resulted in the optimal fruit diameter, fruit length, fruit volume, and fresh weight, while both higher and lower irrigation frequencies reduced fruit size. In black cherry tomatoes, regulated deficit irrigation maintained fruit size and weight while increasing carotenoid content (Coyago-Cruz et al., 2022).

Generally, water deficit or saline irrigation can increase fruit firmness and improve resistance to postharvest handling. However, fruit cracking shows a nonlinear response to irrigation regimes. Both excessively frequent irrigation and severe low-frequency irrigation can significantly increase cracking incidence, with the highest rate reaching 69.53%. In contrast, moderate low-water treatments reduced cracking incidence to 8.75% (Habibi et al., 2025). These changes in fruit physical properties directly affect marketability and storage performance. Restricted irrigation can reduce electrolyte leakage, increase fruit firmness and density, and suppress ethylene production and respiration rates, thereby extending shelf life and improving transport tolerance and postharvest stability.

In processing tomatoes, regulated deficit irrigation increases dry matter content, which reduces the risk of decay during transportation and improves processing efficiency (Burato et al., 2024). Irrigation water quality also influences postharvest performance. Although saline irrigation reduces yield, it can improve fruit sweetness, acidity, overall flavor, and storage-related quality traits under simulated transportation conditions. Under hydroponic conditions, salinity stress may increase the risk of blossom-end rot by reducing calcium uptake; however, this physiological disorder does not necessarily reduce fruit marketability under certain conditions.

6 Precision Irrigation Technologies and Optimization Strategies for Greenhouse Tomato Production

6.1 Irrigation management based on crop water requirements

Irrigation scheduling based on evapotranspiration (ET) remains one of the core approaches for estimating water requirements in greenhouse tomato production. Many optimization studies use crop evapotranspiration (ETc) or a proportion of pan evaporation as irrigation criteria to balance yield, fruit quality, and water-use efficiency. Colimba-Limaico et al. (2022) reported that maintaining 100% ETc with one irrigation event per day achieved a favorable balance among yield, fruit quality, and water-use efficiency, representing a practical irrigation strategy for greenhouse tomato production. ET-based irrigation optimization can be further adjusted by incorporating crop coefficients. A four-season TOPSIS-based comprehensive evaluation study showed that, when yield, quality, and water-fertilizer productivity were considered simultaneously, the optimal pan evaporation coefficient for greenhouse tomato production ranged from 0.74 to 0.78. Under practical production conditions, suitable ranges could be extended to 0.68-0.83 in spring and 0.68-0.82 in autumn (Yu et al., 2023). In substrate cultivation systems, irrigation management based on substrate moisture variation also reflects a crop water demand-oriented approach. Liu et al. (2024) found that initiating nutrient solution supply when coconut coir moisture decreased to 70% improved fruit quality and water-fertilizer use efficiency, while causing only minor yield losses compared with the 80% moisture treatment.

Tomato plants exhibit different sensitivities to water availability during different growth stages; therefore, stage-specific irrigation management is generally more effective than applying a uniform irrigation strategy throughout the entire growth period. Li et al. (2022) demonstrated that maintaining soil moisture at 70%-90% of field capacity during the first stage and 40%-60% during the second stage achieved the highest irrigation water-use efficiency and leaf water-use efficiency, while maintaining stable yield and improving fruit quality. Another greenhouse irrigation experiment based on pan evaporation showed that full irrigation during weeks 1-2 and 21-24, combined with reduced irrigation during intermediate stages, decreased seasonal water consumption and improved water-use efficiency compared with full irrigation throughout the growth period, although full irrigation still produced the highest yield (Singh et al., 2023). A growth-stage-based coupling experiment using yellow sand substrate further indicated that irrigation amount was the primary factor affecting yield and water-use efficiency, whereas fertilizer supply during the flowering and fruit-setting stages was an important secondary factor influencing production performance (Song et al., 2025).