Eleven germplasms were collected in Luoyang city, Henan Province, accounting for 5.5% of the total germplasm; in addition, five germplasms were selected according to the Q_{iW}, and the selection rate was 25%, which was greater than the proportion of total clones.

Table 3. Selection rate of excellent *C. fargesii* clones in various provinces.

Province	City	Total		9 Growth Traits		11 Growth Traits		13 Growth Traits		13 Wood Traits		13 Growth and Wood Traits	
		Number	Rate (%)	Number	Rate (%)	Number	Rate (%)	Number	Rate (%)	Number	Rate (%)	Number	Rate (%)
Gansu	Tianshui	97	48.50	12	60.00	12	60.00	9	45.00	11	55.00	13	65.00
	Longnan	22	11.00	1	5.00	1	5.00	4	20.00	0	0.00	1	5.00
	Qingyang	36	18.00	1	5.00	1	5.00	0	0.00%	2	10.00	1	5.00
	Pingliang	8	4.00	4	20.00	5	25.00	5	25.00	0	0.00	0	0.00
Shaanxi	Xianyang	3	1.50	1	5.00	1	5.00	1	5.00	0	0.00	1	5.00
	Baoji	1	0.50	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Shanxi	Linfen	17	8.50	0	0.00	0	0.00	1	5.00	2	10.00	3	15.00
	Yuncheng	5	2.50	1	5.00	0	0.00	0	0.00	0	0.00%	0	0.00
Henan	Luoyang	11	5.50	0	0.00	0	0.00	0	0.00	5	25.00	1	5.00

The clonal selection rate of each province was analyzed in combination with geographical and climatic factors (Table 2). The average altitude of Tianshui Province is 1509.48 m, ranking first among the nine provinces, with an average longitude of 105.07°E, which is the lowest longitude among the nine provinces. The average altitude of Pingliang Province was 1318.19 m, ranking second, with an average longitude of 107.39°E, which was lower than that of other provinces. The average altitudes of Linfen and Luoyang provinces were 790.35 m and 395.00 m, ranking seventh and ninth, respectively, with longitudes of 111.16°E and 112.45°E, ranking second and first, respectively. The results showed that Tianshui city, Gansu Province, and Pingliang city, Gansu Province, had higher altitudes and western geographical locations, and the germplasms growing in these locations had better growth characteristics; thus, the clones selected according to growth accounted for a relatively high proportion. Linfen city and Luoyang city are at lower altitudes and eastern geographical locations; thus, the germplasms growing there had better wood characteristics, and the proportion of clones selected according to wood properties was relatively high.

4. Discussion

4.1. Intraspecific Variation in C. fargesii Is Substantial and Clone Breeding Potential Is Great

There is abundant genetic variation in trees, and selective breeding can select excellent germplasms from abundant breeding resources for popularization and application according to breeding goals to genetically improve trees [19]. There are high levels of genetic variation in forests. For example, the growth or wood properties of *Catalpa bungei* [20], *C. fargesii* f. duclouxii [21], white poplar (*Populus alba* L.) [22] and *Picea crassifolia* Kom. [23] showed extremely significant differences among clones, and their *CV* values were between 7.21% and 29.18%, which indicates great potential for genetic improvement. In this study, the growth traits of the 1-, 9-, 11- and 13-year-old clones and the wood properties of the 13-year-old clone were extremely significantly different among the 200 clones; the *CV* of each trait ranged from 12.12% to 26.17%, and the genetic diversity ranged from 1.825 to 2.083. The growth and wood properties of *C. fargesii* varied greatly among different clones, and the diversities were rich; thus, selective breeding could be carried out. In addition, repeatability can reflect the degree of genetic diversity affected by environmental factors. The higher the repeatability is, the more stable the trait is, the less affected it is by the external environment, and the better the selection effect [24]. In this study, the repeatability of the growth and wood properties of *C. fargesii* ranged from 0.75 to 0.97, which was similar to the results of high repeatability (0.745–0.983) for the height, DBH and wood density of *C. fargesii* f. duclouxii [21], *C. bungei* [25], and *Picea crassifolia* Kom. [23]. This shows that growth and wood characteristics are highly genetically controlled, providing a good genetic basis for growth and wood property improvements. In addition, the great repeatability of each characteristic of *C. fargesii* may also be due to the establishment of a homogenous garden in Maiji District, Tianshui city, Gansu Province, after the germplasm collection. The growth environment was the same, so the genetic effect played a dominant role in the causes of the variation. The results indicate that the breeding of *C. fargesii* clones for the purpose of improving growth and wood properties has great potential, is feasible and can provide a basis for subsequent artificial breeding.

