日本落叶松木材性状与生长曲线参数的关系及其种源变异对降水的响应

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摘要:了解木材性状的遗传变异及其与生长性状和环境变量的关系对林木复杂性状的遗传改良至关重要。本研究的目的是调查木材性状的变异及其与生长曲线参数的关系，并确定影响木材性状的主要气候因子。测定了来自 6 个种源 450 株日本落叶松的 15 个木材解剖和木材化学性状及生长性状。采用线性混合模型和 Pearson 相关分析估计这些性状的遗传参数以及木材性状与树高和胸径生长曲线参数的相关性。采用线性回归分析和 Mantel 检验来检验气候变量与木材性状之间的关系及相关强度。大部分木材解剖性状在不同种源间差异显著，其遗传力(*hi2*=0.07-0.65)普遍高于木材化学和生长性状(*hi2*=0.01-0.17)。早材解剖性状(*hi2*=0.09-0.65)的遗传力高于晚材解剖性状(*hi2*=0.08-0.45)。在种源效应显著的性状中，木材纤维长度与树高极大值呈正相关，木材纤维宽度与胸径的极大值及生长速率呈正相关。降水变量（年平均降雨，春季、夏季、秋季、冬季平均降雨）与大部分性状显著相关，包括早晚材纤维宽、早材纤维长宽比、晚材率和木材基本密度。空间变量（经度，纬度，海拔）与早材纤维长、早材纤维长宽比和晚材率显著相关。温度变量（年平均温度，春季、夏季、秋季、冬季平均温度）与早材纤维长宽比和晚材率显著相关。早材纤维宽度与春季降水、晚材纤维宽度与夏秋季降水均表现出较强的相关性和预测趋势。早材解剖性状表现出较高的遗传力。树高的极大值、生长速率参数与木纤维长度，胸径的极大值参数与木纤维宽度之间存在显著的遗传相关。因此，早材木纤维长度和宽度是日本落叶松育种和选择的重要参考表型。早材纤维的纤维宽度和长宽比以及木材基本密度与降水变量具有较强的预测关系。在长期适应不同环境的过程中，不同种源地的降水强度影响纤维宽度和长度的遗传组成和表型。为不同育种目的的日本落叶松引种提供了降水范围的参考。这些发现为当前气候变化背景下的日本落叶松育种计划提供了更有价值的育种指标和实证支持。

Provenance variations in wood traits of *Larix kaempferi* and their relationships to growth curve parameters and precipitation

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Abstract： Understanding the genetic variation in wood traits and their relationships to growth traits and environmental variables is essential for the genetic improvement of forest tree species. The aims of this study were to investigate the variation in wood traits and their relationships with growth curve parameters and to identify the main climatic factors affecting wood traits. Fifteen wood anatomical and wood chemical traits and annual growth traits were measured in 450 *Larix kaempferi* (Lamb.) Carr. (Japanese larch) individuals from six provenances. Linear mixed models and Pearson correlation analysis were used to estimate the genetic parameters of these traits as well as the correlations between wood traits and growth curve parameters of tree height and diameter at breast height. Linear regression analysis and the Mantel test were used to examine the relationships and the correlation strength

between climatic variables and wood traits. Most wood anatomical traits varied significantly among different provenances, with heritabilities (h_i^2 = 0.07 to 0.65) generally higher than those of wood chemical and growth traits (h_i^2 = 0.01 to 0.17); the h_i^2 of earlywood anatomical traits (0.09 to 0.65) were higher than those of latewood anatomical traits (0.08 to 0.45). Among the traits with significant provenance variation, wood fiber length was positively correlated with the maximum growth value of tree height, and wood fiber width was positively correlated with the diameter at breast height. Precipitation variables were significantly correlated with most of the traits, including EWFW, LWFW, EWFL_W, LWP and BD (Figure 2a). Spatial variables showed significant correlations with EWFL, EWFL_W, and LWP. Temperature variables showed significant correlations with EWFL_W and LWP. Strong correlations and predictive trends were observed between earlywood fiber width and spring precipitation (R^2 = 0.45 and 0.78), as well as latewood fiber width and summer and fall precipitation (R^2 = 0.55 to 0.80). Wood anatomical traits of earlywood presented high heritability values with high selective accuracies. Significant genetic correlations were found between maximum value, growth rate of tree height and wood fiber length, and between maximum value of diameter at breast height and wood fiber width. Hence, earlywood fiber dimension is an important reference phenotype for breeding and recurrent selection of *L. kaempferi*. Fiber width and length-to-width ratio of earlywood fiber and wood basic density had strong predictive relationships with precipitation variables. In the process of long-term adaptation to different environments, the genetic composition and phenotype of the fiber width and length could be shaped by precipitation in different provenances. For the introduction of L. kaempferi with different breeding purposes, we provided a reference of precipitation range. These findings provide guidance and empirical support for *L. kaempferi* breeding programs in the context of current climate change.