8.3 Prospects for trellising cultivation in sustainable and high-efficiency production

Trellis systems are increasingly framed as a cornerstone of sustainable intensification, enabling higher yields per unit ground area and more efficient use of vertical space. A recent agrivoltaic design study noted that using trellises can double or triple yield per acre while reducing diseases and pests, easing harvest, and producing cleaner crop products, and proposed low-cost wood-based PV racking that simultaneously functions as trellis support and irrigation/fertigation infrastructure. For small and marginal farmers, multilayer trellis farming and off-season trellis-based production have repeatedly outperformed traditional systems in net returns and profit, suggesting a pathway to livelihood improvement and more resilient production systems (Singh et al., 2024).

Within Luffa specifically, sponge gourd has been identified as a high-potential underutilized cucurbit whose yield and fruit quality are strongly enhanced by trellising, and which can be grown with low external inputs and minimal pesticide use, aligning well with organic and low-input strategies. Broader reviews of dioecious cucurbits emphasize that integrating trellising with mulching, biofertilizers and growth regulators holds "immense potential" for future vegetable production and markets, particularly for minor cucurbits cultivated by smallholders, indicating that optimized trellis systems can be central to high-efficiency, resource-conserving production chains (Nayak et al., 2024).

9 Future Perspectives and Conclusions

Existing studies on Luffa and related cucurbits show that trellising can clearly increase yield and improve fruit quality, but the evidence base is still narrow and fragmented. Most work focuses on short-term comparisons of a few trellis designs at single sites and seasons, often without detailed characterization of plant physiology, microclimate, or fruit quality beyond basic traits. For sponge gourd, for example, horizontal systems were identified as promising, yet evaluations were confined to limited environments and short time frames, with explicit calls to repeat experiments across more seasons and to expand trait coverage. Another major limitation is that trellis research on Luffa is largely decoupled from other technological advances in crop management. Studies rarely integrate trellising with rootstock use, controlled environments, or detailed monitoring of water and nutrient dynamics, even though grafting and soilless culture have proved effective for improving yield and quality in closely related cucurbits. Economic and labor aspects are also underexplored: while some work on ridge gourd has compared benefit-cost ratios among trellises, there is little quantitative analysis of labor ergonomics, long-term structural costs, or adoption barriers among smallholders who still rely on fences or trees for support.

Rapid progress in precision agriculture and IoT provides a rich toolbox that has scarcely been applied to Luffa trellis systems. Cloud-based platforms and wireless sensor networks have already been used to monitor greenhouse microclimate, automate control, and increase cucumber yield and quality in soilless systems, demonstrating the potential of data-driven management. Similar sensor architectures, combined with simple actuators, could be adapted to trellised Luffa to control irrigation, fertigation, and possibly shading or ventilation based on real-time canopy and weather data. Beyond basic monitoring, next-generation "smart trellises" could embed low-cost sensors and edge computing into the support structure itself. Reviews of smart sensors and IoT in agriculture emphasize the value of continuous measurements of plant stress, soil moisture, and microclimate, coupled with artificial intelligence for predictive decision-making. Integrating these capabilities with modular, adjustable trellis designs would allow dynamic management of canopy density, pruning, and harvest timing in response to incoming light, temperature, and plant status, linking structural design with automation and making intensive Luffa systems more resilient and resource-efficient.

Overall, research to date indicates that lifting Luffa vines from the ground onto engineered trellises reliably increases total yield, mainly by raising fruit number without compromising basic external quality. However, the optimal trellis configuration clearly depends on cultivar, environment, and production goals, and current evidence is insufficient to define robust design principles across regions. Experience from ridge gourd and other cucurbits suggests that relatively simple, moderately elevated systems can offer a favorable balance of yield, fruit quality, and cost, but systematic comparisons with horizontal pergolas, vertical walls, and three-dimensional designs remain scarce. Future studies on Luffa trellising should therefore be multi-season and multi-site, combining