may still reach 6%-53% (Kürklü et al., 2025). Insufficient or fluctuating light conditions can also reduce dry matter production and affect fruit quality.

In addition to environmental factors, protected tomato production systems generally require high inputs of water, fertilizers, and energy. If management practices do not match crop requirements, resource-use efficiency may decline and environmental pressure may increase (Avasiloaiei et al., 2025). Population structure and canopy management practices, such as plant spacing, topping, and leaf pruning, can influence light interception capacity, source-sink relationships, and fruit load, thereby regulating yield and quality formation. From the perspectives of crop production science and genetic breeding, yield stability in protected tomatoes depends on key traits such as population structure, light interception efficiency, and dry matter production capacity. These traits are not only controlled by genetic background but are also regulated by the protected environment and cultivation management. Different tomato varieties show significant differences in their ability to maintain fruit set and yield under variations in temperature and microclimatic conditions (Ali et al., 2025).

This study aims to explore the key cultivation traits and their regulatory mechanisms involved in achieving high and stable yields in protected tomato production. It particularly focuses on analyzing the linkage between traditional cultivation experience and findings from modern genomics research. From the perspective of plant traits, the study systematically summarizes the main factors influencing yield stability and analyzes their underlying regulatory bases through genetics and physiological ecology, thereby providing a theoretical basis for constructing a high-yield and stable-production technological system integrating traits-genes-management practices. In addition, this study also examines the roles of integrated regulation strategies-such as climate control, supplemental lighting, integrated water and fertilizer management, and intelligent monitoring and decision-making technologies-in protected tomato production to improve production efficiency, enhance resource-use efficiency, and stabilize fruit quality. Through a systematic summary of cultivation traits related to high and stable yields and their regulatory points in protected tomato production, this study aims to provide scientific references for optimizing protected cultivation management strategies, promoting the breeding of facility-adapted varieties, and developing precision cultivation technologies.

2 Plant Growth Trait Foundations for High and Stable Yields in Protected Tomato Production

2.1 Effects of plant vigor and architecture on canopy photosynthetic efficiency

The achievement of high and stable yields in protected tomato production depends on both strong plant vigor and well-optimized plant architecture. Plant vigor is reflected in traits such as stem elongation rate, leaf expansion capacity, internode formation rhythm, and the ability to sustain branching, flowering, and fruiting. Together, these traits determine the efficiency of plant acquisition of light, spatial resources, and nutrients. The greenhouse environment partially buffers external climatic variability, allowing tomatoes to maintain strong vegetative growth potential. However, excessive vegetative vigor often leads to canopy closure, increased self-shading in upper leaves, and insufficient light penetration to middle and lower canopy layers, ultimately reducing canopy photosynthetic efficiency and dry matter accumulation. Even under similar total leaf area, canopy photosynthesis remains highly sensitive to structural traits, including internode length, leaf size, leaflet morphology, inclination angle, and spatial arrangement. Yield stability therefore depends not on leaf area alone, but on whether a structurally optimized effective leaf area can establish a balanced light distribution within the canopy. Moderate increases in internode length, improved leaf length-to-width ratio, and optimized leaflet arrangement can create a more open canopy and enhance vertical light penetration, thereby improving overall photosynthetic efficiency and dry matter production.

From a population perspective, plant architecture influences not only light interception at the individual level but also the distribution and utilization of radiation within the entire canopy. An ideal architecture typically features an upright stem, moderate internode length, evenly distributed leaves, and upper leaves that are extended but not excessively horizontal, promoting a balanced vertical light gradient. The research conducted by Zhang et al. (2022) based on the functional-structural plant model (FSPM) indicates that the combination of longer internodes and