generally better able to maintain leaf structure and photosynthetic activity than sensitive genotypes. This suggests that maintaining photosynthetic continuity is itself an important tolerance trait rather than only a secondary result of stress resistance.

Oxidative damage is another typical feature of saline-alkali stress. Reactive oxygen species (ROS) normally function as important signaling molecules, but under severe stress they accumulate excessively, causing lipid peroxidation, membrane leakage, protein damage, and cellular dysfunction. Many recent reviews on plant systems have identified ROS regulation as a central component of stress-resistance biology rather than just a secondary symptom. Salt-tolerant millet materials also show lower oxidative damage and stronger inducible antioxidant capacity, further indicating that controlled ROS scavenging plays an important role in plant tolerance under real stress conditions (Mittler et al., 2022).

Roots suffer from both direct and indirect damage. High salinity inhibits root elongation, while high pH suppresses root tip growth, root hair development, and nutrient uptake. Because roots are also responsible for maintaining ion selectivity and supporting beneficial microorganisms, root injury can trigger cascading effects on whole-plant adaptation. In millet, tolerant and sensitive genotypes differ significantly in root structure, surface integrity, and transport-related transcriptional responses, suggesting that root resilience forms the basis of shoot resilience (Yuan et al., 2022).

2.3 Agricultural challenges under saline-alkali conditions

At the field scale, saline-alkali stress not only reduces land quality but also limits the flexibility of agricultural management. It lowers seedling emergence, restricts cultivar selection, and decreases fertilizer use efficiency because plants cannot effectively absorb and assimilate nutrients applied to the soil. In areas with unstable rainfall, poor drainage, or secondary salinization, saline-alkali conditions also increase yield fluctuations between years. Therefore, saline-alkali agriculture is not only a productivity issue, but also a challenge for agricultural sustainability (Negacz et al., 2022).

The ecological costs are also serious. Salinization alters microbial diversity, biogeochemical cycling, and soil structural stability, while alkaline conditions further restrict nutrient cycling processes. In other words, degraded saline-alkali land is not simply soil with “too much salt,” but a land environment whose biological functions have been partially reshaped and are no longer suitable for conventional agricultural production. This is also why crop selection must be considered together with rhizosphere management.

3 Ecophysiological Adaptation Mechanisms of Broomcorn Millet under Saline-Alkali Stress

3.1 Morphological adaptation mechanism

The morphological adaptation of broomcorn millet under saline-alkali stress is not simply “slow growth,” but a structural adjustment aimed at survival and reproductive completion. As a typical drought-tolerant and barren-soil-tolerant minor cereal crop, broomcorn millet has characteristics such as a short growth period, strong root adaptability, and relatively moderate aboveground biomass investment. These features allow it to improve reproductive stability under stress by reducing the cost of vegetative growth in saline-alkali environments.

Root structure is the most crop-specific morphological basis for saline-alkali adaptation in broomcorn millet. An alkali stress evaluation of 296 millet germplasm resources showed that Ma et al. (2021) used mixed alkali concentrations of 80 mmol/L and 40 mmol/L to evaluate alkali tolerance at the germination and seedling stages, respectively. At the seedling stage, plant height, green leaf area, biomass, and root structure were further measured. Green leaf area can serve as a direct indicator of alkali tolerance during the seedling stage, while changes in root structure reflect the ability of the plant to maintain absorption functions under the combined effects of high pH and ion stress. Finally, 12 alkali-tolerant resources and 41 sensitive resources were identified.

The morphological adaptation mechanism of broomcorn millet can be summarized as the coordination of “low-consumption canopy-functional root system-rapid recovery.” Moderate control of leaf area expansion can reduce transpiration and ion transport burden, while maintaining the root absorption interface helps acquire water,