4.2. Suitable Tree Age for Early Selection of Excellent C. fargesii Clones

In the process of selective breeding, the correlation coefficient among the traits can reflect the relationship among the target traits, which is conducive to the selection of breeding goals [26]. In the present study, height was significantly positively correlated with DBH among each tree age, indicating that these two growth traits could be used for optimization at the same time, which was consistent with research on rubber trees (*Hevea* spp.) [27] and white poplar [22]. In addition, correlation analysis of early and late traits can determine the appropriate age for early selection; for example, the year-to-year correlation of height of 12-year-old Yunnan pine (*Pinus yunnanensis*) was significant, so 12 years was the final selection year for its early selection [28]. The correlation coefficient between the growth characteristics of 6- and 14-year-old alder (*Alnus cremastogyne* Burk.) was extremely significant, indicating that the early selection of alder was reliable [29]. In this study, after

9 years of age, the growth traits between tree ages reached extremely significant positive correlations, which indicated that height and DBH at 1 year of age could not fully reflect the growth of mature *C. fargesii* clones. After 9 years of age, the growth traits tended to be stable and could be used for evaluation and breeding, while after 11 years of age, there was a stable correlation between growth characteristics and wood properties, which could be used for the joint breeding of clonal growth and wood properties. The DBH was extremely significantly correlated with the Pilodyn value and MOE, and the correlation coefficient increased with growth time. DBH was more suitable for use as a trait for the comprehensive evaluation of wood property height, and the growth of *C. fargesii* was negatively correlated with wood properties. The larger the height and DBH were, the larger the Pilodyn value and the smaller the MOE were, which was consistent with previous research results [30,31]. This result may have been due to the rapid cell division of fast-growing trees, which reduces the wood density and affects its physical properties [12,32]. Therefore, tree age should be over 11 years old when selecting *C. fargesii* clones with excellent growth and wood properties. When breeding elite germplasms, the specific clones and the suitable tree age for early selection should be determined according to the breeding target and the time when the target characteristic becomes stable. Ultimately, the goal of not only predicting mature traits through juvenile traits but also shortening the breeding period can be achieved.

4.3. Effects of Provincial Geographical and Climatic Factors on Clonal Selection

By analyzing the correlation between the target traits and the geographical and climatic factors of the provinces, the suitable provinces were determined. For example, the growth traits of Yunnan pine were significantly negatively correlated with the longitude and altitude of the province and significantly positively correlated with the annual mean temperature. Therefore, the Yunnan pine from Yongren Province grew better [33]. The height of Liquidambar formosana Hance showed a decreasing trend of "southwest–northeast" in terms of geographical location, so the plants in the three provinces of Funing in Yunnan, Bawangling in Hainan and Limusan in Hainan were higher [34]. In this study, the growth of *C. fargesii* clones was highly correlated with altitude and longitude. Among the 20 clones selected according to Q_{i9}, Q_{i11} and Q_{i13}, 9–12 clones of three tree ages were from Tianshui city, Gansu Province, and 4–5 clones were from Pingliang, Gansu Province. The proportion of excellent clones in these two provinces was much greater than that of their total germplasm. This may be because the average altitudes of Tianshui and Pingliang provinces were high (the average altitudes were 1509.48 m and 1318.19 m, respectively), and the positions were western (the average longitudes were 105.07 °E and 107.39 °E, respectively). Another reason why the proportion of germplasms with good growth traits in Tianshui and Pingliang was larger than that of the original germplasms may be that 163 germplasms were collected from Gansu Province, of which 97 were from Tianshui city and were planted in Maiji District, Tianshui city, Gansu Province. The germplasms from Gansu Province could better adapt to the local climatic environment, so the germplasms of Tianshui city and Pingliang city grew better. The Pilodyn values of the *C. fargesii* clones were significantly positively and negatively correlated with altitude and longitude, respectively. Among the 20 clones selected according to the Q_{iW}, 5 germplasms were from Luoyang city, Henan Province, and two germplasms were from Linfen city, Shanxi Province. The proportion of excellent clones in these two provinces was far greater than that in the total germplasms. This may be because the average elevations of Linfen and Luoyang were 790.35 m and 395.00 m, ranking fourth and second among the nine cities, respectively, and the longitudes were 111.16° E and 112.45° E, which were the easternmost geographically located. Therefore, the germplasms in the two cities had good wood properties. The proportion of clones selected according to the wood properties was relatively high. The above results show that in future research, if you want to select and breed *C. fargesii* clones with excellent growth traits, then you can focus on the high-altitude areas in the west. If you want to select clones with excellent wood traits, then you can focus on germplasms from the east. The germplasms collected should be subjected to multipoint assays so that the results will be more reliable.

