Unraveling Mechanisms Associated with Nutrient Use Efficiency in Wheat under Combined Effect of Drought and Arsenic stress

Findings

Of the Ph.D. Thesis

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FINDINGS

Nutrient Use Efficiency (NUE) is crucial for sustainable wheat production, particularly under the dual threats of drought and arsenic (As) stress. These stresses increasingly co-occur in agroecosystems. Drought restricts nutrient solubility and uptake, while arsenic competes with essential nutrients and accumulates in grains. Together, they compromise productivity and food safety. This thesis unravels the physiological, biochemical, and molecular mechanisms through which nitrogen (N) and phosphorus (P) supplementation safeguard NUE and photosynthetic resilience under combined D+As stress in wheat (HD-3237).

Nutrient quantification through ICP-MS revealed that essential nutrient content was drastically reduced under D+As stress. NP-supplementation significantly restored nutrient uptake and accumulation. SEM analysis of root anatomy and root traits showed root shrinkage and xylem collapse under stress. With NP-supplementation, root proliferation and xylem development improved, enhancing nutrient uptake and water transport. Gene expression analysis by RT-qPCR revealed the upregulation of high-affinity transporters (*TaAMT1.1*, *TaNRT2.1*, *TaPHT1.10*). These transporters ensured nutrient uptake efficiency was maintained under dual stress.

Biochemical enzyme assays demonstrated that NP-supplementation reinstated GS-GOGAT activity to improve N-assimilation. It also promoted detoxification through GDH and enhanced phosphatase activity to restore P-assimilation. Together, biochemical assays and nutrient profiling confirmed that NP-supplementation improved assimilation and promoted secondary nutrient synergy. These changes collectively stabilized NUE under stress. Validation through NUE metrics, including physiological nutrient use efficiency (PNUE), agronomical use efficiency (ANUE), and nutrient recovery efficiency (NRE), further confirmed that nutrient use efficiency was significantly enhanced under NP-supplemented dual stress.

At the photosynthetic level, NP-mediated NUE reinstated Rubisco activity and CO_2 fixation. It sustained ATP generation through enhanced phosphorus use efficiency and stabilized light-

harvesting complexes. Hormonal profiling showed that NP enrichment shifted regulation from ABA/SA dominance toward JA-driven control. This promoted stomatal reopening through sugar–K^+ transporters (*TaSTP12, TaSTP51, TaKAT-like1*). Computational docking confirmed JA-mediated TaMYB84–STP interactions as central to sucrose osmoregulation and stomatal conductance. NP also strengthened the ASC–GSH cycle, reducing ROS accumulation and protecting Rubisco and photosystems. Together, these mechanisms restored photosynthetic NUE (PnNUE, PnPUE), biomass accumulation, and yield traits under dual stress. Importantly, wheat cultivar HD-3237 demonstrated drought resilience but arsenic sensitivity, which was substantially alleviated by NP-supplementation. This multidimensional investigation establishes that NUE is the central regulator linking nutrient acquisition, assimilation, and photosynthesis under stress. By decoding NUE-linked mechanisms, the study offers nutrient-smart strategies to enhance wheat resilience, protect grain quality, and secure food safety in stress-prone environments.