RESEARCH ARTICLE

Age-related trends in genetic parameters for wood properties in *Larix kaempferi* clones and implications for early selection

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Abstract Wood properties are important traits that determine quality of structural wood. With the aim of performing efficient early selection for wood properties, we investigated genetic variation in 20 *Larix kaempferi* clones aged from 4 to 15 years for four quality traits: wood density, wall thickness to lumen area, microfibrillar angle (MFA) and modulus of elasticity (MOE). We observed that age-related trends in overall means varied for different traits: MFA decreased with the age, while the others generally increased with the age. Phenotypic variance always showed significant differences from the age of 8 years onward, with CVG ranging from 4% to 25%. Also, clonal repeatability increased steadily until 9 years old and then kept medium or higher intensity (0.4–0.8). After the age of 6, genetic correlations were generally higher than phenotypic correlations. Estimates of early selection efficiency suggested that the optimal selection age for wood density was at age 5–6 years, while it was 9–10 years for the other traits. In combination with previous results, we proposed a comprehensive early selection strategy for larch clonal breeding that involved selection based on nursery rooting ability, phenology, growth traits, and wood properties.

Keywords early selection, genetic variation, wood properties, SilviScan, *Larix kaempferi*

1 Introduction

Wood properties are important traits that can have a significant impact on the quality of structural wood. To study variation in wood properties, the first step is to find the best method to measure wood properties accurately. It was difficult and time-consuming to measure wood properties based on annual rings by manual methods before the invention of SilviScan[1], developed by CSIRO. Importantly, SilviScan provided an automated and rapid method for measurement of several wood characteristics including wood density, microfibrillar angle, modulus elasticity, cell wall and fiber traits without destructive sampling. It has been applied to many tree species to quantify genetic variation in wood properties, such as poplar[2], eucalypt[3], black and Norway spruce[4], radiata pine[5] and red pine[6].

The age-age genetic corrections and selection efficiency for wood properties have been estimated in several species of conifers. These studies include radiata pine[5,7,8], Scots pine[9–12], maritime pine[13], white spruce[4], Norway spruce[14]. The estimated optimal age and selection efficiency varied depending on species, sample size, age of the harvest, sites, and silviculture treatment[5]. For example, the optimal selection ages of wood properties for Scots pine were estimated at 8 years[12] and 11 years[10], respectively.

Japanese larch (*Larix kaempferi*) was introduced at the end of the 19th century into China and is becoming an important timber species with increased plantation area. It grows faster and has higher wood density, longer fiber and stronger pest resistance than the Chinese native species (e.g., *L. principis-rupprechtii* and *L. olgensis*) and shows wider adaptation[15–17]. The age-age genetic corrections have been estimated for growth traits (i.e., tree height, HGT and diameter at breast height, DBH) of *L. kaempferi* in recent years[16,18]. Also, optimum ages of early selection were studied for spiral grain[19] and wood density[20] in hybrid larch, with estimated optimal selection ages of 3–4 years and 8–14 years, respectively. However, no significant correlation was found between DBH trait and mechanical

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properties[21], suggesting no adverse effects from selection of growth on wood properties, and vice-versa.

We have studied optimal selection age for nursery rooting ability[22], phenology[23,24], and growth traits[16] of *L. kaempferi* clones. In this study, we estimated age-related trends of genetic parameters and selection efficiency for wood density, wall thickness to lumen area (T/D), MFA and MOE. From these estimates, we proposed comprehensive early clonal selection procedures for *L. kaempferi* including nursery rooting ability, phenology, growth traits and wood properties after afforestation.

2 Material and methods

2.1 Plant material

Wood samples were collected from a *L. kaempferi* clonal trial which was established in 1998 at Wu Ma Temple Forest Farms (34°14′ N, 112°07′ E) at an altitude of 1400–1600 m, Son Town, Henan Province, China. The annual mean temperature at the site is 8.6°C, with a minimum of −15.5°C in January and maximum of 24.7°C in July. Annual rainfall is 800–1200 mm. The soil pH is 6.0. The clonal trial was set in a randomized complete block design consisting of four replication blocks of 78 different clones. In each replication block, four ramets of each clone were originally planted at a spacing of 2 m × 2 m. Based on previous time course measurement of growth traits[16], we divided the 78 clones into different intervals representing different growth conditions. Then, 20 clones were selected from intervals for wood properties measurements.

