

2 Effects of Planting Density on Tomato Plant Architecture

2.1 Effects on plant morphological characteristics

Planting density clearly alters tomato plant morphological characteristics, but the direction and magnitude of change depend on genotype, stage, and production system. Across several experiments, higher density generally increased plant height or internode elongation while reducing stem thickness, compactness, or vegetative mass per plant, which is consistent with a shade-avoidance response under stronger neighbor competition. In controlled-environment tomato, increasing density promoted internode elongation and higher slenderness, while basal stem diameter declined, showing that plants became less compact as canopy crowding intensified (Karpe et al., 2024). A parallel density study under combined drought and non-drought conditions likewise found taller plants, longer internodes, reduced stem diameter, and lower leaf mass per area at high density, reinforcing that these responses are robust morphological signatures of dense planting (Francesca et al., 2026).

Field and greenhouse studies broadly support the same pattern, although not every trait responds in every environment. In Vietnam, the highest density tested produced the greatest plant height, whereas a moderate density gave better fruit set and yield, indicating that taller growth under crowding does not necessarily reflect superior whole-plant performance (Tuan and Mao, 2015). In a spring film greenhouse, increasing density raised plant height but reduced vegetative mass per plant, and the best overall biometric balance was reported at 3.5 plants/m² (Sievidov and Sievidov, 2020). Other studies show that density effects can be trait-specific or weak under some conditions: one field trial found significant density effects on most agronomic traits except plant height, and another reported no significant differences among planting distances for plant height, branches, leaves, flowering age, stem diameter, or harvested fruit traits (Ariefin et al., 2024). Seedling studies add that density strongly affects specific leaf area, health index, and dry matter ratios, whereas plant height and leaf area can be driven more by facility conditions than density alone (Zhang et al., 2025), so morphological responses should be interpreted in relation to environment and developmental stage.

2.2 Effects on leaf arrangement and canopy structure

Planting density reshapes leaf arrangement and canopy structure mainly by changing leaf area deployment, leaf area index, mutual shading, and the vertical distribution of light within the stand. High density increased LAI sharply in dwarf tomato, reaching 6.7 compared with about 2.1–2.2 at lower-density treatments, while also accelerating loss of shaded basal leaves (Karpe et al., 2024). The same study showed that low density produced much greater leaf area and leaf dry weight per plant, indicating that sparse stands favor larger individual canopies, whereas dense stands favor greater canopy occupation per unit ground area rather than per-plant expansion. This canopy trade-off is central to tomato density responses because canopy coverage determines light interception, but excessive crowding worsens lower-canopy shading and leaf senescence (Jiang et al., 2017).

Several studies suggest that optimum canopy structure is achieved not by maximizing density indefinitely, but by reaching an LAI range that improves interception without excessive self-shading. For processing tomato, an LAI of about 4–5 has been identified as ideal for light interception and productivity, and densification early in the season was suggested where LAI is otherwise suboptimal (Evangelista et al., 2025). In winter single-truss tomato, the densest fixed treatment produced the tallest stems but the lowest leaf area and shoot dry weight, whereas movable or lower-density arrangements improved the lower-canopy light environment (Jiang et al., 2017). Modeling work further indicates that canopy performance depends not only on density per se but also on structural traits such as internode length and leaf dimensions, because longer internodes and optimized leaf shape can improve within-canopy light penetration and interception (Zhang et al., 2022). Recent imaging research also highlights LAI as a practical structural indicator for greenhouse tomato management, although measurement accuracy can decline when leaf density and occlusion increase (Naito et al., 2025).

2.3 Effects on photosynthetic characteristics and dry matter accumulation

Planting density affects photosynthetic characteristics primarily through its control over light interception, light distribution, and assimilate availability per plant. Greenhouse synthesis shows that total dry matter production is closely linked to intercepted light, with light interception determined largely by LAI and canopy light extinction