

从 C₃ 到 C₄: 梭梭植物光合作用途径转变的解剖与分子机制探究*

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摘 要:探究西北荒漠地区 C₄ 木本植物梭梭 (*Haloxylon ammodendron* Bunge) 光合作用的调控机制。通过测定碳同位素值评估梭梭不同生长阶段的光合作用类型、使用解剖切片观察和比较其不同生长阶段的组织结构,利用转录组分析锁定 C₄ 光合途径关键基因的表达模式,并筛选可能与 Kranz 解剖结构发展相关的基因。在拟南芥中过表达光合调控相关功能基因和转录因子,分析其具体的生物学功能和调控机制。研究揭示了梭梭树在子叶阶段进行 C₃ 光合作用,生长出初期的同化枝时即使具有 C₄ 光合的 Kranz 解剖结构,其碳同位素也显示出类似 C₃ 光合途径的 $\delta^{13}\text{C}$ 值。直至同化枝发育成熟,才能观察到类似 C₄ 的 $\delta^{13}\text{C}$ 值并在此时转向 C₄ 光合途径。C₄ 关键基因在成熟的同化枝条中的表达高于初期的同化枝,过表达 *HaANT1* 的转基因拟南芥植株相比于野生型其叶脉密度更高、叶脉更发达,生物量显著增加,叶绿体解剖观察显示转基因植株具有更高的基粒层数和更大淀粉粒体积,并且光合速率也得到显著提升。进一步理解了梭梭 C₄ Kranz 解剖结构的发育过程和光合调控机制。

From C₃ to C₄: Anatomical and Molecular Mechanisms of Photosynthetic Pathway Transition in *Haloxylon ammodendron*

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Abstract: To investigate the regulatory mechanisms of photosynthesis in the C₄ woody plant *Haloxylon ammodendron* Bunge in the arid northwest region. The pathway of photosynthesis at different growth stages of *H. ammodendron* was assessed by measuring carbon isotope ratios, and the tissue structures at different growth stages were observed and compared using anatomical sections. Transcriptome analysis was employed to analyze the expression patterns of key C₄ photosynthetic genes and to screen genes potentially related to the development of Kranz anatomy. Overexpression of photosynthetic regulatory functional genes and transcription factors in Arabidopsis and poplar was performed to analyze their specific biological functions and regulatory mechanisms. The study revealed that *H. ammodendron* performs C₃ photosynthesis at the cotyledon stage, and even when the initial assimilative branches have a C₄ Kranz anatomical structure, the carbon isotope discrimination shows a $\delta^{13}\text{C}$ value similar to that of C₃. It is not until the assimilative branches mature that a $\delta^{13}\text{C}$ value similar to C₄ can be observed, and at this point, the plant shifts to the C₄ photosynthetic pathway. The expression of key C₄ genes in mature assimilative branches is higher than in the initial assimilative branches. Transgenic Arabidopsis overexpressing *HaANT1*

has higher vein density and more developed veins compared to the wild type, with a significant increase in biomass. Chloroplast anatomical observation shows that transgenic plants have a higher number of grana layers and larger starch grain volumes, and the photosynthetic rate is also significantly enhanced. The study further understands the developmental process of the C₄ Kranz anatomical structure and the regulatory mechanism of photosynthesis in *H. ammodendron*.