Proso millet originated in the dry farming regions of northern China, and its long domestication history has given it strong environmental adaptability. It is a self-pollinated C4 crop that can mature within 60~90 d and maintain relatively stable productivity under drought and saline-alkaline conditions (Baltensperger, 2002). Significant differences exist among genotypes in salt-alkaline tolerance, nutritional quality, and environmental adaptability.

The rhizosphere is not simply the soil surrounding roots, but an important interface where plants interact with microorganisms. Plant-associated microorganisms can improve plant salt tolerance through different mechanisms, including promoting nutrient uptake, regulating Na^+/K^+ balance, enhancing antioxidant capacity, and improving the soil environment (Zhao et al., 2020). Recent studies on proso millet have started to combine plant physiology, transcriptomics, and rhizosphere microbial community analysis, showing that the microbiome has become an essential component for understanding its saline-alkaline tolerance mechanisms (Yuan et al., 2023).

This study explains the characteristics of saline-alkaline stress and its effects on plant growth performance, summarizes the ecophysiological adaptation mechanisms that help proso millet survive and recover under saline-alkaline conditions, discusses how the rhizosphere microbiome is reshaped during stress and how microbial recruitment enhances plant tolerance, evaluates the effects of saline-alkaline stress on millet metabolism and nutritional quality, and analyzes the potential role of this crop in soil improvement, marginal land agriculture, feed security, and climate-resilient food systems. The aim is to provide theoretical references for the agricultural development of saline-alkaline land and the utilization of stress-resistant crops.

2 Saline-Alkali Stress and Ecophysiological Adaptation

2.1 Physicochemical characteristics of saline-alkali soils

Saline-alkali soil is not defined by a single threshold. Instead, it is characterized by a series of interconnected physicochemical imbalances. The continuous accumulation of soluble salts lowers soil osmotic potential, while sodium ions usually dominate both soil exchange sites and soil solution composition. In alkaline saline soils, bicarbonates and carbonates increase soil pH, sometimes above 8.5, which further promotes nutrient precipitation and weakens transport processes on the root surface. Therefore, crops growing in this type of soil are not simply facing “reduced water uptake,” but are exposed to a rhizosphere environment whose chemical properties have already been altered (Mukhopadhyay et al., 2021).

From the plant perspective, high concentrations of Na+ are especially damaging because they compete with K+ at ion transport and enzyme activation sites. Excess external sodium also disrupts cell membrane stability and induces secondary injuries, including oxidative stress. In alkaline soils, high pH further intensifies these problems by reducing the solubility of micronutrients and interfering with proton-driven transport systems. As a result, plants experience a combined stress environment in which water absorption, ion selectivity, and nutrient assimilation are all restricted at the same time.

2.2 Physiological damage caused by saline-alkali stress

Seed germination is one of the earliest life processes affected by saline-alkali stress. Germinating seeds must quickly mobilize stored reserves and establish root-soil contact, but high salinity reduces seed imbibition efficiency and alters the activity of enzymes required for reserve degradation. Elevated pH also suppresses root emergence and affects the maintenance of membrane integrity. In broomcorn millet, evaluations of different genotypes under alkaline stress showed clear differences in seed germination and seedling growth. This not only demonstrates the high sensitivity of the germination stage to saline-alkali conditions, but also indicates the existence of exploitable genetic variation (Ma et al., 2021).

Photosynthesis is then inhibited through several interconnected mechanisms. Salt stress reduces stomatal conductance, suppresses chlorophyll metabolism, damages chloroplast ultrastructure, and limits carbon assimilation. Since ion toxicity and osmotic stress often occur simultaneously, canopy symptoms usually show both dehydration and metabolic inhibition. Alkaline conditions further aggravate the problem by disrupting nutrient supply to the photosynthetic system. In proso millet and related systems, salt-tolerant genotypes are