2.2 Wood properties measurement

Measurements of wood properties were conducted for three randomly selected ramets of each of the 20 clones at Year 15 after planting. A small piece of wood block was taken from each ramet at breast height with the help of a 12-mm-diameter increment borer and subject to measurements of wood properties using the SilviScan-3® technology[25–27]. The cross-dating test[28] was utilized to determine the age of each tree ring. The wood properties included four types: (1) wood density: ring density (RD), earlywood density (ED), latewood density (LD); (2) wall thickness to lumen area: ring wall thickness to lumen area (RT/D), earlywood wall thickness to lumen area (ET/D), latewood wall thickness to lumen area (LT/D); (3) microfibrillar angle: ring microfibrillar angle (RMFA), earlywood microfibrillar angle (EMFA), latewood microfibrillar angle (LMFA); and (4) modulus of elasticity: ring modulus of elasticity (RMOE), earlywood modulus of elasticity (EMOE), latewood modulus of elasticity (LMOE). Additionally, earlywood and latewood were distinguished by manually analyzing the mean of the

maximum and minimum density within a given annual ring[29].

2.3 Statistical analysis

We analyzed the annual ring data from year 4 to year 15 due to missing annual rings for some samples near the pith.

The variance-covariance structures were positive-definite at both the clone L and replication R levels, and specified as:

$$\Psi_L = \begin{pmatrix} \sigma_{vL}^2 & \sigma_{v\omega L}^2 \\ \sigma_{v\omega L}^2 & \sigma_{\omega L}^2 \end{pmatrix} \text{ and } \Psi_R = \begin{pmatrix} \sigma_{vR}^2 & \sigma_{v\omega R}^2 \\ \sigma_{v\omega R}^2 & \sigma_{\omega R}^2 \end{pmatrix} \quad (1)$$

and distributed bivariate normally with normal random errors:

$$E\begin{pmatrix} v_L \\ \omega_L \end{pmatrix} = 0 \ v_{ar}\begin{pmatrix} v_L \\ \omega_L \end{pmatrix} = \begin{pmatrix} \sigma_{vL}^2 & \sigma_{v\omega L}^2 \\ \sigma_{v\omega L}^2 & \sigma_{\omega L}^2 \end{pmatrix}$$

$$E\begin{pmatrix} v_R \\ \omega_R \end{pmatrix} = 0 \ v_{ar}\begin{pmatrix} v_R \\ \omega_R \end{pmatrix} = \begin{pmatrix} \sigma_{vR}^2 & \sigma_{v\omega R}^2 \\ \sigma_{v\omega R}^2 & \sigma_{\omega R}^2 \end{pmatrix}$$

$$\varepsilon \sim N(0, \sigma^2) \quad (2)$$

At each age, analysis of variance was conducted using the following linear model[30]:

$$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \quad (3)$$

where y_{ij} is the performance of the ith clone within the jth block, and μ is the general mean, α_i is the effect of the ith clone, β_j is the effect of the jth block, and ε_{ij} is the random error.

The repeatability of clonal mean, which refers to genotypic heritability, was estimated as[30]:

$$R = \sigma_c^2/\sigma_p^2 = \sigma_c^2/(\sigma_c^2 + \sigma_e^2/r) \quad (4)$$

where r is the number of blocks, σ_p^2 is the phenotype variance, σ_c^2 is the variance of clone, and σ_e^2 is the residual variance.

The phenotypic and genetic variation coefficients (CVP and CVG) were calculated using the following formulas[31], respectively:

$$\text{CVP} = 100 \times \sqrt{\sigma_p^2}/\overline{X} \quad (5)$$

$$\text{CVG} = 100 \times \sqrt{\sigma_c^2}/\overline{X} \quad (6)$$

where $\overline{X}$ is the trait phenotypic mean. The equation expresses a standardized measure of the genetic variance relative to the trait mean.