In addition, during the process of introduction, excellent provinces with similar habitats and adjacent provinces should be selected for popularization and application.

4.4. Selection of Excellent C. fargesii Clones

Breeding methods are determined by breeding objectives. Xiao [21] et al. evaluated the clones through cluster analysis and the membership function method and divided the *C. fargesii* f. duclouxii clones into four types: high wood density type, short fiber type, low wood density type and long fiber type, which could be used for different breeding purposes. Ling [9] et al. used principal component analysis and the membership function method to screen 6 fast-growing and high-yield varieties and 4 high-quality timber clones from 33 *C. fargesii* clones for directional cultivation. In this study, 20 *C. fargesii* clones were selected according to Q_{iG}. Among them, 11 clones were selected at three tree ages, and their growth characteristics were relatively stable. The two clones, 11317-012 and 11521-044, were not selected at the age of 9 but were selected at the ages of 11 and 13. In particular, 11317-012 ranked first, indicating that it had great growth potential. In addition, breeding value is an important parameter in selective breeding, which can eliminate the influence of the environment and accurately reflect genetic effects [35,36]. The breeding values of 13 excellent growth clones were calculated. The breeding values of nine clones, 11212-129, 11215-020, 11213-194, 11521-225, 11522-067, 21626-076, 11213-240, 11213-232 and 11521-044, were high and could be used for the breeding of *C. fargesii* clones with good growth properties. Twenty clones were selected according to the Q_{iW}. Among them, six clones, 11213-238, 42034-211, 42034-175, 11213-236, 11213-089 and 11213-081, had higher breeding values and could be used for the selection of *C. fargesii* clones with good wood properties. Twenty clones were selected according to Q_{iG+W}, and the growth and wood properties of six clones, 31828-139, were at the upper middle level. Among the six clones, 11212-2071, 11213-190 and 11213-242 had higher breeding values and could be selected as clones with better growth and wood properties. Finally, nine excellent growth clones with stable or high growth potential, six high-quality wood clones, and three clones with excellent growth and wood properties were selected, which can be popularized and applied according to needs and used for genetically improving *C. fargesii*.

5. Conclusions

In the process of forest tree breeding, almost no elite variety can integrate all the target traits, so different candidate populations can be selected according to the breeding purpose. There is abundant intraspecific variation in *C. fargesii*, which has great potential for breeding excellent clones. The suitable age for early selection of *C. fargesii* clones with excellent growth and wood properties is after 11 years old. In this study, nine excellent clones with stable or high growth potential, six high-quality wood clones and three clones with better growth and wood properties were selected, which can be popularized and applied according to needs and finally used for genetically improving *C. fargesii*. In addition, *C. fargesii* grows faster in high-altitude and western areas, while *C. fargesii* in eastern and low-altitude areas has better wood properties, which can provide a reference for the further collection of *C. fargesii* resources in the future.

