L and significantly lowering eutrophication risks through reduced nutrient leaching (Parada et al., 2021). Water-retaining materials, such as superabsorbent hydrogels, can enhance water and nutrient retention in the root zone and improve plant resilience under drought conditions (Idrissi et al., 2023).

Integrated water-nitrogen management is another important strategy for sustainable production. Ma et al. (2024) reported that excessive irrigation and fertilization not only increase resource losses but also elevate environmental risks, whereas optimized water-nitrogen combinations can simultaneously improve yield, water-use efficiency, fruit quality, and nitrogen-use efficiency while reducing greenhouse gas emission intensity. Therefore, future greenhouse tomato production will benefit from climate-smart management systems that dynamically adjust irrigation strategies according to crop growth stages, greenhouse microclimate, and nutrient status. Such approaches can support high yield and stable quality while improving resource-use efficiency and promoting long-term sustainable production.

8 Concluding Remarks

Irrigation management is a key factor regulating growth, yield formation, and fruit quality in greenhouse tomato production. Its effects are achieved through coordinated regulation of root activity, nutrient uptake, photosynthetic capacity, dry matter accumulation, and fruit development. Existing studies have shown that full irrigation promotes vegetative growth, increasing plant height, stem diameter, leaf area, and biomass accumulation, and contributes to higher yield production. However, excessive water supply over long periods can reduce water-use efficiency, increase the risk of nutrient leaching, and potentially impair fruit quality due to excessive vegetative growth. Therefore, irrigation management in greenhouse tomato production should focus on balancing water input and production benefits according to crop requirements and production objectives.

Moderate deficit irrigation provides an effective approach for balancing yield, water-use efficiency, and fruit quality improvement. Studies have demonstrated that mild water limitation can induce adaptive responses, including increased root-to-shoot ratio, enhanced water acquisition capacity, and promoted accumulation of quality-related compounds, thereby improving water productivity while maintaining relatively high yield levels. Particularly during fruit ripening, moderate reductions in irrigation commonly promote the accumulation of soluble sugars, soluble solids, vitamin C, lycopene, and phenolic compounds, improving fruit flavor and nutritional value. However, responses to water regulation are strongly dependent on growth stage and genotype, and excessive water deficit can restrict cell expansion, reduce fruit size, and decrease marketable yield.

Current irrigation optimization strategies in greenhouse tomato production are gradually shifting from conventional experience-based management toward precision and intelligent approaches. Irrigation systems based on evapotranspiration models, soil moisture monitoring, sensor control, the Internet of Things, and machine learning can provide real-time regulation according to crop status and greenhouse environmental changes, thereby improving water-use efficiency and production stability. Meanwhile, irrigation management should be integrated with fertilization, root-zone regulation, and greenhouse microclimate control to further enhance production efficiency through coordinated water-nutrient management and environmental regulation.

The core objective of greenhouse tomato irrigation strategies is to achieve a dynamic balance among yield, quality, resource-use efficiency, and economic benefits under different production conditions. Future research should further clarify irrigation response patterns across different cultivars, growth stages, and environmental conditions, and develop more precise decision-making systems by integrating multi-source sensor data with intelligent models. In addition, greater attention should be given to water recycling, water-nitrogen coordination, and long-term ecological benefits to promote greenhouse tomato production toward higher efficiency, greater stability, and long-term sustainability.

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