The selection gain among clones was estimated by:

$$G(\%) = 100 \times iR\sigma_p / \overline{X} \qquad (7)$$

where i is the standardized selection intensity, R is the repeatability, and σ_p is the phenotypic standard deviation.

The phenotypic correlation of the same trait at different ages was calculated as:

$$r_p = \sigma_{p(xy)} / \sqrt{\sigma_{p(x)}^2 \times \sigma_{p(y)}^2} \qquad (8)$$

where $\sigma_{p(xy)}$ is the phenotype covariance component between traits x and y, $\sigma_{p(x)}^2$ is the phenotype variance component for trait x and $\sigma_{p(y)}^2$ is the phenotype variance component for trait y. The genotypic correlation of the same trait was calculated as[30]:

$$r_g = \sigma_{c(xy)} / \sqrt{\sigma_{c(x)}^2 \times \sigma_{c(y)}^2} \qquad (9)$$

where $\sigma_{c(xy)}$ is the clone covariance component between traits x and y, $\sigma_{c(x)}^2$ is the clone variance component for trait x and $\sigma_{c(y)}^2$ is the clone variance component for trait y.

Efficiency of early selection was examined by taking wood properties traits at age 15 as the targets to be improved. Assuming equal intensity of selection at target and young ages, the selection efficiency (Qyear), expresses as the ratio of correlated response in trait y at target age T_2 from a selection on trait x at early age T_1 per year, was calculated as[32]:

$$Qyear = r_g \sqrt{R_x} T_2 / \sqrt{R_y} T_1 \qquad (10)$$

where T_1 and T_2 are the ages for trait x and target trait y, respectively, r_g is the calculated genetic correlation between trait x at T_1 and trait y at T_2, and $\sqrt{R_x}$ and $\sqrt{R_y}$ are the square roots of clonal repeatability for trait x at T_1 and trait y at T_2, respectively.

3   Results

3.1   Age-related trends of overall means for wood properties in *L. kaempferi* clones

We found that there were three obvious patterns for age-related trends in overall means for four wood properties (Fig. 1). First, wood densities and their respective T/D had the same pattern, with an increased ring and latewood density along the ages, while earlywood decreased. Intriguingly, peaks were generally found at 9–10 years for all the trait components. The change of latewood was larger than earlywood. Also, MFA generally steadily decreased over time. At the same age, EMFA was higher than LMFA. The radial variation for MFA was similar
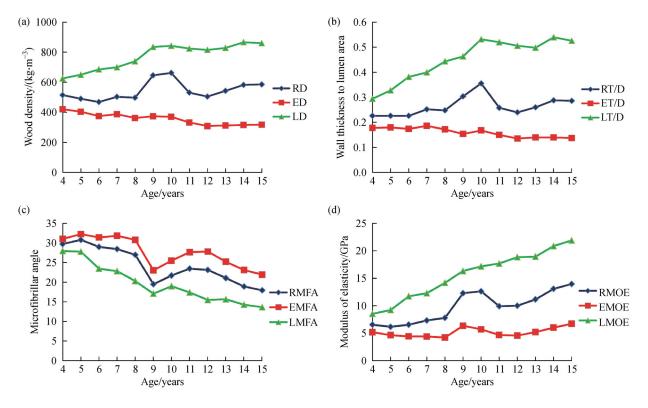

Fig. 1   Age-related trends of overall means in wood properties of *L. kaempferi* clones. (a) Wood density and (b) T/D (wall thickness to lumen area) showed the same pattern: ring and latewood increased, earlywood decreased; (c) MFA (microfibrillar angle) for all wood components decreased; (d) MOE (modulus of elasticity) for all wood components increased.

among the different components, with 17.89°–30.71° for whole ring, 21.85°–32.18° for earlywood and 13.59°–27.88° for latewood, respectively. Additionally, MOE had a steady increase over time. Latewood had the larger variation for MOE (8.52–21.87 GPa), than earlywood (4.20–6.71 GPa). Peaks occurred at the age of 9–10 years for RMOE and EMOE, but not LMOE.

