Irrigation strategies directly regulate tomato growth, photosynthetic performance, and yield formation. Appropriate water supply promotes root development, nutrient uptake, photosynthesis, and dry matter accumulation, thereby improving plant growth and productivity (Lyu et al., 2025; Song et al., 2025). Studies under protected cultivation have demonstrated that suitable increases in irrigation amount can enhance plant height, stem diameter, leaf area, chlorophyll content, and fruit yield, while promoting nitrogen uptake and coordinated water-nitrogen utilization (Singh et al., 2024). However, excessive irrigation may reduce water productivity, whereas regulated deficit irrigation can maintain yield while reducing water inputs, making it an important management strategy in water-limited regions.

Water status also plays a critical role in tomato fruit development and quality formation. Severe water stress reduces fruit size, fresh weight, and water content, with particularly strong effects during cell division and fruit expansion stages (Medyouni et al., 2021). Moderate water regulation can promote the accumulation of quality-related compounds, such as soluble solids, sugars, and lycopene, thereby improving fruit flavor and nutritional quality (Lu et al., 2021; Bai et al., 2022). However, the effects of irrigation on fruit quality are jointly influenced by multiple factors, including genotype, growth stage, irrigation level, and cultivation conditions. Understanding how different irrigation strategies affect greenhouse tomato growth, yield, and quality is important for optimizing water management practices. An effective irrigation strategy should consider multiple objectives, including yield formation, quality improvement, water-use efficiency, and economic benefits.

This study analyzed the effects of different irrigation strategies on greenhouse tomato growth, photosynthetic characteristics, yield formation, and fruit quality, with the aim of exploring how water supply levels regulate plant physiological responses and production performance. The changes in growth, yield, and quality indicators under different irrigation regimes were compared to determine suitable water management ranges. The results are expected to provide theoretical support and practical guidance for water-saving, efficient, and high-quality tomato production, as well as contribute to irrigation optimization under water-limited conditions.

2 Water Requirement Characteristics and Physiological Basis of Greenhouse Tomato

2.1 Water demand patterns during tomato growth stages

Research has shown that tomato water requirements vary considerably among different growth stages (Figure 1). Chen et al. (2025) reported that sufficient water supply during the seedling and early vegetative growth stages is essential for maintaining plant height, stem diameter, chlorophyll accumulation, biomass production, and nutrient uptake, whereas insufficient water availability during the seedling and early flowering stages may restrict subsequent yield formation. Measurements of water consumption under greenhouse conditions showed that tomato plants have relatively low water demand during the seedling stage, followed by increased demand during flowering and fruit setting, with the highest water consumption occurring during fruit expansion (Lyu et al., 2025). Long-term water stress studies by Yuan et al. (2016) further demonstrated that tomato responses to drought depend not only on the severity of water deficit but also on the developmental stage at which stress occurs. Although mild water limitation during the vegetative stage can often be tolerated, water deficiency during the reproductive stage is more likely to reduce fruit set and final marketable yield (Cui et al., 2019; Ghannem et al., 2021).

Water regulation is particularly important during fruit expansion and ripening because these stages determine the balance between fruit size and quality. Zhang et al. (2025) showed that leaf net photosynthetic rate, transpiration rate, and stomatal conductance generally increase from flowering to fruit expansion, reaching their maximum levels during fruit enlargement, and then gradually decline during ripening. These changes indicate a high demand for water supply and assimilate transport during this period. Deficit irrigation applied during fruit development or ripening can improve fruit firmness, coloration, soluble solids, sugars, organic acids, and vitamin C contents, whereas severe water stress still restricts fruit growth and reduces yield (He et al., 2024).

Moderate deficit irrigation may provide a suitable balance between yield maintenance and quality improvement. A greenhouse study by Ghannem et al. (2021) found that reducing irrigation water by 20% during the second growth