umbrella-shaped trellis derived from overhead pergolas more than doubled yield relative to a traditional pergola while maintaining external fruit quality and improving internal quality through better shading of the fruiting canopy (Deng et al., 2023). Outside orchards, innovative tower-based vertical cultivation devices partition three-dimensional space into chambers with differentiated light, temperature and humidity, achieving large water savings and more efficient use of vertical volume, which conceptually parallels multi-tier trellising for high-density vine crops. Together, these developments indicate that future Luffa trellis designs may evolve toward configurable, three-dimensional systems that fine-tune light interception, labor efficiency, and fruit quality beyond what simple horizontal or single-plane vertical trellises can provide.

4 Effects of Trellising Systems on Sponge Gourd Growth and Development

4.1 Effects on plant morphological characteristics

Trellising and training systems markedly shape vine architecture, vegetative growth, and canopy structure in climbing crops, with clear implications for Luffa and related cucurbits. In organically grown ridge gourd, six trellis types produced distinct vine growth responses: the farmer-standard pandal trellis favored somewhat more vigorous vegetative growth, whereas a T-trellis gave slightly higher yields and better fruit quality despite similar growth metrics, indicating that subtle architectural changes can redirect assimilates without necessarily increasing total vine size. In greenhouse cucumber, a single-head training system produced the longest vines and largest leaf area at multiple growth stages compared with umbrella and low-middle systems, showing that more vertical, simplified training can promote extension growth and canopy expansion under protected conditions (Shivaraj et al., 2020).

Similar structural effects are evident in perennial trellised fruit crops. In dragon fruit, a single-pole training system promoted “balanced growth,” whereas a T-trellis enhanced vegetative expansion with wider plant spread but also induced stress symptoms such as canopy overheating and photodamage, illustrating that vigorous morphological growth can be decoupled from functional canopy health (Karunakaran et al., 2026). In grape, fan-shaped and divided-canopy trellis systems increase shoot vigour, shoot leaf area and total leaf area per vine relative to vertical single-curtain systems, confirming that three-dimensional trellis designs can generate larger, more voluminous canopies that must then be managed to balance vegetative and reproductive sinks.

4.2 Effects on leaf photosynthetic performance

Trellis-induced canopy architecture strongly conditions the light environment and thus leaf-level photosynthesis. In high-density mango, a Y-trellis form improved photosynthetic photon flux density in both upper and lower canopy layers compared with open-centre and espalier canopies, and this arrangement supported higher net photosynthetic rates and stomatal conductance at both heights, indicating that moderate light interception with better vertical distribution enhances whole-canopy gas exchange (Kishore et al., 2023). In dwarf mango trained as open-vase versus espalier-trellis, digital canopy modelling showed that the espalier system increased light distribution efficiency per unit leaf area and, when normalized by leaf area, achieved a small productivity advantage, underscoring that trellis geometry can improve photosynthetic efficiency even when total leaf area is reduced (Cheesman et al., 2025) (Figure 2).

Comparative studies in pear and peach further link trellis systems with photosynthetic performance. Pear trees trained on a flat-type trellis exhibited higher net photosynthetic rates than a freestanding system, especially in interior canopy leaves on the sunny side, and transcriptomic analyses implicated enhanced light-harvesting and circadian-clock regulation under the open trellis architecture. In peach, a planar 2D “fruiting wall” training system had lower overall light interception than a 3D Quad-V canopy but achieved 15%-20% higher net photosynthetic rates and better water-use efficiency, particularly maintaining higher photosynthetic efficiency in the shaded lower canopy, illustrating that trellis-driven light uniformity can outweigh total intercepted radiation for photosynthetic performance (Chatzieffraimidis et al., 2025).

4.3 Effects on flowering, fruit set, and assimilate allocation

Training and trellising interact with flowering and fruiting through their influence on canopy microclimate, source–sink relations, and competition among reproductive structures. In dragon fruit, a single-pole system