The harmful effect of drought on wheat productivity is mediated through a cascade of physiological disturbances, among which impairment of photosynthesis is one of the earliest and most consequential responses (Nyaupane et al., 2024). Under water deficit, wheat leaves rapidly close stomata to limit transpirational water loss, but this protective response also restricts CO_2 diffusion and reduces carbon assimilation, leading to declines in net photosynthetic rate and stomatal conductance. Experimental studies across wheat genotypes consistently show that drought reduces net photosynthesis, stomatal conductance, relative water content, chlorophyll content, and grain yield, although the magnitude of decline differs among cultivars according to drought tolerance capacity. In the early phase of drought, photosynthetic inhibition is often dominated by stomatal limitation, whereas under prolonged or severe stress non-stomatal limitations become increasingly important, including chlorophyll loss, reduced Rubisco-related activity, inhibition of PSII electron transport, and damage to the oxygen-evolving complex and light-harvesting system (Todorova et al., 2022). Chlorophyll fluorescence measurements confirm that drought decreases Fv/Fm, ΦPSII, qP, and electron transport rate, while often increasing energy dissipation pathways, indicating progressive photochemical impairment and photoinhibition risk. This physiological progression is further intensified when drought co-occurs with heat, because high temperature amplifies declines in PSII efficiency, carbon uptake, and water use efficiency, particularly above critical thermal thresholds and in sensitive genotypes. At the same time, drought disturbs photosynthetic electron flow and enhances the incomplete reduction of oxygen, promoting the formation of reactive oxygen species such as superoxide and hydrogen peroxide that damage lipids, proteins, membranes, and the photosynthetic apparatus if not effectively detoxified. Accordingly, antioxidant defense is a central component of drought tolerance in wheat. Water deficit commonly elevates the activities of superoxide dismutase, catalase, peroxidase, and ascorbate peroxidase, together with osmotic regulators such as proline, soluble sugars, and related metabolites that help preserve membrane integrity and cellular hydration. Tolerant genotypes generally sustain lower hydrogen peroxide and lipid peroxidation, stronger or longer-lasting antioxidant activity, and better recovery after rewatering, indicating that resistance depends not only on limiting water loss but also on maintaining redox homeostasis and protecting photosynthetic tissues.

Against this background, understanding the coordinated responses of photosynthetic characteristics and antioxidant systems in wheat leaves is essential for clarifying how drought injury develops and how tolerance is expressed at the physiological level. Existing research has established that drought affects gas exchange, chlorophyll fluorescence, pigment stability, osmotic adjustment, and antioxidant metabolism, but several important questions remain open, particularly regarding the temporal coupling between photosynthetic decline and oxidative defense, the extent to which stomatal versus non-stomatal limitation predominates under different stress intensities, and which leaf traits best distinguish tolerant from susceptible wheat genotypes. There is also strong practical value in identifying physiological indicators that respond sensitively to drought and recovery, because such traits can support cultivar screening, mechanistic phenotyping, and management strategies aimed at improving water productivity and resilience. Therefore, this study is framed to examine how drought stress alters leaf photosynthetic performance and antioxidant defense in wheat, with emphasis on changes in gas exchange, chlorophyll-related traits, reactive oxygen metabolism, and protective enzyme activities. The central scientific questions are whether drought-induced reductions in photosynthetic capacity are accompanied by coordinated activation of antioxidant enzymes, whether these responses are sufficient to limit oxidative injury in leaves, and which physiological indices can most effectively explain variation in drought tolerance). By integrating these dimensions, the study can help bridge the gap between whole-plant drought outcomes and leaf-level mechanisms, and provide a physiological basis for breeding and management strategies that enhance wheat adaptation to increasingly water-limited environments.

2 Effects of Drought Stress on Leaf Water Status and Physiological Processes in Wheat

2.1 Changes in leaf water status and water relations

Drought stress first disrupts leaf water balance in wheat by lowering leaf water potential and relative water content, thereby weakening turgor maintenance and impairing normal physiological activity. This decline in water status is consistently accompanied by higher leaf or canopy temperature, indicating reduced evaporative cooling and