3.2 Variance components and clonal repeatability of wood properties in *L. kaempferi* clones

We further investigated four parameters to study the age-related trends in phenotypic and genetic variations for wood properties with age. They included phenotypic variance, phenotypic variation coefficients (CVP), genetic variation coefficients (CVG) and clonal repeatability.

For phenotypic variance, a significant difference was defined as P value < 0.05. Under this criterion, most wood properties showed significant differences from 8 years onward (Table 1), increasing with age later. This suggested that phenotypic variation in *L. kaempferi* clones steadily accumulated over time. Additionally, the trend in significance for wood components was generally consistent with those of the overall means, which also revealed the accumulated variance of phenotype.

For CVP (Figs. 2a–2d), RD and ED had the same pattern, lower at the early years and higher in the later years, with maximums at 5 years (8.72%) and 15 years (6.57%), respectively. However, LD showed a steadily decreasing trend, with a maximum 6.57% at 4 years (Fig. 2a). Overall patterns for the T/D traits (Fig. 2b) were the same as those for RD and ED. Their maximums occurred at 4 years (RT/D, 11.86%), 15 years (ET/D, 9.12%) and 4 years (LT/D, 14.13%), respectively. Furthermore, CVP of MFA (Fig. 2c) generally increased with age, showing significant peaks at 9 years and maximums at 15 years.
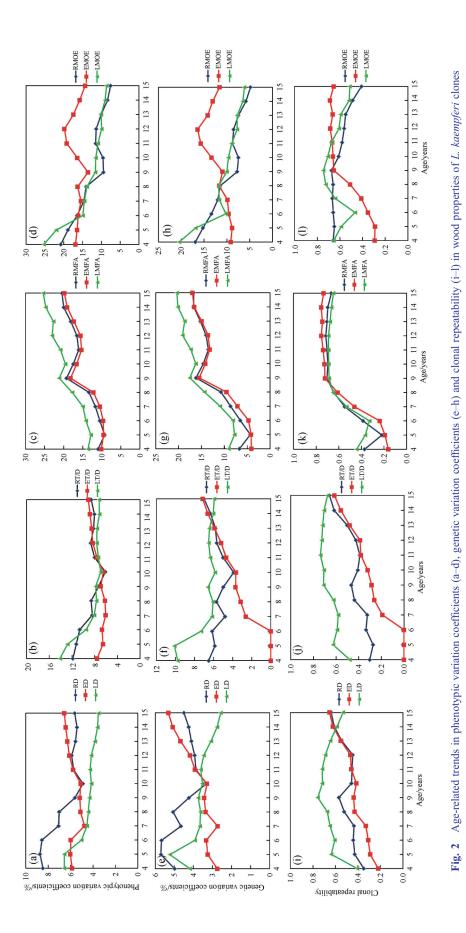
Additionally, CVP of RMOE and LMOE decreased, with maximums at 4 years (20.79% and 25.26%, respectively). There was no obvious pattern in CVP for EMOE (Fig. 2d).

For CVG (Figs. 2e–2h), RD and LD decreased with age, while ED increased. Maximums occurred at the age of 5 years (RD, 5.7%), 15 years (ED, 5.31%) and 5 years (LD, 5.23%), respectively (Fig. 2e). T/D in three wood components (Fig. 2f) followed markedly different trends: RT/D was relatively stable, ranging from 3.91% (at 10 years) to 7.00% (at 15 years); ET/D steadily increased, with a maximum at 15 years (7.15%); LT/D generally decreased up to 7 years and then remained stable, with a maximum at 5 years (10.11%). Moreover, CVG of all MFA traits (Fig. 2g) increased, with peaks at 9 years and maximums at 15 years. Additionally, CVG of RMOE and LMOE generally decreased, with the maximums at 4 years (16.88% and 20.43%, respectively), while CVG of EMOE showed no significant pattern (Fig. 2h).

