and longer vines than ground trailing, underscoring the importance of lifting the canopy to exploit vertical space and reduce shading within the foliage layer (Thakur and Pathania, 2025). Beyond yield, trellising simplifies management operations, enables better disease surveillance, and facilitates integration with practices such as mulching, nutrient management, and direct sowing layouts that orient trellis mesh to optimize natural light exposure and space use in diverse soils and climates.

3 Major Trellising Systems and Their Technical Characteristics

3.1 Horizontal pergola trellis system

Horizontal pergola or bower systems create an overhead canopy that maximizes interception of solar radiation and leaf area, which can substantially increase yield and fruit quality in climbing crops. In sponge gourd, above-ground bower training produced the highest yield, fruit number, and vine length compared with netting and ground trailing, indicating that an overhead horizontal framework effectively exploits the vigorous vine habit (Thakur and Pathania, 2025). Similar pergola systems in grape and kiwifruit have been associated with higher productivity and improved quality composition, supporting the general principle that spreading canopies on horizontal roofs enhances assimilation and crop performance when light is abundant (Danko et al., 2024).

However, traditional pergolas can be labor-intensive and difficult to manage due to their height and dense canopy, which complicates pruning, harvesting and plant protection. In grapevine, horizontal pergola trellises are reported to increase yields 2-3 times relative to vertical systems but require more time-consuming manual operations with arms raised above the head, highlighting ergonomic and cost constraints. New “mobile pergola” or modified overhead designs attempt to retain the yield gains of horizontal canopies while permitting temporary vertical positioning during pruning and harvesting, illustrating a broader trend toward pergola-inspired but more manageable systems that could be relevant for intensive Luffa cultivation.

3.2 A-frame and fence trellis systems

T-type and A-frame trellises represent intermediate architectures between horizontal pergolas and strictly vertical systems, often using sloped or cross-arm structures to support hanging vines. In ridge gourd, a T-trellis achieved the highest marketable yield (24.8 t ha^{-1}) among six systems, outperforming ground trailing and simple staking while providing a better benefit-cost ratio than the locally common pandal system, which produced similar yields but higher costs (Sen et al., 2023). These results suggest that for Luffa crops, moderately elevated, cross-armed trellises can balance canopy expansion, fruit exposure, and construction costs, making them attractive for organic and smallholder systems.

For other cucurbits, A-frame, V, and inverted-V trellises have been tested alongside bower, netting, and cage systems, with bower often giving the highest yield per hectare but inverted-V trellises showing superior benefit-cost ratios, indicating economic advantages despite slightly lower yields (Singh et al., 2023). Farmers may also use simple fence-like supports; while detailed quantitative data for fence systems in Luffa are limited, experiences from ridge gourd and bottle gourd imply that structured supports consistently outperform ground trailing in fruits per plant, total yield, and net returns, pointing to broad benefits of moving vines off the soil surface.

3.3 Vertical training and innovative three-dimensional trellis systems

Strictly vertical or high-wire trellising arranges shoots upward along single or double planes, improving plant density, pollination efficiency, and management access. In sponge gourd, cultivation on a 3-m high trellis increased yield by 33.41% over control and produced yields comparable to bower systems, leading to recommendations for both bower and high trellis training in commercial practice. Vertical training in cucumber and bottle gourd similarly enhanced fruit number per plant, total yield and uniformity, especially when combined with optimized plant growth regulators or bower-type support, underscoring the value of precise canopy orientation in cucurbits (Manna and Singh, 2024).

Emerging three-dimensional and multi-layered systems extend vertical concepts by creating stacked or umbrella-shaped canopies that manage light gradients and microclimate more precisely. In kiwifruit, an