### 4.4 Root exudates and microbial recruitment

Root exudates are the key medium through which broomcorn millet regulates the rhizosphere microbiome. Sugars, amino acids, organic acids, phenolic acids, flavonoids, lipids, and purine compounds not only provide carbon and nitrogen sources for microorganisms, but also play roles in chemotaxis, signal recognition, and selective screening. Under saline-alkali stress, the composition of root exudates usually changes, thereby influencing which microorganisms can migrate to the rhizosphere, colonize roots, and form stable communities. Root exudates can drive microbial recruitment and community assembly and promote plant health and stress resistance by influencing microbial chemotaxis, community diversity, and functional complementarity (Yang et al., 2025).

The reshaping of the rhizosphere microbiome in broomcorn millet is probably not a passive outcome, but an actively driven process induced by stress-related metabolic changes in roots. Under saline-alkali stress, millet roots may release organic acids to regulate rhizosphere microdomain pH, provide sugars and amino acids as substrates for salt-tolerant growth-promoting bacteria, and use phenolic or flavonoid compounds as selective signaling molecules. The final microbial recruitment pattern is determined not by a single exudate, but by the overall “metabolite combination” formed by roots under saline-alkali conditions. Future research on broomcorn millet should combine rhizosphere metabolomics with 16S/ITS sequencing to clarify which exudates are associated with enriched groups such as Nocardioides, Nitriliruptoraceae, and Cryptococcus.

### 4.5 Plant-microbe synergistic mechanisms under saline-alkali stress

The plant-microbe synergistic mechanisms of broomcorn millet under saline-alkali stress are mainly reflected in four aspects. First, microorganisms alleviate nutrient limitations in saline-alkali soils by improving nutrient availability, such as promoting organic matter decomposition, phosphorus activation, and nitrogen cycling. Second, microorganisms reduce direct $Na^+$ damage to roots through extracellular polysaccharides, biofilms, and ion adsorption. Third, PGPR and endophytes can regulate root elongation, lateral root formation, and stomatal behavior through IAA, ACC deaminase, and ABA-related pathways. Fourth, microorganisms can induce antioxidant enzyme systems and osmotic adjustment processes in the host, helping plants maintain higher cellular stability under ROS accumulation and membrane lipid peroxidation stress.

Salt-tolerant broomcorn millet under salt stress does not rely only on its own gene expression regulation. It also shows simultaneous reshaping of rhizosphere bacterial and fungal communities. Under saline-alkali conditions, nutrient accumulation in broomcorn millet is closely related to changes in rhizosphere microorganisms. Specific bacteria and fungi enriched under high-salt treatment are associated with soil nutrient cycling, nutrient absorption, and organic matter decomposition.

Cultivation of broomcorn millet on saline-alkali land should therefore not rely only on evaluating varietal salt tolerance, but should also pay attention to the recovery of soil microbial functions. In the future, salt-tolerant variety screening, rhizosphere functional microorganism isolation, AMF inoculation, organic fertilizer improvement, and intercropping systems can be integrated into a comprehensive rhizosphere regulation strategy. Only in this way can the stress-resistance potential of broomcorn millet be effectively translated into stable yields on saline-alkali soils.

## 5 Metabolic Reprogramming Induced by Saline-Alkali Stress and Agricultural Applications

### 5.1 Protein accumulation and nitrogen metabolism

The study of protein accumulation in broomcorn millet grains under saline-alkali stress should not simply follow the generalized conclusion that “stress increases protein content.” Instead, it should be understood within the combined framework of nitrogen redistribution, amino acid synthesis, and restricted grain filling. Saline-alkali conditions simultaneously affect root nitrogen uptake, nitrogen assimilation, amino acid transport, and grain protein deposition. Different proportions of neutral salts and alkaline salts produce different effects on millet germination and seedling growth, and they can distinguish the relative contributions of osmotic stress, ion toxicity, and high-pH damage. This indicates that the metabolic changes of broomcorn millet under saline-alkali stress are not caused by a single salt effect, but by the combined influence of multiple stresses altering growth and material allocation.