narrower leaves reduces excessive shading in the upper canopy and redistributes light toward middle canopy layers, improving photosynthetic performance at both plant and population scales. This has led to the concept of a photosynthetic ideotype for greenhouse tomato cultivation. Further studies demonstrate strong interactions between planting configuration and plant architecture. Planting pattern, spacing, and row orientation often exert greater effects on canopy radiation interception and photosynthesis than individual traits alone. When optimized together with appropriate architecture, these factors produce synergistic effects (Zhang et al., 2024a).

In high-density, long-cycle production systems, plant architecture plays a critical role in maintaining canopy photosynthetic efficiency. Excessive density combined with luxuriant growth accelerates light attenuation within the canopy, leading to premature senescence of lower leaves and reduced photosynthetic contribution, ultimately compromising fruit set continuity and yield stability. Conversely, optimizing plant architecture and planting configuration-such as adjusting row spacing, orientation, and canopy thickness-can significantly enhance light interception, promote dry matter accumulation, and improve fruit quality. Yield increases of approximately 3.92%-9.78% have been reported under optimized configurations across different seasons (Li et al., 2024). Therefore, achieving high and stable yields in protected tomato production requires moderate and stable plant vigor combined with a well-balanced architecture that supports both efficient light interception in the upper canopy and adequate light penetration to lower canopy layers.

2.2 Regulatory effects of internode length and leaf distribution on ventilation and light conditions

Internode length is a key structural trait shaping plant architecture in protected tomatoes. It determines the three-dimensional distribution of leaves and influences canopy porosity, light penetration, and the surrounding microclimate. Moderate internode length promotes uniform vertical leaf stratification, reduces leaf overlap, and enhances the penetration of scattered light into lower canopy layers. When internode length increases from approximately 7 cm to 10-12 cm, the canopy becomes more open, vertical light penetration improves, and canopy photosynthetic efficiency can increase by about 10%, particularly under high radiation conditions. Moreover, the combination of longer internodes and narrower leaves facilitates the redistribution of light from upper to middle canopy layers and fruit-bearing zones, enhancing their photosynthetic contribution without substantially reducing total light interception. These findings indicate that internode length functions not only as a morphological trait but also as a key structural regulator of canopy light distribution.

Leaf distribution patterns further regulate canopy ventilation and light conditions. Due to their large and compound structure, densely arranged tomato leaves can create localized shading and high-humidity zones. A balanced leaf arrangement maintains sufficient photosynthetic area while creating interleaf spaces that enhance air circulation, reduce humidity, and shorten leaf wetness duration, thereby lowering the risk of diseases such as gray mold and leaf mold. Variations in leaf area distribution, leaflet inclination, and plant-to-plant structural heterogeneity influence the uniformity of light absorption within the canopy. Although their effects on total canopy photosynthesis may be smaller than those of planting density or spacing, they can significantly alter local microenvironments and inter-plant variability, ultimately affecting yield stability. Therefore, leaf distribution uniformity and canopy ventilation capacity should be considered key criteria in evaluating plant architecture in protected tomato systems.

Beyond light regulation, canopy openness also influences airflow, heat dissipation, and temperature stratification. As canopy closure increases, ventilation efficiency declines, leading to the accumulation of heat and humidity-especially under high-temperature conditions. Li et al. (2025) conducted field measurements and aerodynamic studies show that moderate removal of older leaves can modify airflow pathways, increase within-canopy wind speed, and reduce localized heat accumulation, indicating that leaf management is essentially a process of microclimate optimization rather than simple defoliation. Leaf area index (LAI) serves as an integrative parameter linking leaf distribution, light interception, and ventilation. Excessively low LAI limits photosynthetic capacity, whereas excessively high LAI intensifies shading. Maintaining LAI within an optimal range of approximately 3.0-3.5 allows a balance between light interception and internal light penetration. Thus,