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ORIGINAL ARTICLE

Alleviative effects of nitric oxide on *Vigna radiata* seedlings under acidic rain stress

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Abstract
Although nitric oxide (NO) is a key regulatory molecule in plants, its function in plants under conditions of simulated acid rain (SAR) has not been fully established yet. In this study, exogenous sodium nitroprusside (SNP) at three different concentrations were applied to mung bean seedlings. Malondialdehyde (MDA), NO, hydrogen peroxide (H_2O_2), antioxidant enzyme activities, and nitrate reductases (NR) were measured. Real time PCR was used to measure the NR expression. Compared to the control, the NR activity and NO content under the pH 2 SAR decreased by 79% and 85.6% respectively. Meanwhile, the SAR treatment reduced the activities of superoxide dismutase (SOD), peroxidase (POD), ascorbate peroxidase (APX), while increased MDA content. Application of SNP could potentially reverse the adverse impact of SAR, depending on its concentration. For plants under the pH 2 SAR and 0.25 mM SNP condition, the activities of SOD, POD, APX increased by 123%, 291%, and 135.7% respectively, meanwhile, MDA concentration decreased by 43%, NR activities increased by 269%, and NO concentration increased by 123.6% compared with plants undergoing only pH 2 SAR. The relative expression of the NR1 gene was 2.69 times higher than that of pH 2 SAR alone. Overall, the application of 0.25 mM SNP eliminated reactive oxygen species (ROS) by stimulating antioxidant enzyme activities, reducing oxidative stress and mitigating the toxic effects of SAR on mung bean seedlings. This research provides a foundation for further research on the mechanism of NO on plants under SAR conditions.

Keywords Acid rain stress · Antioxidant enzymes · Nitrate reductase · Nitric oxide

Introduction

In recent decades, acid rain (AR) has been recognized as one of the most serious environmental issues globally, requiring urgent attention [1]. Specifically, AR refers to rain or any other form of precipitation that is unusually acidic (pH ≤ 5.6), possessing elevated levels of hydrogen ions. Acid rain mainly tends to be caused by the presence of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), which are released from the burning of fossil fuel [2]. With the rapid development of industry, the use of fossil fuels in China has soared, producing large amounts of SO_2 and NO_x. As a result, most regions in China tend to be severely affected by AR [3]. Besides, China is a major agricultural country. Therefore, there is a need to understand the mechanism behind AR stress on crops to improve crop resistance [4].

Although the stress mechanism of AR on plants is not yet fully understood, it is well known that AR stress inhibits plant growth and development through direct deposition of acidic substances on plant leaves and indirect acidification of surface water and soil. Subsequently, AR contributes towards a range of adverse effects within plants, such as the disruption of photosynthesis, the triggering of lipid peroxidation, the disturbance of the balance of the antioxidant system, and causing a loss of nutrients [2].

Nitric oxide (NO) is a molecule that plays an important function in plants, by regulating physiological processes such as seed dormancy, germination, growth, and anti-stress responses [5, 6]. Studies have shown that NO plays a critical role in countering abiotic stress caused by excessive salinity and drought [7]. More specifically, the bulk of available research has shown that under abiotic stress, NO acts through a complex system, including participating in signal transduction by regulating cyclic guanosine monophosphate

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