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Physiological Responses of Photosynthetic Characteristics and Antioxidant Systems in Wheat Leaves under Drought Stress

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Abstract Drought stress is one of the major environmental constraints limiting wheat growth, productivity, and yield stability, particularly under increasing climate variability. This review summarizes the physiological responses of wheat leaves to drought stress, with emphasis on photosynthetic characteristics and antioxidant defense mechanisms. Drought-induced reductions in leaf water status and stomatal conductance restrict CO_2 diffusion and progressively impair photosynthetic carbon assimilation. Meanwhile, disturbances in photosynthetic electron transport enhance the production and accumulation of reactive oxygen species (ROS), resulting in oxidative damage to cellular membranes and photosynthetic structures. Wheat responds to oxidative stress by activating enzymatic antioxidant defenses, including superoxide dismutase, catalase, peroxidase, ascorbate peroxidase, and glutathione reductase, together with non-enzymatic antioxidants involved in the ascorbate-glutathione cycle. The coordinated regulation of stomatal behavior, chlorophyll fluorescence, photoprotection, ROS scavenging, hormonal signaling, and redox homeostasis contributes to drought adaptation. Case studies further demonstrate differences among drought intensity, duration, and rewatering conditions in determining photosynthetic recovery and antioxidant capacity. Finally, strategies involving irrigation management, nutritional regulation, exogenous substances, drought-tolerant cultivar selection, and precision agriculture are discussed. Integrating physiological, biochemical, and molecular approaches will improve the understanding and practical management of wheat drought tolerance.

Keywords Wheat; Drought stress; Photosynthesis; Antioxidant system; Reactive oxygen species

1 Introduction

Wheat is one of the world's most important staple crops and provides a substantial share of human calories and protein, so its stability under water-limited environments is tightly linked to global food security. Yet drought has become one of the most serious abiotic constraints on wheat production worldwide, and climate change is increasing both the frequency and severity of water scarcity across major wheat-growing regions (Franco-Navarro et al., 2025). Projections suggest that the area exposed to drought in wheat-producing regions could expand markedly during this century, with simultaneous severe water scarcity affecting far more wheat land than at present even under mitigation scenarios. This threat is especially serious because much of global wheat production already occurs in water-stressed breadbaskets; one analysis estimated that 65% of wheat produced across major global breadbaskets faces high water scarcity. At regional scales, winter wheat frequently experiences serious crop water deficit in major production zones such as the North China Plain and northwestern China, especially from greening to jointing and from jointing to anthesis, and these deficits can reduce yield by 60% and 55%, respectively, when water supply is insufficient. Future modeling further indicates that concurrent meteorological and agricultural drought can widen wheat yield gaps more than single-type drought, with projected impacts on wheat often stronger than on maize and strongly shaped by soil moisture constraints. Although global mean production losses may appear moderate in some projections, the burden is highly uneven, with many countries expected to face large drought-related crop losses, reinforcing the need for drought adaptation in wheat systems (Kraklow et al., 2025). Because reproductive and grain-filling stages are particularly sensitive to water deficit, drought not only depresses biomass accumulation and grain formation but also threatens the reliability of wheat production under increasingly unstable climates (Bohra et al., 2024).