For clonal repeatability, most wood property traits reached their maximums or had peaks at 9 years of age (Figs. 2i–2l). The ranges for clonal repeatability for RD, ED and LD were similar at 0.347–0.637, 0.218–0.652 and 0.405–0.756, respectively. Both RD and LD had peaks at 9 years, while ED showed a steady increase (Fig. 2i). Clonal repeatability for RT/D and ET/D exhibited a stable rise, while LT/D fluctuated before the age of 9 years and remained stable later (Fig. 2j). Variation in RMFA (0.217–0.714), EMFA (0.161–0.755) and LMFA (0.328–0.691) was high, all increasing up to 9 years and then remaining stable (Fig. 2k). The ranges for RMOE, EMOE and LMOE were 0.409–0.674, 0.289–0.688 and 0.466–0.746, respectively. Trends for these MOE traits varied among wood components: RMOE remained stable up to the 9 years and then decreased; EMOE increased up to the 9 years and remained stable later; and LMOE showed no significant pattern (Fig. 2l).

Table 1 Phenotypic variance in wood properties of *Larix kaempferi* clones

Age/years	Wood density			Wall thickness to lumen area			Microfibrillar angle			Modulus of elasticity		
	RD	ED	LD	RT/D	ET/D	LT/D	RMFA	EMFA	LMFA	RMOE	EMOE	LMOE
4	0.129	0.253	0.085	0.169	0.774	0.043	0.110	0.313	0.062	0.002	0.178	0.003
5	0.071	0.181	0.004	0.198	0.845	0.005	0.254	0.487	0.115	0.003	0.181	0.010
6	0.063	0.165	0.007	0.141	0.676	0.010	0.100	0.233	0.145	0.002	0.125	0.049
7	0.067	0.146	0.003	0.150	0.444	0.010	0.019	0.052	0.024	0.002	0.082	0.004
8	0.026	0.070	0.002	0.065	0.209	0.005	0.003	0.007	0.003	0.002	0.030	0.000
9	0.013	0.065	0.000	0.050	0.185	0.001	0.001	0.001	0.001	0.002	0.003	0.000
10	0.054	0.080	0.001	0.084	0.153	0.001	0.002	0.001	0.001	0.006	0.002	0.001
11	0.057	0.053	0.001	0.097	0.103	0.002	0.001	0.001	0.001	0.011	0.002	0.002
12	0.060	0.049	0.001	0.073	0.098	0.001	0.003	0.001	0.001	0.015	0.001	0.007
13	0.019	0.018	0.003	0.033	0.043	0.002	0.001	0.001	0.002	0.018	0.002	0.009
14	0.007	0.005	0.010	0.006	0.016	0.001	0.001	0.001	0.002	0.040	0.001	0.027
15	0.004	0.003	0.023	0.002	0.006	0.002	0.002	0.000	0.003	0.083	0.003	0.029

Fig. 2   Age-related trends in phenotypic variation coefficients (a–d), genetic variation coefficients (e–h) and clonal repeatability (i–l) in wood properties of *L. kaempferi* clones

3.3 Phenotypic and genetic correlations between early and reference ages

Phenotypic and genetic correlations of wood properties between early age and 15 years indicated the optimal age for early selection. The maximum age-age phenotypic correlation (1.000) was at 15 years, and minimums at 4 years (Fig. 3). There was a generally increasing trend in these traits, with slight differences. Wood density, T/D and MOE increased steadily, while MFA increased rapidly from the age of 4 to 7 then continued to increase slowly. Phenotypic correlations were generally above 0.50 at 5 years and above 0.70 at 8 years. Moreover, we found that earlywood showed significant differences with ring and latewood for wood density, while this pattern did not exist for the other three properties.

Age-age genetic correlations are shown in Fig. 4. For wood density, RD steadily increased with age, while ED and LD values remained relatively high (> 0.8). Similarly, apart from ET/D of 0 at 4–6 years, the T/D showed the same trend to wood density. Furthermore, age-age genetic correlations of all MFA traits rapidly increased in the early years (4–6) and then remained high and stable (≈1.000). Additionally, genetic correlations of RMOE and EMOE steadily increased with age. Both of them were over 0.8 from 7 years. However, LMOE had a high and stable value (≈1.000) over all years, with a maximum of 1.297 at 6 years. For wood components, earlywood had the highest

genetic correlations with wood density and T/D, while latewood showed dominance in MFA and MOE.

