Postprint: Variation in Seed and Seedling Traits of Dalbergia odorifera from Different Provenances

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Abstract

To explore variation patterns of phenotypic traits in seeds and seedlings of *Dalbergia odorifera* from different provenances and their relationships with geo-climatic factors, seeds from 10 provenances across Hainan, Fujian, Guangxi, and Guangdong provinces, together with seedlings cultivated in Guilin, Guangxi, served as experimental materials. Nine phenotypic traits of seeds and seedling growth were comparatively analyzed using variance analysis, correlation analysis, and principal component analysis. The results indicated considerable variation in phenotypic traits of *D. odorifera* seeds and seedlings, with highly significant differences among all nine traits. The mean coefficient of variation (CV) was 12.50%, ranging from 7.94% to 18.89%. Variation in seedling growth traits surpassed that in seed traits, indicating higher stability of seed traits. Correlation analysis revealed varying correlations among phenotypic traits and between these traits and geo-climatic factors. No significant correlations were found between phenotypic traits and longitude, latitude, or annual precipitation, whereas altitude, mean annual temperature, and annual rainfall were the primary factors influencing *D. odorifera* seed and seedling traits. Using the principal component comprehensive scoring method, three superior provenances were selected based on seed morphology, seedling growth, and germination performance, ranked by comprehensive scores as Xianyou, Danzhou, and Jianfengling provenances. These findings provide a scientific basis for selecting superior germplasm resources of *D. odorifera*.

Full Text

Preamble

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Geographic Variation of Seed and Seedling Traits of *Dalbergia odorifera* from Different Provenances

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Abstract: To investigate the variation patterns of phenotypic traits of seeds and seedlings of *Dalbergia odorifera* from different provenances and their relationships with geographic-climatic factors, we conducted a comparative study on nine phenotypic traits of seeds and seedlings from ten provenances across Hainan, Fujian, Guangxi, and Guangdong provinces. Seeds were collected from these locations, and seedlings were cultivated in Guilin, Guangxi. Variance analysis, correlation analysis, and principal component analysis were employed. The results revealed considerable variation in phenotypic traits of *D. odorifera* seeds and seedlings, with highly significant differences observed among all nine traits. The average coefficient of variation (CV) was 12.50%, ranging from 7.94% to 18.89%. Seedling growth traits exhibited greater variation than seed traits, indicating higher stability in seed traits. Correlation analysis demonstrated varying relationships among phenotypic traits and between these traits and geographic-climatic factors. No significant correlations were found between phenotypic traits and longitude, latitude, or annual precipitation. However, altitude, annual mean temperature, and annual rainfall emerged as the primary factors influencing seed and seedling traits. Using the principal component comprehensive scoring method, we identified three superior families with excellent performance in seed morphology, seedling growth, and germination, ranked in order as Xianyou, Danzhou, and Jianfengling provenances. These findings provide a scientific basis for screening superior germplasm resources of *D. odorifera*.

Keywords: *Dalbergia odorifera*, seed, seedling traits, geographic-climatic factors, correlation

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Introduction

Dalbergia odorifera T. Chen is an evergreen semi-deciduous tree belonging to the Fabaceae family (Papilionoideae) and *Dalbergia* genus. It is native to regions in Hainan Province including Dongfang, Ledong, Changjiang, and Sanya, and was subsequently introduced to Guangdong, Guangxi, and southern Fujian from the late 1960s onward (Ni et al., 2008; Yao et al., 2013). The wood of *D. odorifera* is dense and beautifully grained, making it a premium material for high-end furniture. The dried heartwood from its trunk and roots has medicinal

properties, including blood pressure reduction, qi and blood circulation promotion, and pain and bleeding cessation. Due to its prominent economic value, wild resources of *D. odorifera* have suffered devastating destruction, pushing the species to the brink of extinction and earning it classification as a nationally protected second-class wild plant (Yang et al., 2007). Therefore, protecting existing wild resources and vigorously developing artificial cultivation of *D. odorifera* holds significant ecological and economic importance. In recent years, with the vigorous promotion of precious tree species in southern China, the planting area of *D. odorifera* has increased annually. Most artificial afforestation relies on seed propagation without improved variety selection, resulting in uneven seedling quality and severe growth differentiation. Consequently, there is an urgent need to select superior families to enhance cultivation benefits.

