

过氧化氢调控马尾松幼苗“冬季变红”过程中花色苷的积累

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摘要: 常绿针叶树种与落叶树种冬季因衰老而变红的机制不同, 但引起常绿针叶树种冬季变红的机制, 尚缺乏系统。本研究通过对常绿针叶树种马尾松 (*Pinus massoniana* Lamb.) 幼苗从未变红 (PT1) 到部分变红 (PT2) 再到完全变红 (PT3) 的生理特征及转录组测序进行了分析, 生理特征分析表明, 花色苷积累是幼苗冬季变红的直接因素, 而过氧化氢是引起花色苷积累的主要物质, 并且过氧化氢增加也会触发可溶性糖和果糖的积累, 从而抑制淀粉和叶绿素含量的增加。筛选了花青素生物合成的关键结构基因: *phenylalanine ammonia-lyase (PAL)*、*chalcone synthase (CHS)*、*flavanone 3-hydroxylase (F3H)*、*flavonoid 3'-hydroxylase (F3'H)*、*flavonoid 3', 5'-hydroxylase (F3' 5' H)*、*dihydroflavonol 4-reductase (DFR)* 和 *anthocyanidin synthase (ANS)* 等。通过对这些 DEGs 和转录因子 (TF) 表达分析表明, H₂O₂ 可通过调节 bHLH、MYB 和 mTERF 等转录家族和花青素生物合成相关基因的表达来影响花青素的生物合成。为深入探讨常绿针叶树种冬季变红的分子机制提供了基础数据。

关键词: 马尾松; 花青素; 冬季变红; 转录组; 过氧化氢

Regulation of Anthocyanin Accumulation in *Pinus massoniana* Lamb. Seedlings During "Winter Reddening" by Hydrogen Peroxide(H₂O₂)

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Abstract: The mechanism underlying winter reddening in evergreen conifers differs from that of deciduous trees, yet a systematic understanding of the winter reddening mechanism in evergreen conifers is lacking. In this study, we analyzed the physiological characteristics and transcriptome sequencing of *Pinus massoniana* Lamb. seedlings at different stages of winter reddening, from non-red (PT1) to partially red (PT2) and fully red (PT3). Physiological analysis indicates that the accumulation of anthocyanins is the direct factor leading to the red coloration in the seedlings during winter, while hydrogen peroxide(H₂O₂) serves as the primary substance inducing the accumulation of anthocyanins. Furthermore, the increase in H₂O₂ levels also triggers the accumulation of soluble sugars and fructose, thereby inhibiting the increase in starch and chlorophyll content. Key structural genes involved in anthocyanin biosynthesis were identified, including *phenylalanine ammonia-lyase (PAL)*, *chalcone synthase (CHS)*, *flavanone 3-hydroxylase (F3H)*, *flavonoid 3'-hydroxylase (F3'H)*, *flavonoid 3',5'-hydroxylase (F3'5'H)*, *dihydroflavonol 4-*

reductase (DFR), and *anthocyanidin synthase (ANS)*. Analysis of the differentially expressed genes (DEGs) and transcription factors (TFs) indicated that H₂O₂ can influence anthocyanin biosynthesis by regulating the expression of transcription factor families such as bHLH, MYB, and mTERF, as well as genes related to anthocyanin biosynthesis. These findings provide fundamental data for further investigation into the molecular mechanisms underlying winter reddening in evergreen conifers.

Keywords: *Pinus massoniana* Lamb.; anthocyanin; winter reddening; transcriptome; H₂O₂