

The role of root health in stress resistance is especially evident under water stress and nitrogen stress. Drought stress significantly reduces root length, root biomass, and root activity, thereby weakening water and nutrient uptake capacity and leading to reduced shoot growth and photosynthesis. Under high nitrate stress, root structure is also inhibited, with development of both coarse and fine lateral roots being restricted and membrane stability declining, thereby affecting overall uptake and growth performance. Correspondingly, exogenous regulatory measures that improve root structure and vitality often have clear mitigating effects. For example, melatonin and sodium nitroprusside treatments can promote the growth of both coarse and fine lateral roots, increase root activity and antioxidant enzyme activity, and thereby enhance plant adaptation to high-nitrate conditions. Similarly, tannin-based biostimulants can increase root length and root weight under salt stress and upregulate the expression of genes related to root development and salt tolerance, thereby improving nutrient uptake and root salt tolerance.

Root health also determines the plant's basic resistance to biotic stress. Roots are a major entry point for soil-borne pathogens. If roots are damaged, if the rhizosphere microecology is imbalanced, or if aeration is poor, diseases such as root rot and wilt can be easily induced, thereby threatening whole-plant growth stability. Conversely, inoculation with beneficial microorganisms can enhance root health by promoting root growth, improving antioxidant capacity, enhancing rhizosphere nutrient cycling, and competitively suppressing pathogens. *Trichoderma asperellum* or plant growth-promoting rhizobacteria can significantly increase tomato root and shoot biomass, improve soil enzyme activity and nutrient availability, and effectively suppress soil-borne diseases such as *Fusarium oxysporum* (Zhang et al., 2025b). This indicates that root health is not only an inherent plant trait, but is also strongly influenced by the state of the rhizosphere ecosystem.

5.3 Improvement of root development and yield stability through grafting cultivation

In recent years, grafting cultivation has become one of the key technologies in protected tomato production for improving root performance, enhancing stress resistance, and increasing yield stability. Its core mechanism lies in using superior rootstocks with strong root systems, stress tolerance, and disease resistance to compensate for deficiencies of scion cultivars in root absorption, rhizosphere adaptation, and environmental stress tolerance. Through grafting, tomato plants can develop greater total root length, more root tips, a higher root-to-shoot ratio, and stronger root activity by relying on the rootstock, thereby enhancing water and nutrient uptake capacity and improving growth stability under adverse conditions such as low temperature and salt stress. Different rootstocks differed significantly in root traits, and grafted combinations using superior rootstocks increased yield by 14.6%-17.2% compared with nongrafted plants without reducing fruit quality; in some cases, lycopene and ascorbic acid contents were also increased.

The improvement in root development brought about by grafting is not limited to an increase in root quantity, but is more importantly reflected in optimized root function. Superior rootstocks usually have stronger root branching capacity, higher mineral nutrient uptake efficiency, and better osmotic adjustment ability, enabling them to maintain stable resource supply under unfavorable conditions. For example, in coconut coir-based cultivation systems, some tomato rootstocks can increase root and shoot biomass, chlorophyll content, and the uptake of mineral elements such as K, Ca, Mg, Fe, Mn, and Cu, thereby improving both yield and fruit quality. This indicates that grafting can fundamentally strengthen the growth basis of protected tomatoes by improving root growth and mineral nutrient acquisition.

Grafting is particularly valuable in buffering environmental stress and disease pressure. Under deficit irrigation and partial root-zone drying, grafted tomatoes can still maintain relatively high vegetative growth, mineral nutrient uptake, and fruit yield, even with a 30%-40% reduction in irrigation water, while achieving higher water-use efficiency. This indicates that the enhanced root absorption and water regulation capacity provided by the rootstock can significantly improve the resilience of resource use under protected cultivation conditions. In addition, when wild *Solanum* species are used as rootstocks, grafted plants show improvements in plant height, branch number, fruit number, average fruit weight, and yield per plant, while also exhibiting significant resistance to soil-borne diseases such as bacterial wilt (Kamble et al., 2025). Regarding adaptation to high temperatures,