

Integration with temperature and greenhouse control systems is equally important. In a subtropical forcing system, controlled-environment greenhouses increased yield relative to conventional houses, and adding daytime LED supplemental lighting produced a further increase, especially during winter periods of persistent cloudiness and low solar radiation, although benefits became limited in spring under high external radiation (Nakayama and Nakazawa, 2023). More intensive combinational control that included supplemental lighting, elevated CO₂, and regulated air temperature accelerated flowering, increased fruit number, and, when paired with movable beds and higher planting density, achieved more than a twofold increase in yield per unit land area, underscoring that lighting delivers its greatest value when embedded in whole-system greenhouse optimization.

5 Canopy Light Management and Cultivation Practices

5.1 Effects of leaf removal and canopy structure optimization

Canopy structure strongly determines how much radiation reaches strawberry leaves and fruits, and fruit quality changes measurably with fruit light exposure. Under field conditions, light incidence altered flavor and antioxidant content, and the response was genotype-dependent, indicating that canopy-opening practices such as leaf removal are most likely to be effective when they improve fruit exposure without overexposing sensitive cultivars. The same study found that cultivars with larger canopies compensated by producing longer peduncles, which helped maintain a similar proportion of exposed fruits despite canopy-size differences, showing that canopy architecture itself is a plastic determinant of fruit light interception.

Broader photobiology evidence supports canopy optimization as a quality-management tool because strawberry responses depend on how light is distributed through the plant rather than on total irradiance alone. Controlled-environment studies summarized in recent review work show that tailored light strategies can optimize fruit production and consumer-desired quality traits, while wavelength-specific effects on flavonoids vary enough that better canopy light penetration should be paired with spectral management rather than treated as a stand-alone intervention (Warner et al., 2021). This logic is reinforced by shading experiments showing that low light reduces photosynthetic rate, sugar synthesis, and commercial fruit yield, implying that canopy-thinning practices that relieve self-shading can improve assimilate supply to fruit as long as total leaf area is not excessively reduced (Choi, 2021).

5.2 Influence of plant density and training systems on light distribution

Plant density is one of the clearest cultivation variables affecting canopy light distribution in strawberry, and its effects extend to photosynthesis, fruit quality, and profitability. In southern Brazil, plant spacing altered photosynthetic efficiency, production, fruit quality, and economic return, with 5-15 cm spacing providing a practical compromise for the high-quality cultivar ‘Pircinque’. In alpine mountain production, lower density increased aboveground biomass, leaf photosynthetic rate, and the number of crowns and flower trusses per plant, while fruits from low density also showed a higher color index, consistent with improved within-canopy light penetration (Soppelsa et al., 2023).

Higher density, however, often increases yield per unit land area even when individual plants receive less light and produce smaller fruit. A recent review found positive linear relationships between density and hectare-scale yield across annual hill culture, protected systems, and matted rows, with no clear upper limit imposed by light competition in most experiments, likely because inter-row spacing still allowed acceptable interception (Menzel, 2024). In hydroponic and vertical systems, higher planting density similarly reduced yield per plant but increased yield per square meter, while light limitation inside vertical structures remained a key reason why optimum density depends on greenhouse irradiance and system configuration.

5.3 Application of reflective mulching and light redistribution materials

Reflective mulches and light-redistribution materials improve the light environment around the lower canopy and fruiting zone, where direct interception is often limited. In one of the clearest demonstrations, strawberries ripened over red mulch were about 20% larger and had higher sugar-to-organic-acid ratios and higher concentrations of favorable aroma compounds than fruit over black mulch, indicating that reflected red and far-red light can directly improve flavor-related chemistry. Highly reflective polythene mulches also increased growth and yield through