apical shoots to frost while preserving basal buds, thereby reducing damage and sometimes delaying maturity into a cooler window (Poni et al., 2022). These approaches modify canopy structure and functioning over the whole cycle, with cascading effects on photosynthesis and berry quality.

6.2 Leaf removal and shoot thinning techniques

Leaf removal and shoot thinning are key summer pruning operations used to adjust canopy density, fruit exposure, and the source–sink balance. Pre-bloom leaf removal and shoot trimming, applied at different positions along the shoot, differentially altered fruit set, berry number per bunch, berry weight, and composition by modifying local source leaves and assimilate supply (Mataffo et al., 2023). Basal defoliation at fruit set in Cabernet Sauvignon increased single-leaf photosynthesis, changed berry temperature profiles, and shifted soluble solids, titratable acidity, and phenolic composition, with moderate defoliation often favoring higher Brix and extractable anthocyanins (Figure 3) (Cataldo et al., 2021).

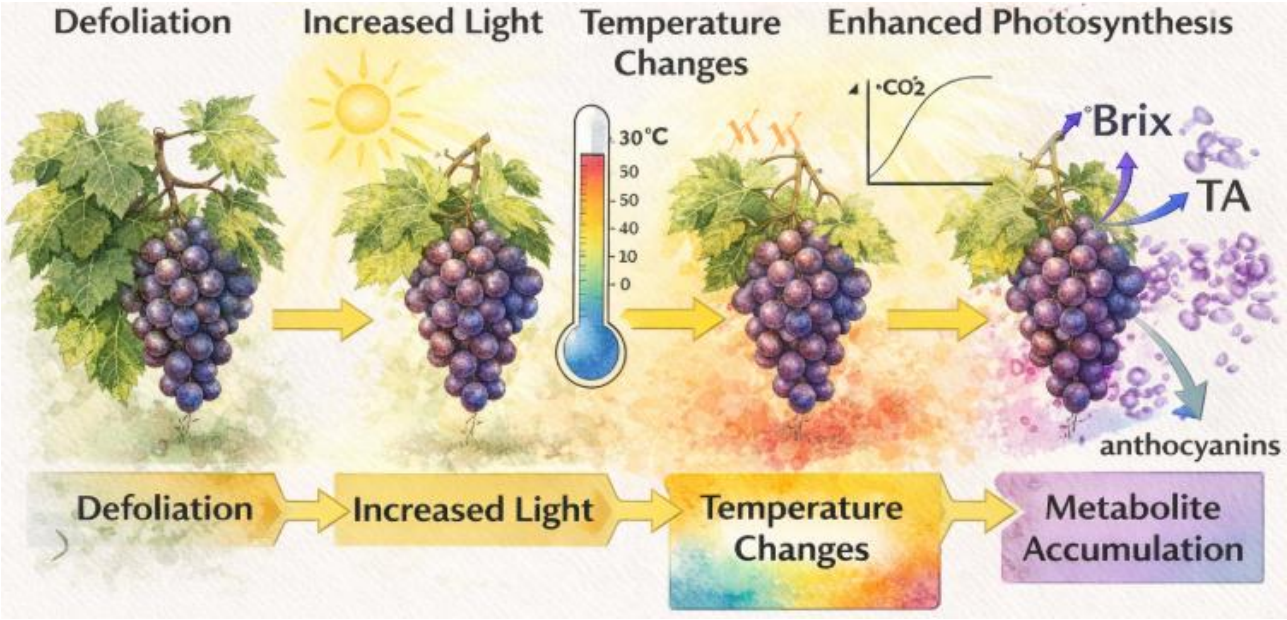

Figure 3 Effects of basal defoliation on fruit-zone microclimate and berry composition, including changes in temperature, photosynthesis, and metabolite accumulation (Adopted from Cataldo et al., 2021)

Shoot thinning and its combination with defoliation can open the fruiting zone and reduce leaf layer number, but their effects on yield and composition are not uniform across climates and seasons. In Montepulciano, shoot thinning alone reduced canopy density but did not consistently reduce yield or improve fruit composition, whereas shoot thinning combined with pre-flowering defoliation decreased yield, reduced Botrytis incidence, and improved berry composition, with carry-over effects on yield the following year (Silvestroni et al., 2018). A broader study showed that leaf removal and shoot thinning modify bud light interception and carbohydrate status, thereby influencing bud fruitfulness and inflorescence primordia size, which link current-season canopy management to future yield potential (Collins et al., 2020).

6.3 Training systems and shoot positioning

Training systems and shoot positioning define canopy geometry, affecting total leaf area, exposed leaf area, and the proportion of sunlit versus shaded leaves. A comprehensive review highlights that divided canopy systems and alternatives to classical VSP can simultaneously increase yield and improve fruit composition by optimizing the light microclimate of leaves and clusters (Reynolds and Heuvel, 2009). Recent whole-canopy gas-exchange work comparing VSP, single high wire, and pergola structures in Sangiovese showed that, per unit leaf area, single high wire canopies achieved higher net CO_2 exchange and better drought resilience, whereas pergola attained superior fruit maturity at similar yields (Del Zozzo et al., 2024).