Current research on *D. odorifera* primarily focuses on introduction and cultivation (Guo & Jia, 2006; Chen et al., 2015; Wei & Chen, 2017), seed propagation (Yu et al., 2010; Yang et al., 2012; Liu et al., 2017), stress resistance (Jia et al., 2013; Yang et al., 2014), and pests and diseases (Chen et al., 2017; Xiang & Cui, 2018). In recent years, studies on superior provenance (family) selection have included: Chen (2015) conducted comprehensive analysis of growth indices in a 6-year-old experimental forest, preliminarily screening ten superior families suitable for coastal areas of southern Fujian; Ma et al. (2017) and Liang et al. (2019) evaluated seedling growth of different families; and Zhang et al. (2018) conducted cold resistance tests on seedlings from different provenances, providing experimental evidence for cold-tolerant germplasm breeding. Nevertheless, research on superior provenances (families) of *D. odorifera* remains relatively weak, with narrow geographic coverage in seed collection areas. This study selected *D. odorifera* from ten provenances across Hainan, Fujian, Guangdong, and Guangxi to investigate variation characteristics in seed quality and seedling growth among different provenances, aiming to provide a scientific basis for screening superior germplasm resources.

1. Materials and Methods

1.1 Experimental Materials

The experimental materials consisted of *D. odorifera* seeds from ten provenances across four provinces: Jianfengling (JFL) and Danzhou (DZ) in Hainan; Puning (PN) and Zhaoqing (ZQ) in Guangdong; Xianyou (XY), Fuzhou (FZ), and Xiamen (XM) in Fujian; and Guilin (GL), Nanning (NN), and Pingxiang (PX) in Guangxi. The natural conditions of each provenance are detailed in Table 1 . Seeds were collected during the maturity period from December 2015 to January 2016. Seed-bearing trees were 10–15 years old, with seeds collected from more than 15 superior mother trees per provenance in equal quantities and mixed to form the test material for each provenance. The seedling nursery experiment was conducted at the Guangxi Institute of Botany Nursery in Yanshan Town, Guilin City (110°30 58.29 E, 25°07 78.65 N). Sowing trials and management were carried out in March 2016 using a randomized block design

with three replications.

1.2 Trait Measurements

1.2.1 Seed Morphological Traits Collected pods of *D. odorifera* were air-dried naturally, rubbed to remove edges. Thirty seeds from each provenance were randomly selected to measure seed length, width, and thickness using electronic calipers, with three replications. One hundred seeds per provenance were randomly weighed using an electronic balance, repeated eight times, to calculate thousand-grain weight. Seed germination rate was determined according to the "Forest Tree Seed Testing Procedures" (GB2772–1999).

1.2.2 Seedling Growth Traits In June 2017, growth data were collected from seedlings of the ten provenances. Plant height and ground diameter were measured for 30 randomly selected seedlings per provenance. Three seedlings with ground diameter close to the mean value were selected to measure aboveground and underground biomass.

1.3 Data Processing and Statistical Analysis

Data were processed using Excel 2010. SPSS 24.0 software was used for variance analysis and Duncan' s multiple comparisons. Correlation analysis was performed between seed and seedling traits and geographic-climatic factors of each provenance. Principal component analysis (PCA) was conducted on all traits (extracting principal components with eigenvalues > 1).

2. Results and Analysis

2.1 Comparison of Seed and Seedling Traits Among Different Provenances

Measurements of nine phenotypic traits—seed length, seed width, seed thickness, thousand-grain weight, germination rate, plant height, ground diameter, underground biomass, and aboveground biomass—are presented in Table 2 . The results showed highly significant differences among all seed and seedling traits of *D. odorifera*, indicating substantial variation and rich diversity among provenances. Thousand-grain weight was highest for Jianfengling (80.7 g), 1.34 times that of Guilin (60.52 g). For seed morphological traits (length, width, thickness), seeds from Jianfengling, Danzhou, and Pingxiang were larger, while those from Zhaoqing, Puning, and Guilin were significantly smaller than other provenances. The highest germination rate was observed in Xiamen seeds (91.66%), while Pingxiang showed the lowest (67.22%). Plant height and ground diameter were greatest in Zhaoqing (122.7 cm and 9.85 cm, respectively), 16.3% and 26.4% higher than the mean values. The smallest plant height (90.2 cm) and ground diameter (6.97 cm) were from Fuzhou. Underground and aboveground biomass were highest in Xianyou (8.68 g and 58.2 g, respectively), 1.32 and 1.40 times the minimum values (from Guilin).