3.4 Efficiency of early selection for wood properties relative to selection at reference age 15

Early selection efficiency for wood properties is shown in Fig. 5. For different traits, the optimal selection age was different: (1) 5–6 years for wood density, with ED and LD having peaks, while RD was nearly 60%; (2) 9–10 years for T/D, with selection efficiency of RT/D and ET/D both more than 70%, while that of LT/D was nearly 90%; (3) 9–10 years for MFA, with selection efficiency ranging from 85% to 105%; and (4) 9–10 years for MOE, with selection efficiency of all being over 90%. Thus, the optimal age for early selection was 5–6 years for wood density, and 9–10 years for the other three traits.

To test the optimal ages above, we further analyzed selection results for 5 and 10 clones, respectively (Table 2). All wood properties had relatively high percent success. Specifically, percent success for wood density and T/D was 60% to 80%, whilst it was 80% to 100% and 60% to 90% for MFA and MOE, respectively.

3.5 Steps of comprehensive early selection for superior *L. kaempferi* clones
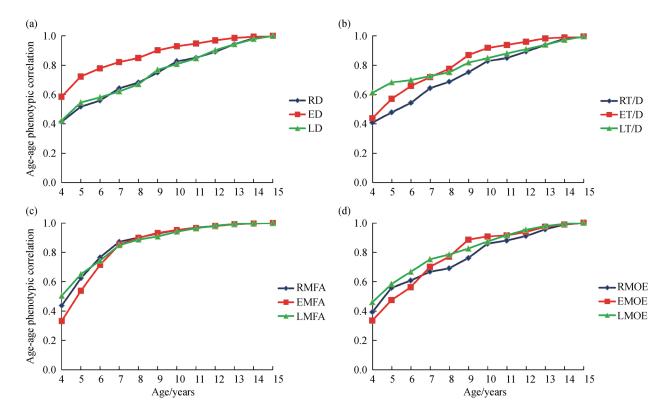
Based on this and our previous studies[16,22–24], we

Fig. 3 Estimated phenotypic correlations between early age and the 15 years wood properties of *L. kaempferi* clones
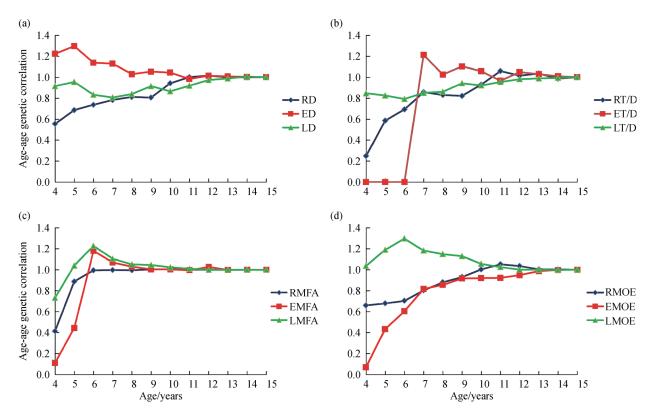
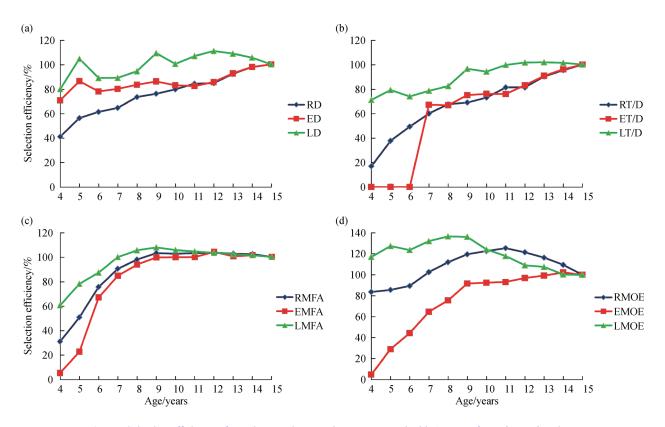**Fig. 4** Estimated genotypic correlations between early ages and 15 years wood properties of *L. kaempferi* clones

Fig. 5 Selection efficiency of wood properties at early age compared with 15 years for *L. kaempferi* clones

Table 2 Percent success of early selection in wood properties for 5 and 10 clones of *L. kaempferi*.

