Shoot orientation and trellis form interact strongly with cultivar architecture to determine light interception and fruit exposure. Three-dimensional modeling of VSP versus non-positioned systems (gobelet and bilateral free cordon) demonstrated that free-standing canopies can have higher light interception and a greater proportion of sunlit leaf area at intermediate LAI, particularly benefiting cultivars with procumbent shoots (Louarn et al., 2008). In a humid Chinese region, a single-curtain system increased cluster-zone PPFD, improved leaf chlorophyll content and mid-shoot photosynthetic capacity, and enhanced assimilate allocation to fruit compared with a pergola system, resulting in higher soluble solids and more favorable vegetative–reproductive balance (Du et al., 2023). Thoughtful choice of training and shoot positioning thus provides a structural framework within which pruning, leaf removal, and thinning can fine-tune canopy function and fruit quality.

7 Interactive Effects of Environmental Factors and Canopy Structure

7.1 Influence of light intensity and climatic conditions

Light intensity and thermal regime interact with canopy structure to shape photosynthesis and berry composition. Row orientation modifies the angle and timing of solar radiation on canopy walls, creating distinct patterns of leaf water potential and photosynthetic activity among orientations and canopy sides (Hunter et al., 2020). In Shiraz, canopies oriented north-south or east-west showed the highest average photosynthesis, while south- and southwest-facing sides had lower photosynthetic output under less favorable radiation and temperature conditions. At the berry level, different orientations and exposure patterns generate contrasting pulp temperatures, which in turn drive differences in sugar ripening and skin phenolics (Hunter et al., 2021).

Climate warming increases the risk of radiative excess and high berry temperatures, which can accelerate sugar ripening but compromise acid balance and color stability (Miccichè et al., 2023). In warm regions, porous or divided canopies that temper afternoon heat loads can support better phenolic accumulation than highly exposed VSP walls, especially when combined with adjusted row orientation (Reynolds and Heuvel, 2009). Shading nets applied at fruit set reduced berry temperature, delayed phenology, increased must acidity and decreased pH, illustrating how reduced light and moderated heat can slow ripening and modify grape composition under hot conditions. Such findings highlight the need to match canopy openness and exposure with local radiation and temperature regimes.

7.2 Regulation of canopy structure by water and nutrient supply

Water availability strongly regulates canopy size, density, and thus microclimate. In potted Sangiovese, reduced irrigation to 50%-35% of full supply decreased net CO_2 exchange and transpiration, especially in VSP and pergola geometries, while single high-wire canopies maintained higher photosynthetic efficiency and drought resilience (Figure 4) (Del Zozzo et al., 2024). Field trials combining six trellis systems with three irrigation levels showed that higher applied water increased leaf area, berry size, and yield, whereas low water (25% ET replacement) limited vegetative growth but enhanced berry anthocyanin and flavonol concentrations (Yu et al., 2022). These responses indicate that irrigation regimes co-define canopy architecture and its functional quality in warm climates.

Nutrient status, particularly nitrogen, interacts with water to control vigor and canopy development. Reviews of deficit irrigation and vine mineral nutrition emphasize that limited water combined with moderate nitrogen can reduce canopy size, berry size, and disease incidence, while accelerating ripening and improving color (Keller, 2005). Growth is more sensitive than photosynthesis to both water and nitrogen shortage, so controlled deficits can restrain excessive canopy expansion and prevent overly dense, shaded canopies. However, severe water or nitrogen limitation may reduce assimilate supply and lead to excessive fruit exposure, suggesting that water-nutrient management must be finely tuned to sustain a functional canopy structure.

7.3 Adaptability of canopy structures in different ecological regions

The suitability of canopy systems differs among ecological regions, depending on temperature, radiation, and water availability. In Californian warm climates, single high-wire and high-quadrilateral trellises achieved greater yields and higher berry anthocyanin derivatives than conventional VSP, while increased crown porosity in VSP raised flavonol levels but was associated with lower photosynthetic capacity and translocation efficiency (Yu et al.,