Author Contributions: Conceptualization, Q.Z., J.W. and X.G.; methodology, F.Y., J.W., W.M. and P.Z.; formal analysis, X.Y., F.Y. and W.M.; investigation, F.L. and Y.L.; resources, F.L.; writing—original draft preparation, X.Y.; writing—review and editing, W.M. and F.Y.; funding acquisition, J.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key R & D Program of China, grant number 2021YFD2200301 and the APC was funded by the China Academy of Forestry Sciences.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Neale, D.B.; Kremer, A. Forest tree genomics: Growing resources and applications. *Nat. Rev. Genet.* **2011**, *12*, 111–122. [CrossRef] [PubMed]
2. Pan, H.X.; Huang, M.R.; Ruan, X.G.; Li, H.G.; Wang, M.M. Study on Wood Property Improvement * VI. Populus deltoides × Genetic Correlation Analysis of Wood Characters of New Clones of Populus microphylla. *Scient IA Silvae Sin.* **1997**, *01*, 84–93.
3. Zhu, R.Q.; Chen, Y.; Han, Y.J.; Zhang, C.Y.; Yuan, Z.S.; Zhong, Y.L.; Li, S.W.; Dong, Y.F. Preliminary Evaluation on Seedling Stage of *Populus deltoides* Clones. *Shandong For. Sci. Tech.* **2022**, *52*, 53–57.
4. Shu, W.L. *Fast-Growing Clone Selection and Growth Rhythm of Liriodendron Sino-Americanum*; Nanjing Forestry University: Nanjing, China, 2018; pp. 7–8.
5. Zhang, L.; Zhang, Y.; Duan, R.Y.; Wei, X.L.; Xu, X.Q. Genetic variation among origin locations of *Phoebe bournei* (Hemsl.) Yang and a preliminary selection based on seedling growth and root traits. *Nan-ching Lin Yeh Ta Hsueh Hsueh Pao.* **2016**, *40*, 33–40.
6. Zhang, Z.W.; Cao, S.J.; Liao, J.Y.; Wu, L.S.; Xu, W. Growth adaptability comparison of different provenances of Rhododendron simsii. *J. Cent. South Univ. For. Technol.* **2018**, *38*, 61–67.
7. Zhao, Q.L.; Ma, J.W.; Wang, J.H.; Feng, X.Q.; Chen, N. Blastation and Diversities of Catalpa Fargesii Genetic Resources amona Basins. *J. Plant Genet. Resour.* **2012**, *13*, 803–809.
8. Hamrick, J.L. Factors influencing levels of genetic diversity in woody plant species. *New For.* **1992**, 95–124. [CrossRef]
9. Ling, J.J.; Xiao, Y.; Yang, G.J.; Ma, J.W.; Zhao, Q.L.; Yun, H.L.; Wang, J.H.; Ma, W.J. Variation and Selection of Growth and Trunk Shape Traits of *Catalpa fargesii* Clones. *For. Res.* **2019**, *32*, 149–156.
10. Cown, D.J. Comparison of the Pilodyn and torsiometer methods for the rapid assessment of wood density in living trees. *N. Z. J. For. Sci.* **1978**, *8*, 384–391.
11. Yamashita, K.; Okada, N.; Fujiwara, T. Use of the Pilodyn for estimating basic density and its applicability to density-based classifying of Cryptomeria japonica green logs. *J. Wood Sci.* **2007**, *53*, 72–81.
12. Fukatsu, E.; Hiraoka, Y.; Matsunaga, K.; Tsubomura, M.; Nakada, R. Genetic relationship between wood properties and growth traits in larix kaempferi obtained from a diallel mating test. *J. Wood Sci.* **2014**, *61*, 10–18. [CrossRef]
13. Pâques, L.E.; Millier, F.; Rozenberg, P. Selection perspectives for genetic improvement of wood stiffness in hybrid larch (*Larix x eurolepis* Henry). *Tree Genet. Genomes* **2010**, *6*, 83–92. [CrossRef]
14. Gilmour, A.; Gogel, B.; Cullis, B.; Thompson, R. *ASReml User Guide Release 3.0*; VSN International Ltd.: Harpenden, UK, 2009; pp. 87–96.
15. Liu, C.Y.; Cheng, X.Z.; Wang, S.H.; Wang, L.X.; Sun, L.; Mei, L.; Xu, N. The Genetic Diversity of Mungbean Germplasm in China. *J. Plan Gen. Res.* **2006**, *7*, 459–463.
16. Xu, J.R. *Tree Quantitative Genetics*; China Forestry Press: Beijing, China, 2006; pp. 31–55.
17. Xie, X.M.; Li, J.T.; Zhao, H.E.; Liu, J.J.; Duan, C.L.; Zhu, Q.; Yuan, Y.; Bian, G.M. Genetic determination and selection of willow clones at seedling stage. *J. Jiangsu For. Sci. Tech.* **2008**, *35*, 6–9.
18. Zhu, Z.T. *Fundamentals of Forest Genetics*; China Forestry Press: Beijing, China, 1989; pp. 190–191.
19. Mwase, W.F.; Savill, P.S.; Hemery, G. Genetic parameter estimates for growth and form traits in common ash (*Fraxinus excelsior*, L.) in a breeding seedling orchard at Little Wittenham in England. *New For.* **2008**, *36*, 225–238. [CrossRef]
20. Xiao, Y.; Ma, W.J.; Lu, N.; Wang, Z.; Wang, N.; Zhai, W.J.; Kong, L.S.; Qu, G.Z.; Wang, Q.X.; Wang, J.H. Genetic variation of growth traits and genotype-by-environment interactions in clones of Catalpa bungei and *Catalpa fargesii* f. *duclouxii*. *Forests* **2019**, *10*, 57. [CrossRef]
21. Xiao, Y.; Yao, S.J.; Yang, G.J.; Zhang, M.G.; Ouyang, F.Q.; Wang, J.H.; Ma, W.J. Early Variations of Wood Property of *Catalpa fargesii* f. *duclouxii* Clone and Their Evaluation. *For. Res.* **2019**, *32*, 79–87.
22. Zhao, X.; Hou, W.; Zheng, H.; Zhang, Z. Analyses of genotypic variation in white poplar clones at four sites in china. *Silvae Gene* **2013**, *62*, 187–195. [CrossRef]
23. Li, Q.F.; Wang, J.H.; Li, D.P.; Hu, C.S.; Qi, S.X. Wood traits of *Picea crassifolia* clones. *J. Northeast For. Uni.* **2015**, *3*, 12–16+35.
24. Wu, Y.; Mao, C.L. Simple Introduction to Heritability, Repeatability and Genetic Gain in Percent in Tree Breeding. *Trop. Agr. Sci. Tech.* **2012**, *35*, 47–50.
25. Ma, J.W.; Wang, J.H.; Song, L. Genetic variation of wood properties of Catalpa bungei hybrid clones at the young stage. *J. Northeast For. Uni.* **2014**, *42*, 11–15+19.
26. Akihiro, S.; Tomiyasu, M.; Hitoshi, T. Relationships of tree height and diameter at breast height revisited: Analyses of stem growth using 20-year data of an even-aged *Chamaecyparis obtusa* stand. *Tree Physiol.* **2013**, *1*, 106–118.
27. Gonçalves, P.S.; Souza, P.D.; Bortoletto, N.; Cardinal, Á.B.; Átila, B.B. Age-age correlation for early selection of rubber tree genotypes in são paulo state, brazil. *Gene Mol. Biol.* **2005**, *28*, 758–764. [CrossRef]
28. Xu, B.; Yuan, D.S.; Wang, L.; Zhang, H.J.; Huang, C.; Zhang, G.J. Correlation analysis of growth shape of Pinus tabulae formis in early and late stages. *Hebei For. Sci. Tec.* **2018**, *4*, 6–9.
29. Wang, J.H.; Gu, W.C.; Li, B.; Guo, W.Y.; Xia, L.F. Study on selection of Alunus Cremastogyne province/family-analysis of growth adaptation and genetic stability. *Sci. Silvae Sin.* **2000**, *3*, 59–66.
30. Fujimoto, T.; Akutsu, H.; Nei, M.; Kita, K.; Kuromaru, M.; Oda, K. Genetic variation in wood stiffness and strength properties of hybrid larch (*Larix gmelinii* var. japonica× L. kaempferi). *J. Forest. Res-JPN.* **2006**, *11*, 343–349. [CrossRef]

