genotypes, although tolerant materials maintained higher function under severe stress. These case studies indicate that progressive drought in wheat begins with stomatal restriction but eventually extends to pigment loss, altered PSII energy partitioning, and broader metabolic inhibition. They also show that evaluating drought response against available soil water, rather than stress duration alone, gives a clearer view of physiological thresholds.

7.2 Case study 2: antioxidant system responses to drought stress

A second case-study pattern is the strong activation of the wheat leaf antioxidant system under drought-induced oxidative stress. Water deficit increases hydrogen peroxide, malondialdehyde, and proline while stimulating the main enzymatic defenses, including SOD, CAT, and APX, and these responses become stronger as stress severity increases (Nasirzadeh et al., 2020). In a separate greenhouse study across growth stages, drought likewise increased SOD, CAT, POD, and APX activities in leaves, supporting the view that enzymatic detoxification is a core component of wheat drought defense. This antioxidant activation reflects the need to detoxify ROS generated when drought restricts carbon assimilation and disturbs cellular redox balance. At the same time, the response is not uniform across all genotypes or all enzymes, which makes antioxidant profiling useful for distinguishing different drought-response strategies.

Case comparisons further show that drought tolerance depends on the coordination, rather than the mere presence, of antioxidant defenses. Drought-resistant varieties often rely more heavily on enhanced ROS-detoxifying enzyme activity, whereas drought-sensitive genotypes can depend more on non-enzymatic antioxidant components that become particularly important during recovery. Repeated stress exposure can also prime the antioxidant machinery: in acclimated wheat seedlings, severe subsequent drought caused less H_2O_2 accumulation and membrane damage because APX activity and the ascorbate-glutathione redox pool were maintained more effectively. These findings suggest that the most informative antioxidant case studies are those that integrate ROS levels, membrane injury, osmolyte accumulation, and enzyme coordination across contrasting genotypes or stress histories. They also underline that antioxidant capacity contributes directly to preserving leaf function under drought, not merely to damage repair after stress has already occurred.

7.3 Case study 3: photosynthetic recovery and antioxidant regulation during drought-rewatering cycles

Drought-rewatering case studies show that many wheat leaf responses are reversible, but recovery depends strongly on prior stress severity and genotype. After rewatering, photosynthetic traits such as net assimilation, stomatal conductance, transpiration, and water use efficiency can show full or even over-compensatory recovery following drought, indicating substantial physiological resilience when stress has not exceeded critical thresholds (Todorova et al., 2022). This reversibility is not unlimited, however, because moderate stress tends to permit near-complete restoration of photosynthetic processes, whereas severe drought often leaves persistent impairment in membranes, ROS balance, and final productivity. Recovery therefore reflects both the extent of prior injury and the plant's ability to reactivate gas exchange, re-establish water relations, and restore redox control. In this context, fast recovery of photosynthesis is a meaningful indicator of drought tolerance rather than a simple return to pre-stress values.

Antioxidant regulation during rewatering is equally dynamic and can persist even after visible stress relief. In winter wheat, most pigment, photosynthetic, and antioxidant traits recovered effectively after stress relief within a certain range, but after longer combined stress, antioxidant activities remained elevated while oxidative damage was still not fully mitigated. Repeated drought-rewatering cycles can even enhance post-stress performance: intermittent drought increased the maximum photosynthetic rate after rewatering and strengthened stress-response indicators relative to non-primed plants, with ABA responding particularly rapidly. Lower-ranked but important recovery studies extend this picture by showing that after atmospheric-soil drought, stomatal conductance and photosynthetic rate recovered relatively quickly, whereas leaf hydraulic conductance recovered more slowly, suggesting different repair kinetics within the same leaf system (Wang et al., 2025). Taken together, these case studies show that rewatering success in wheat depends on coordinated restoration of photosynthesis, antioxidant defenses, and hydraulic function, with moderate prior stress often producing the strongest recovery capacity.