Trait	Age for selection/years	Clones selected	Clones successfully selected			Correction percentage
			Ring	Earlywood	Latewood	
Wood density	5	5	3	3	3	60%
	5	10	8	7	7	70%–80%
	6	5	3	3	3	60%
	6	10	8	7	8	70%–80%
T/D	9	5	3	4	4	60%–80%
	9	10	8	7	7	70%–80%
	10	5	3	4	4	60%–80%
	10	10	8	7	7	70%–80%
MFA	9	5	4	4	5	80%–100%
	9	10	8	8	8	80%
	10	5	4	4	5	80%–100%
	10	10	8	8	8	80%
MOE	9	5	3	4	4	60%–80%
	9	10	8	7	9	70%–90%
	10	5	3	4	4	60%–80%
	10	10	8	7	9	70%–90%

proposed several steps for a comprehensive early selection strategy to select *L. kaempferi* superior clones. Four main factors (nursery rooting ability, phenology, growth and wood properties) at different stages were presented (Fig. 6). The optimal age and corresponding selection intensity were: 50% select percentage for nursery rooting ability, 70% select ratio for phenology at 2 years after planting, 30% to 50% select ratio for growth traits (mainly HGT and DBH) at 5 years, and 3–5 clones for wood properties at 9 years.

4　Discussion

In this study, we conducted systematic analysis of age-related trends for multiple genetic parameters in wood properties using *L. kaempferi* clones. Based on the findings, we proposed comprehensive selection methods to select for *L. kaempferi* clones at an early age. Our study provided valuable guidance for early selection of *L. kaempferi* clones.

4.1　Radial variation of overall means in wood properties for *L. kaempferi* clones

Radial variation of wood properties and their correlations provide an important basis for predicting time of early selection and determining scientific rotation period. We found that most properties reached their maximum radial variation at age 9. The variation with age may be caused by climate factors. For wood density, our finding was consistent with previous investigations in Norway spruce[33], American aspen (*Populus tremuloides*)[34], maritime pine (*Pinus pinaster*)[13] and poplar[35], which also increased from pith to sapwood. For T/D, the variation with radial direction in our study was consistent with the finding for Mediterranean conifer *Juniperus thurifera*[36], in which T/D also increased with age. The trend observed for MFA in *L. kaempferi* was consistent with the trend reported for Norway spruce[37,38], Scots pine[12] and white spruce[4], i.e., MFA decreased over time. Additionally, our finding that LMFA was higher than EMFA was the same as found in white spruce[4], but the opposite of that found in Norway spruce[39]. This difference may be a consequence of tree species, population, investigating years or environment factors. The general trend for MOE was similar to the trends reported for white spruce[4], Norway spruce[38], radiata pine[5] and Scots pine[12], in which MOE increased over time.

4.2　Age-related trends in genetic parameters for wood properties for *L. kaempferi* clones

To determine the appropriate age for early selection and estimate the selection effects, it is quite important to estimate the age-related trends of genetic variation coefficients and clonal repeatability. The CVG, i.e., the genetic variance standardized to trait mean, is an important parameter predicting the ability of response to natural or artificial selection[40]. In our study, the CVG of MFA and MOE was significantly higher than those of wood density and T/D for the same period of time, indicating that MFA
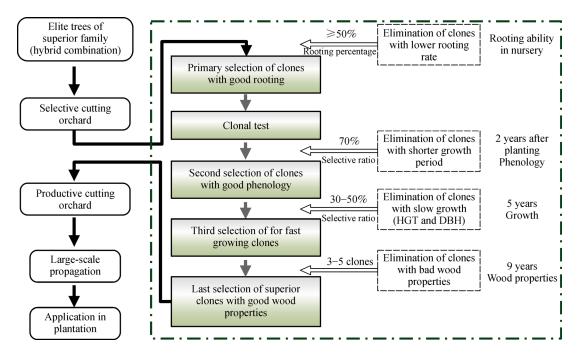
Fig. 6 Steps for comprehensive early selection for superior *L. kaempferi* clones. The procedure located in the dashed rectangle indicates the main processes of early selection for *L. kaempferi* clones. Four grades are separated in accordance with four key factors: (1) nursery rooting ability; (2) phenology, at 2 years after planting; (3) growth traits, at 5 years, and (4) wood properties, at 9 years.