31. Kennedy, S.G.; Cameron, A.D.; Lee, S.J. Genetic relationships between wood quality traits and diameter growth of juvenile core wood in Sitka spruce. *Can. J. Forest. Res.* **2013**, *43*, 1–6. [CrossRef]
32. Mäkinen, H.; Saranpää, P.; Linder, S. Effect of growth rate on fibre characteristics in Norway spruce (*Picea abies* (L.) Karst.). *Holzforschung* **2002**, *56*, 449–460. [CrossRef]
33. Li, X.; Li, K.; Duan, A.A.; Cui, K.; Gao, C.J. Biomass allocation and allometry of *Pinus yunnanensis* seedlings from different provinces. *J. Beijing For. Univ.* **2019**, *41*, 41–50.
34. He, Q.H.; Fang, R.; Li, W.X.; Xie, Y.K.; Zhang, Y.Q.; Shi, C.G.; Yang, S.Z. Geographical variation of growth traits of Liquidambar formosana seedlings from different provinces. *J. Plla Res. Eni.* **2019**, *28*, 88–95.
35. Deng, H.Y.; Hu, D.H.; Lin, J.; Lai, X.E.; Deng, W.J.; Wei, R.P.; Wang, R.H.; Yan, S.; Zheng, H.Q. Reseach on influencing factor of the survival rate of Catalpa fargesii seedlings. *J. Gansu For. Sci. Tech.* **2020**, *28*, 513–519.
36. Sun, X.M.; Yang, X.Y. Application and analysis of forest breeding value prediction method. *J. Beijing For. Uni.* **2011**, *33*, 65–71.