

whereas optimized architectures maintain adequate total interception while improving light penetration and use efficiency. Through informed selection of training systems and targeted canopy management, growers can refine light interception, enhance photosynthetic efficiency, and better support desirable fruit composition.

## 4 Effects of Canopy Structure on Grapevine Photosynthesis

### 4.1 Changes in leaf photosynthetic characteristics

Canopy structure alters the light and thermal environment around leaves, driving changes in net photosynthetic rate ( $P_n$ ), stomatal conductance ( $G_s$ ) and transpiration ( $T_r$ ). Opening dense Cabernet Sauvignon canopies increased photon flux density and daily light integral, leading to higher photosynthetic rate and transpiration during vegetative growth (Hernández-Ordoñez et al., 2024). Under field shading, reduced PAR lowered  $P_n$ , transpiration and stomatal conductance, while light compensation and saturation points shifted downward, indicating acclimation to low light but with reduced radiation-saturated  $P_n$ .

Stomatal regulation links these structural and microclimatic shifts to water use. At the canopy scale, bulk stomatal conductance varies diurnally with vapor pressure deficit and net radiation, and declines seasonally as soil water deficits develop (Gowdy et al., 2022). Grapevine canopies can reduce conductance exponentially with increasing vapor pressure deficit to stabilize transpiration, maintaining near-constant water loss despite large atmospheric demand changes. Progressive drought reduces  $P_n$  and  $T_r$  first in sun-exposed leaves, and later across the canopy, with stomatal conductance emerging as a key integrative indicator of photosynthetic down-regulation in C3 plants including grapevine (Medrano et al., 2002; Escalona et al., 2020).

### 4.2 Differences in photosynthesis among leaves at different canopy layers

Light gradients created by canopy structure cause strong vertical differences in leaf gas exchange. In overhead parronal systems, the highest canopy photosynthesis comes from mid-layers (about 20-40 cm above the trellis), where leaves experience mixed shade and sunflecks; leaves at the very top show some photoinhibition, while lower leaves remain productive rather than parasitic (Cortázar et al., 2005). In vertically trellised Shiraz, photosynthetic output declines from apical to basal canopy zones, with particularly low and erratic values in the light-limited interior, reflecting strong light constraints in the centre of dense canopies (Hunter et al., 2020).

Drought and row orientation further modulate these layer differences. Under progressive water deficit, photosynthesis and transpiration are first reduced in outer sunlit leaves, with shaded inner leaves affected later and some deeply shaded leaves remaining almost unresponsive but with negligible carbon gain (Escalona et al., 2020). Orientation-driven radiation patterns lead to higher average  $P_n$  on east and north-facing sides, while south-exposed layers show lower photosynthesis and more negative water status. Functional-structural modelling confirms that differences in leaf nitrogen distribution and light interception among layers translate into substantial variation in their contribution to whole-canopy carbon gain under different training systems (Prieto et al., 2019).

### 4.3 Accumulation and transport of photosynthates

Changes in  $P_n$ ,  $G_s$  and  $T_r$  at leaf and canopy levels ultimately determine the supply of photosynthates available for growth and fruit ripening. Defoliation experiments show that reductions in leaf area (source) have a stronger effect on season-long carbon assimilation, sugar-induced growth and speed of ripening than changes in crop load, underscoring the dominance of canopy size and activity over sink level (Martínez-Lüscher and Kurtural, 2021). Under shading, reduced  $P_n$  is accompanied by lower leaf soluble carbohydrates and starch, as well as decreased vine yield and berry soluble solids, indicating limited carbohydrate production and altered allocation.

Photosynthate transport depends on both whole-plant carbon balance and phloem capacity. Long-term shading experiments reveal that, despite depressed photosynthesis, shaded grapevine leaves can maintain non-structural carbohydrate pools due to reduced sink demand, but this accumulation constrains full photosynthetic recovery when leaves are re-exposed to sun (Gallo et al., 2024). Hormonal regulation by abscisic acid and gibberellin can shift carbon allocation by increasing non-structural carbohydrates in leaves, enlarging phloem area, and up-regulating sugar transporter genes in leaves and berries, thereby accelerating hexose accumulation in fruit or enhancing stem growth (Figure 2) (Murcia et al., 2016; Li et al., 2021).