

‘Shine Muscat’ depends not only on reducing vigor, but on reshaping canopy architecture into a more open and better-distributed structure (Collins et al., 2020).

Training and canopy-positioning studies support the same conclusion from a structural perspective. In grapevines, canopy manipulation is used to optimize canopy structure, balance vegetative and reproductive growth, and ensure more effective fruit exposure to sunlight (Collins et al., 2020). In a related table-grape system, the single-curtain training system reduced vegetative growth, shortened internodes, and redistributed leaf area toward the middle canopy, producing a more functionally efficient canopy than pergola training (Du et al., 2023). Under heat stress in rain-shelter ‘Shine Muscat’, trellis-system effects were also integrated canopy effects, simultaneously altering vigor, water relations, and canopy microclimate, with the upward-trained pendulous system maintaining the lowest canopy heat load and the least sunburn damage (Luo et al., 2026). Structural optimization is therefore best understood as a coordinated adjustment of shoot growth, branch density, leaf distribution, and cluster exposure, rather than simple canopy reduction (Zarrouk et al., 2024).

4.2 Effects on photosynthetic characteristics and dry matter accumulation

The clearest physiological effect of canopy optimization in ‘Shine Muscat’ is the improvement of the canopy light environment, especially under rain-shelter or facility cultivation where incoming light is often limited (Yuan et al., 2024; Li et al., 2025). In protected ‘Shine Muscat’, reflective ground film increased net leaf photosynthetic rate by 24.9% on 3309C and 35.2% on 5BB rootstocks, showing that light-environment optimization can substantially raise leaf carbon assimilation even without major changes in vegetative growth indices. Supplemental lighting also improved production performance in the same cultivar, although the mechanism was more complex: night lighting at 300 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ produced the highest yield, sugar-acid ratio, and economic return, while differences in Pn, Pmax, and apparent photosynthetic efficiency among treatments were small. This suggests that canopy-light optimization can enhance whole-vine productivity not only by increasing instantaneous leaf photosynthesis, but also by extending effective light use and improving the fruit developmental environment (Yuan et al., 2025).

Evidence from related grape systems clarifies how these changes translate into dry matter accumulation. In ‘Miguang’, the single-curtain system increased cluster-zone photon flux density, chlorophyll content, net photosynthetic capacity of basal and middle leaves at berry expansion and veraison, and assimilate distribution to fruit, while also increasing shoot soluble sugar and starch content and reducing vegetative growth (Figure 2) (Du et al., 2023). In ‘Shine Muscat’, reduced light intensity had the opposite effect: shading decreased leaf photosynthetic activity, transpiration, and stomatal conductance, reduced organic matter accumulation, and then suppressed glucose, fructose, and soluble solids while increasing malic, tartaric, and citric acids in berries (Yang et al., 2024). Heat-tolerant trellis optimization also preserved stomatal aperture, chlorophyll content, chlorophyll fluorescence, and net photosynthetic rate under prolonged heat stress, especially in the U-PT system, indicating that canopy optimization protects dry matter production by maintaining photosynthetic apparatus stability under stress (Luo et al., 2026). Grafting adds a related resilience mechanism in ‘Shine Muscat’, because grafted plants under drought maintained better water status, photosynthesis, and antioxidant defense than self-rooted plants, helping sustain assimilate production under environmental stress (Jiao et al., 2023).

4.3 Effects on fruit enlargement, maturation, and quality formation

The most direct fruit response to canopy optimization in ‘Shine Muscat’ is improved berry enlargement and more favorable ripening, but the benefit depends strongly on treatment intensity and combination. Moderate shoot-control treatments such as MC 500 mg/L or CCC 100 mg/L improved berry size, soluble solids, and the sugar-acid ratio while maintaining effective shoot control, whereas high concentrations restricted leaf and cluster development (Cheng et al., 2025). The combined Pro-Ca 300 mg/L + MC 300 mg/L treatment also increased single-berry weight, berry diameter, and SSC, supporting the idea that regulating vigor can redirect growth toward fruit development (Cheng et al., 2026). Floral cluster thinning further improved fruit development in this cultivar: thinning to 4 cm promoted fruit growth and maintained an appropriate sugar-acid ratio, whereas 5 cm thinning left more berries but produced smaller berries and a lower sugar-acid ratio (Choi et al., 2023). More broadly, low crop load increased single-berry weight, sugar-acid ratio, phenolics, antioxidant activity, terpene and