The coefficient of variation (CV) allows comparison of variation degrees among different phenotypic traits—higher CV indicates greater trait dispersion. CVs for the nine seed and seedling traits across ten provenances are shown in Table 3 . Average CVs among provenances ranged from 6.43% to 11.24%, with Xianyou showing the highest (11.24%), followed by Jianfengling > Guilin > Zhaoqing > Puning > Fuzhou > Danzhou > Pingxiang > Xiamen > Nanning. For the nine traits, average CVs ranged from 7.94% to 18.89%, with plant height showing the greatest variation (18.89%), indicating more pronounced differences among provenances, while seed length showed the smallest CV (7.94%), suggesting relatively minor differences among provenances.

2.2 Correlation Analysis Among Traits and with Geographic-Climatic Factors

Correlation analysis among the nine phenotypic traits and between traits and geographic-climatic factors is presented in Table 4 . Seed length showed significant positive correlation with thousand-grain weight (r = 0.713), indicating that longer seeds have greater mass. Seed thickness showed significant negative correlation with seed width (r = -0.659) and significant positive correlation with plant height (r = 0.743). Plant height was extremely significantly positively correlated with ground diameter (r = 0.837) and significantly positively correlated with aboveground biomass (r = 0.755), suggesting that biomass accumulation is strongly influenced by plant height—taller plants have correspondingly higher biomass levels—while ground diameter showed no significant correlation with other traits. Underground biomass was extremely significantly positively correlated with aboveground biomass (r = 0.810). Germination rate showed no significant correlation with any other trait.

Correlations between seed/seedling traits and geographic-climatic factors revealed that among seed traits, seed width was significantly negatively correlated with annual rainfall (r = -0.661), while thousand-grain weight was significantly positively correlated with annual mean temperature (r = 0.722), indicating that provenances with higher annual temperatures produce seeds with greater thousand-grain weight. Among seedling traits, altitude was significantly positively correlated with underground biomass (r = 0.714). No significant correlations were found between any traits and longitude or latitude.

2.3 Principal Component Analysis and Comprehensive Evaluation

2.3.1 Principal Component Analysis of Phenotypic Traits To determine the influence of each trait on phenotypic variation, PCA was performed on nine traits. The results (Table 5) showed that the first three principal components had eigenvalues > 1, with a cumulative contribution rate of 83.507%, essentially reflecting most information from the original indicators. These three components could represent the original nine traits for analysis and evaluation. The first principal component (eigenvalue = 3.873, contribution rate = 43.036%) was represented by plant height, ground diameter, underground biomass, and

aboveground biomass, representing a comprehensive seedling growth trait. The second principal component (eigenvalue = 2.121, contribution rate = 23.569%) was represented by seed length, seed width, and thousand-grain weight, representing comprehensive seed morphology and quality traits. The third principal component (eigenvalue = 1.521, contribution rate = 16.901%) had high loading for germination rate, representing germination characteristics.

2.3.2 Comprehensive Evaluation of Different Provenances The three principal components comprehensively reflected the nine traits of *D. odorifera* seeds and seedlings. After standardizing the original data of major traits, component scores were calculated. Using the proportion of each component' s eigenvalue to the sum of the three eigenvalues as weights, the comprehensive evaluation formula was: F = 0.515F + 0.282F + 0.202F . Comprehensive scores for different provenances were calculated and ranked to evaluate seed and seedling trait quality. Table 6 shows the ranking from highest to lowest: Xianyou > Danzhou > Jianfengling > Zhaoqing > Pingxiang > Nanning > Puning > Fuzhou > Xiamen > Guilin. Fujian' s Xianyou provenance had the highest comprehensive score, while Guangxi' s Guilin had the lowest.

