红砂幼苗对 PEG 胁迫下外源 NO 的生理生化响应

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摘　要:【目的】红砂*(Reaumuria soongorica)*属于超旱生小灌木，具有耐旱、抗逆性强等特点，适于生长在干旱半干旱地区，因其具有防风固沙的能力，常用于维持荒漠生态系统的稳定性，对植被的恢复具有重要意义。但是由于极端气候频发，红砂的荒漠植物群落面临着退化或大面积死亡的风险，因此提高红砂抗旱能力是一项重要举措。外源一氧化氮(NO)可以促进植物生长发育，在植物的抗逆性调节中应用十分广泛。聚乙二醇(PEG)是一种大分子聚合物，能够夺取水分，从而对植物造成渗透胁迫。由于红砂生长的地理环境不同，可能会导致其在 PEG 胁迫下对外源物质的响应也有所差异。【方法】本研究以武威的红砂幼苗为研究对象，用 10% 的聚乙二醇 6000(PEG 6000)和 3 种浓度外源 NO 供体硝普钠(SNP)(0.10, 0.50, 1.00 mmol/L) 进行处理，分析外源 NO 对 PEG 胁迫下红砂幼苗生长特性、生理生化特征及碳氮磷特征等的调控作用，从而筛选出最适的外源 NO 浓度，以期为提高不同种源红砂幼苗的抗旱性提供理论依据。【结果】1.PEG 胁迫下，红砂幼苗的株高、根长、基部直径、鲜重和干重均显着降低。外源 NO 可显著提高 PEG 胁迫下红砂幼苗的各项生长指标 ($P < 0.05$)，尤其在 0.10mmol/L 时，红砂的枝高分提高了 45.13%，基径提高 38.66%。0.50 mmol/L 处理后，红砂地上部生物量增加了 52.43%，表明外源 NO 作为植物生长调节剂可以减轻 PEG 胁迫对红砂生长的抑制作用。2.SNP 在 0.10-1.0 mmol/L 浓度间均可显著的增加 PEG 胁迫红砂的可溶性糖（SS）、可溶性蛋白（SP）和脯氨酸（PRO）的含量($P<0.05$)。其中 0.10mmol/L 浓度 SNP 下，红砂 SS 比仅 PEG 胁迫下的高 3.4 倍；在 0.10 mmol/L 浓度 SNP 下，红砂 SP 增加了 48.42%。外源 NO 处理使 PEG 胁迫下红砂的丙二醛（MDA）含量有所下降，0.10 mmol/LSNP 降幅最大，分别为 79.72%；表明外源 NO 虽可修复红砂因干旱引起的膜损伤，但种源间有差异。SNP 处理可使红砂在 PEG 胁迫下活性氧清除酶（SOD、POD、CAT）的活性均呈上升趋势。3.在 PEG 胁迫下，红砂叶和根的碳(C)、氮(N)和磷(P)表现出不同的变化趋 势。外源性 NO 可以显著提高 PEG 胁迫下红砂叶和根的 C、N 和 P 含量，其中 0.10mmol 浓度的 SNP 对红砂叶和根的 C 含量影响最大，叶片分别增加了 60.86%，根部分别增加了 34.09%；红砂叶和根的 N 含 量在 1.00 mmol/L 时提高了 93.25 和 44.36；红砂叶和根的 P 含量在 0.10 mmol/L 有所增加。红砂的 C:N、C:P 和 N:P 的化学计量在 0.50mmol/L 时最大。【结论】综合评价结果表明，缓解红砂幼苗 PEG 胁迫最有效的外源 NO 供体 SNP 浓度为 0.10 mmol/L，其有助于改善红砂生长，控制其渗透调节物质和膜脂过氧化水平，提高抗氧化酶的活性，并改善红砂叶和根的 C、N、P 水平。

关键词: 红砂幼苗；PEG 胁迫；外源 NO；生理生化响应

Physiological and Biochemical Responses of Red Sand Seedlings to Exogenous NO under PEG Stress

Abstract: 【Objective】Red sand *(Reaumuria soongorica)* belongs to the super arid small shrub, which has the characteristics of drought resistance and strong stress resistance. It is suitable for growing in arid and semi-arid areas. Due to its ability to prevent wind and fix sand, it is commonly used to maintain the stability of desert ecosystems and is of great significance for vegetation restoration. However, due to the frequent occurrence of extreme weather, the desert plant community of Red Sand faces the risk of degradation or large-scale death, so improving the drought resistance ability of Red Sand is an important measure. Exogenous nitric oxide (NO) can promote plant growth and development, and is widely used in the regulation of plant stress resistance. Polyethylene glycol (PEG) is a macromolecular polymer that can capture water and cause osmotic stress on plants. Due to the different geographical environments in which red sand grows, its response to exogenous substances may also vary under PEG stress.【Methods】Red sand seedlings in Wuwei were treated with 10% polyethylene glycol 6000 (PEG 6000) and three concentrations of exogenous NO donor Sodium nitroprusside (SNP) (0.10, 0.50, 1.00 mmol/L), To provide theoretical basis for improving the drought resistance of red sand seedlings from different sources.【Result】1.Under PEG stress, the plant height, root length, basal diameter, fresh weight, and dry weight of red sand seedlings were significantly reduced. Exogenous NO can significantly improve the various growth indicators of red sand seedlings under PEG stress ($P<0.05$), especially at 0.10mmol/L, the branch height fraction of red sand increased by 45.13% and the basal diameter increased by 38.66%. After treatment with 0.50 mmol/L, the aboveground biomass of red sand increased by 52.43%, indicating that exogenous NO as a plant growth regulator can alleviate the inhibitory effect of PEG stress on the growth of red sand.

SNP significantly increased the content of soluble sugar (SS), soluble protein (SP), and proline (PRO) in red sand under PEG stress at concentrations ranging from 0.10 to 1.0 mmol/L ($P<0.05$). Under the concentration of 0.10mmol/L SNP, the SS of red sand was 3.4 times higher than that under PEG stress alone; At a concentration of 0.10 mmol/L SNP, the SP of red sand increased by 48.42%. Exogenous NO treatment reduced the Malondialdehyde (MDA) content of red sand under PEG stress, with the largest reduction of 0.10 mmol/L SNP, 79.72%; This indicates that although exogenous NO can repair membrane damage caused by drought in red sand, there are differences among different sources. SNP treatment can increase the activity of reactive oxygen species scavenging enzymes (SOD, POD, CAT) in red sand under PEG stress. 3. Under PEG stress, the carbon (C), nitrogen (N), and phosphorus (P) of red sand leaves and roots exhibit different changing trends. Exogenous NO can significantly increase the C, N, and P content of red sand leaves and roots under PEG stress, with a concentration of 0.10mmol SNP having the greatest impact on the C content of red sand leaves and roots, with leaves increasing by 60.86% and roots increasing by 34.09%, respectively; The N content of red sand leaves and roots increased by 93.25 and 44.36 at 1.00 mmol/L; The P content of red sand leaves and roots increased at 0.10 mmol/L. The stoichiometry of C: N, C: P, and N: P in red sand is maximum at 0.50 mmol/L.【Conclusion】The comprehensive evaluation results indicate that the most effective concentration of exogenous NO donor SNP to alleviate PEG stress in red sand seedlings is 0.10 mmol/L. It helps to improve the growth of red sand, control its osmotic regulatory substances and membrane lipid peroxidation levels, increase the activity of antioxidant enzymes, and improve the C, N, and P levels of red sand leaves and roots.

Key words: Red sand seedlings; PEG stress; Exogenous NO; Physiological and biochemical response