

怪柳耐盐及耐镉分子机制比较分析

解庆军¹, 王媛媛¹, 王丹妮¹, 李京航¹, 刘百超¹, 高彩球^{1*}

(东北林业大学 林木遗传育种全国重点实验室 哈尔滨 150040)

摘要: 怪柳属 (*Tamarix*) 是典型的盐生植物, 具有发达根系和分泌盐分的能力, 在盐碱土壤的恢复中起着重要作用。研究表明, 怪柳也具有较高的镉 (Cd) 耐受性, 并且具有分泌有毒金属的能力, 展现出修复重金属和盐碱土复合污染土壤的潜力。一方面, 有关怪柳的研究大都与抗旱耐盐相关; 另一方面, 经过对怪柳耐 Cd 机制的初步研究, 发现其耐盐和耐 Cd 机制之间既存在交叉适应, 又存在特异的抗性机制, 这有待进一步研究。通过高通量测序, 对 Cd 胁迫处理不同时间点的刚毛怪柳 (*Tamarix hispida*) 根部进行转录组测序, 对差异基因进行分析, 并通过自上而下的 graphic Gaussian model (GGM) 算法构建怪柳 Cd 胁迫应答基因调控网络, 以揭示怪柳 Cd 胁迫响应机制。进一步通过转录组和代谢组学比较分析盐胁迫、Cd 胁迫和盐-Cd 复合胁迫下怪柳响应机制。对刚毛怪柳根部的转录组进行分析, 结果表明刚毛怪柳可能通过调节细胞壁成分和苯丙烷类物质生物合成响应 Cd 胁迫, 并且通过转录因子介导的多层级调控网络 (ML-hGRN) 调节基因表达, 从而调节其对 Cd 胁迫的耐受性, ML-hGRN 中的一些成员, 例如 DRE1A、MYC1 和 FEZ 可能通过清除活性氧 (ROS) 在刚毛怪柳 Cd 胁迫应答过程中起关键作用。代谢组和转录组联合分析表明, 在盐胁迫下, 大量的酶被激活以维持怪柳的正常生长和发育。而在 Cd 胁迫下怪柳产生更多的次级代谢产物以应对 Cd 毒性, 维持正常的脂质合成和代谢可能是提高怪柳 Cd 耐受性的重要途径。而黄酮类化合物在怪柳对盐、Cd 和盐-Cd 复合胁迫的应答中都起着重要的作用。并且发现在盐-Cd 复合胁迫下, 盐胁迫通过激活或抑制一些离子转运基因的表达, 从而影响刚毛怪柳对 Cd 的吸收。刚毛怪柳通过一些转录因子层级调控其靶基因应答 Cd 胁迫。类黄酮物质的调节属于盐胁迫和 Cd 胁迫的交叉适应, 而调节脂质水平可能是怪柳应对 Cd 胁迫的重要途径。盐和 Cd 之间可能存在着复杂的互相作用机制影响怪柳离子吸收。

Comparative Analysis of Molecular Mechanisms of Salt and Cadmium Stress Tolerance in *Tamarix hispida*

Qingjun Xie¹, Yuanyuan Wang¹, Danni Liu¹, Jinghang Li¹, Baichao Liu¹, Caiqiu Gao^{1*}

(State Key Laboratory of Tree Genetics and Breeding Northeast Forestry University Harbin 150040)

Abstract: *Tamarix* is a typical halophyte, which has the ability to develop roots and secrete salt, and plays an important role in the restoration of saline soil. Research has shown that *Tamarix* also has high cadmium (Cd) tolerance and the ability to secrete toxic metals, demonstrating the potential for remediation of heavy metal and saline alkali contaminated soil. On the one hand, research on *Tamarix* is mostly related to drought resistance and salt tolerance. On the other hand, after preliminary research on the Cd tolerance mechanism of *Tamarix*, it was found that there is both cross adaptation and specific resistance mechanism between its salt tolerance and Cd tolerance mechanisms, which requires further research. Through high-throughput sequencing, Transcriptome sequencing was carried out on the roots of *Tamarix hispida* at different time points of Cd stress treatment, and the differential genes were analyzed. The top-down graphic Gaussian model (GGM) algorithm was used to construct the regulation network of *T. hispida* Cd stress response genes, so as to reveal the mechanism of *T. hispida* Cd stress response. Further, the response mechanism of *T. hispida* under salt stress, Cd stress and salt-Cd combined stress was analyzed by comparing Transcriptome and metabolomics. The analysis of the Transcriptome of the roots of *T. hispida* showed that it might respond to Cd stress by regulating cell wall components and phenylpropane biosynthesis, and regulate

its tolerance to Cd stress through transcription factor mediated multi-level regulatory network (ML-hGRN) regulator gene expression. Some members of ML-hGRN, such as DRE1A MYC1 and FEZ may play a key role in the Cd stress response process of *T. hispida* by clearing reactive oxygen species (ROS). Conjoint analysis of metabolome and transcriptome showed that under salt stress, a large number of enzymes were activated to maintain the normal growth and development of *T. hispida*. Under Cd stress, *T. hispida* produces more Secondary metabolite to cope with Cd toxicity, and maintaining normal lipid synthesis and metabolism may be an important way to improve the Cd tolerance of *T. hispida*. Flavonoid play an important role in the response of *T. hispida* to salt, Cd and salt-Cd stress. And it was found that under salt-Cd complex stress, salt stress affects the absorption of Cd by *T. hispida* by activating or inhibiting the expression of some ion transport genes. *T. hispida* regulates its target gene response to Cd stress through several transcriptional factor levels. The regulation of flavonoids belongs to the cross adaptation of salt stress and Cd stress, and regulating lipid levels may be an important pathway for *T. hispida* to cope with Cd stress. There may be a complex interaction mechanism between salt and Cd that affects ion absorption in *T. hispida*.