and MOE have greater selection potential. This observation was consistent with a report in Norway spruce[38]. Additionally, CVG of wood density is usually low, as was observed in poplar (4.0% to 6.8%)[41]. Also, at wood component level, CVG of earlywood for all four categories of wood property traits increased over time, reflecting steady increases in selection potential. This indicated that ring and latewood had similar genotypic patterns and selection potential for wood properties.

Clonal repeatability estimates for wood properties generally increased with age, mainly through decreased residual variation[35]. After 9 years, the values of clonal repeatability ranged from 0.4 to 0.8 for most traits, which suggested that variation in wood property traits of *L. kaempferi* clones were controlled genetically at medium or high intensity. For the four categories of wood properties, stability of clonal repeatability in MFA was significant higher than the others, suggesting the higher genetic control of MFA. For each annual ring, we found that overall means of clonal repeatability were slightly lower than in radiata pine[42–44].

4.3 Age-age Genetic Correlations of Wood Properties for *L. kaempferi* Clones

Strong age-age genetic correlations were found for all four categories of wood properties measured in our study. Most of them were greater than 0.8 after 8 years, in agreement with the report in Scots pine[12]. This may indicate that the genes associated with wood properties at the early age

appeared to have similar impacts on the same trait at 15 years. The strong age-age genetic correlations highlight the advantages of early selection or tree breeding, for which there are three main advantages: (1) increased selection intensity or reduced field testing size; (2) a shortened generation interval; and (3) genetic information from early testing can be used to enhance selection efficiency at maturity[45]. According to these advantages, early selection for long-rotation species is particularly attractive to increase genetic gain per year[12]. MFA had the most stable age-related trend compared to the other traits. This may indicate a greater effect of related genes on the MFA over the other traits.

4.4 Optimal age of early selection in wood properties for *L. kaempferi* clones

The optimal selection age for wood density was 5 years. Our results generally agreed well with an optimal age of 4–5 years for radiata pine found in two studies[7,46], but differed slightly from the optimal age of 6–7 years found in another study[20]. Also, the optimal age of early selection for both MFA and MOE was 9–10 years, which was similar to the 8 years for Scots pine[12]. But the optimal age was later than that of Wu et al.[5] (3–5 years in radiate pine), Dungey et al.[47] (4–8 years in radiate pine) and Chen et al.[38] (6–7 years in Norway spruce). The difference may be due to the tree species and site factors. Expected genetic gains and the correlated responses estimated are based on genotypic variances,

clone repeatability and genotypic correlations[41]. Considering all wood properties, we concluded that 9–10 years was the optimal age to perform early selection for wood property traits of *L. kaempferi* clones.

5 Conclusions

In *L. kaempferi*, wood density, T/D and MOE steadily increased with age, while MFA decreased. For age-related trends of genetic parameters, CVG of MFA and MOE were significantly higher than for others; clonal repeatability steadily increased up to 9 years, and then stabilized at medium or higher genetic intensity between 0.4 and 0.8. The optimal selection age for wood density was estimated at 5–6 years, while it was 9–10 years for the other traits. Taken together, comprehensive steps for early selection were presented for *L. kaempferi* clonal selection.

Compliance with ethics guidelines Chao Sun, Meng Lai, Shougong Zhang, and Xiaomei Sun declare that they have no conflicts of interest or financial conflicts to disclose.

This article does not contain any studies with human or animal subjects performed by any of the authors.

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