3. Discussion

3.1 Analysis of Variation Characteristics in Seed and Seedling Traits

Plant trait characteristics are jointly influenced by genetic diversity and ecological environment, representing adaptive expressions to survival conditions (Liu et al., 2012). In this study, substantial phenotypic variation was observed among the ten provenances of *D. odorifera*, with highly significant differences among all nine traits, likely representing adaptive strategies to different environments. This pattern is similar to variation observed in *Lycoris radiata* (Yang et al., 2010) and *Tripterygium wilfordii* (Long et al., 2016). Based on CV values, the nine seed and seedling traits of *D. odorifera* ranged from 7.94% to 18.89%, indicating considerable genetic variation and substantial potential for genetic selection. Traits ranked by mean CV from high to low were: plant height, ground diameter, aboveground biomass, seed thickness, underground biomass, thousand-grain weight, germination rate, seed width, and seed length. Plant height and ground diameter showed the highest average within-population CVs (18.89% and 18.67%, respectively), while seed width and seed length showed the lowest (9.16% and 7.94%, respectively). CV values reflect variation amplitude—higher values indicate greater dispersion, while lower values indicate greater stability. Thus, seed length and width are relatively stable phenotypic traits, while plant height and ground diameter show greater variation within provenances, likely being more strongly influenced by environmental factors.

3.2 Correlation Between Traits and Geographic-Climatic Factors

Geographic and climatic factors are closely linked to plant growth and development, affecting both seed development and forest growth, with different tree species exhibiting distinct variation patterns. Seed and seedling trait variation in *Xanthoceras sorbifolium* is primarily influenced by altitude and annual sunshine hours (Yu et al., 2019). Liu et al. (2017) reported that altitude is the main environmental factor affecting seeds and fruits of *Keteleeria fortunei* var. *cyclolepis*. Lin et al. (2016) found that seed size in *Zenia insignis* shows latitudinal variation, with annual temperature and rainfall being the main climatic factors affecting seed size. Phenotypic traits of seeds and seedlings of *Syringa reticulata* subsp. *amurensis* correlate with frost-free period, annual mean temperature, and altitude (Yang et al., 2016). Our correlation analysis revealed that seed width was significantly negatively correlated with annual rainfall, thousand-grain weight was significantly positively correlated with annual mean temperature, and altitude was significantly positively correlated with underground biomass. These results indicate that altitude, annual mean temperature, and annual rainfall are the main factors affecting *D. odorifera* seed and seedling traits. Yao et al. (2013) identified annual mean temperature, annual sunshine hours, and altitude as the dominant climatic factors affecting *D. odorifera* introduction and cultivation in Fujian, consistent with our findings. Therefore, annual mean temperature and altitude should be prioritized as environmental factors in superior provenance selection and introduction programs.

3.3 Comprehensive Evaluation of Seed and Seedling Traits

Principal component analysis simplifies multiple evaluation indices into fewer independent comprehensive indicators, enabling more scientific, objective, and accurate evaluation by reflecting original variable information with minimal variables (Lin & Du, 2013). Mo et al. (2007) used PCA to analyze 11 seed traits in *Ginkgo biloba*, identifying key trait indicators for each variety. Chen et al. (2018) comprehensively compared 13 morphological and physiological indices of *Machilus pauhoi* seedlings from eight provenances using PCA to select superior provenances for various functions. Du et al. (2018) evaluated nine major traits of walnut nuts through PCA to screen ten superior individual plants. Thus, PCA has become an important method for solving practical forestry production problems. This study established a comprehensive quality evaluation system including nine seed and seedling traits to provide theoretical basis for selecting superior *D. odorifera* families. Using the principal component comprehensive scoring method, we identified three superior families with excellent performance in seed morphology, seedling growth, and germination, ranked as Xianyou, Danzhou, and Jianfengling provenances. However, this selection was based solely on seed and seedling traits without corresponding wood property analysis, and seedling traits were only evaluated at the juvenile stage, representing early performance. Therefore, combined selection for growth traits and wood properties would facilitate more comprehensive screening and utilization

of *D. odorifera* germplasm resources. Additionally, due to the complexity of tree growth, mid- and late-stage tracking studies are recommended to identify more stable superior families.

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Note: Figure translations are in progress. See original paper for figures.