8.2 Empirical analysis of moderate leaf removal on fruit quality improvement

Moderate basal leaf removal is widely used to alter cluster microclimate without excessively reducing source capacity. In Cabernet Sauvignon, removal of four basal leaves at fruit set (LR4) increased single-leaf photosynthesis and resulted in grapes with higher Brix and greater extractable anthocyanins and polyphenols compared with the untreated control, showing that a modest reduction in leaf area can enhance both technological and phenolic ripeness (Cataldo et al., 2021). A more severe treatment (removal of eight leaves) increased titratable acidity and did not further improve color compounds, indicating that beyond a certain threshold defoliation may cool clusters and slow sugar and phenolic accumulation.

Regional trials in continental Croatia likewise demonstrated quality gains from moderate cluster-zone defoliation in Merlot. Basal leaf and lateral removal at berry set increased UV radiation in the fruiting zone, which did not change sugar concentration but significantly reduced titratable acidity and enhanced skin phenols, anthocyanins, flavonols, and flavan-3-ols, particularly in the cooler ripening season (Anić et al., 2021). A multiyear transcriptomic analysis of pre-flowering defoliation further showed consistent up-regulation of genes involved in flavonoid biosynthesis and hormonal signaling across sites and cultivars, supporting the robustness of early leaf removal in improving composition when carefully calibrated to climate and vigor (Zenoni et al., 2017).

8.3 Successful regional practices of canopy optimization

Successful canopy optimization strategies are strongly region- and climate-specific, combining training choice with targeted summer operations. In rainy eastern China, a single-curtain (SCT) system outperformed a pergola for ‘Miguang’ by increasing photosynthetic photon flux density in the cluster zone, enhancing chlorophyll and leaf area of mid-shoot leaves, and promoting assimilate allocation to fruit, which translated into higher berry soluble solids and lower titratable acidity under humid, low-light conditions (Du et al., 2023). In cold semiarid Ukraine, free-growing shoots on a 1.2-m cordon created a canopy with optimal leaf index and relatively low transpiration, improving photosynthetic apparatus activity and yield stability in dry years, thus enabling non-irrigated production (Shtirbu et al., 2022).

In warm and hot regions, canopy modifications increasingly aim to buffer heat and radiation while maintaining efficient photosynthesis. Leaning VSP canopies 30° toward the west in a temperate-warm Spanish site increased morning radiation on Bobal vines and reduced afternoon heating, resulting in musts and wines with higher acidity, lower pH, and greater color intensity, anthocyanins, polyphenols, and aroma esters than standard VSP (Ferrer-Gallego et al., 2024). Systematic reviews of adaptation strategies underline that combining such architectural changes with irrigation and other levers at multiple scales offers the most promising path to maintain productivity and quality under climate change while respecting local constraints and grower capacity (Naulleau et al., 2021).

9 Conclusions and Future Perspectives

Research on canopy structure in grapevines shows that training system, geometry and density jointly determine light interception, whole-canopy gas exchange and, ultimately, fruit composition. Systems such as single high wire, high quadrilateral or pergola can achieve higher whole-canopy net CO_2 exchange per unit leaf area and better drought resilience than traditional VSP, while still reaching good fruit maturity in warm climates. Across systems, the best predictor of photosynthesis is the amount and timing of direct light intercepted by the canopy, whereas transpiration is tightly related to vapor pressure deficit, highlighting the central role of canopy architecture in mediating climate effects. Canopy manipulation techniques including defoliation, shading nets, and early canopy management at pre-bloom further refine this structural control over microclimate and source–sink balance. Basal defoliation at fruit set can increase single-leaf photosynthesis, adjust berry temperature, and improve soluble solids and anthocyanin extractability when severity is moderate. Shading nets and altered training height or leaning reduce berry temperature and slow ripening, often preserving acidity and preventing flavonoid degradation under hot conditions. Early leaf removal or shoot trimming at specific positions along the shoot modulates fruit set, bunch compactness and berry composition, showing that both the amount and spatial distribution of leaf area are critical for balancing yield and fruit quality.