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Influence of Canopy Structure on Photosynthesis and Fruit Quality in Grapevines

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Abstract Canopy structure plays a critical role in regulating light distribution, photosynthetic efficiency, and ultimately fruit quality in grapevines. This study systematically reviews the characteristics of different canopy architectures and their effects on the vineyard light environment. It further analyzes how variations in canopy density and spatial configuration influence leaf photosynthesis, including differences among canopy layers and the accumulation and transport of photosynthates. The relationship between canopy structure and key fruit quality parameters, such as sugar content, organic acids, and secondary metabolites, is also discussed. In addition, common canopy management practices, including pruning, leaf removal, and training systems, are evaluated for their effectiveness in optimizing canopy microclimate. Case studies comparing different training systems and management strategies highlight practical approaches to improving grape quality. The interactions between canopy structure and environmental factors, such as light, water, and nutrients, are also addressed. Overall, this study provides a theoretical basis and practical guidance for optimizing canopy structure to enhance grapevine productivity and fruit quality.
Keywords Canopy structure; Grapevine; Photosynthesis; Fruit quality; Canopy management

1 Introduction

Grapevine canopy structure governs how light, temperature, and air flow are distributed within the vine, thereby regulating photosynthesis, carbon balance, and berry development. Light interception and its spatial distribution strongly affect sugar accumulation, acidity, color, and aroma compounds that define grape and wine quality. In the context of climate change and increasingly warm, dry regions, refining canopy architecture has become a key strategy to maintain productivity and fruit quality while moderating excessive heat and radiation loads (Torres et al., 2020; Pallotti et al., 2025). Understanding how specific structural features of the canopy translate into physiological responses and fruit composition is therefore of both scientific and practical importance (Zhu et al., 2021).

Biomass production and yield potential are closely related to the amount of solar radiation intercepted by the foliage, while grape composition depends on the exposure of leaves and clusters to light within the canopy microclimate. Excessive shading reduces photosynthesis and is linked to poor grape and wine quality, whereas overly open canopies may induce overheating, sunburn, and degradation of acids and phenolics (Torres et al., 2020). Canopy management practices such as leaf removal, shoot thinning, and crop load adjustments are widely used to balance source–sink relationships, control microclimate, and optimize ripening. Recent work shows that canopy size and architecture largely determine whole-plant carbon gain, the speed of ripening, and the allocation of non-structural carbohydrates, often more strongly than crop level itself. Consequently, quantitative knowledge of how canopy structure shapes photosynthetic efficiency and berry composition is essential for designing training systems and management strategies adapted to diverse climates (Zhu et al., 2021; Del Zozzo et al., 2024).

Internationally, detailed studies have linked canopy geometry, light interception, and grape quality using field measurements, 3D digitizing, and radiation models. Structural indices and light microclimate variables explain variation in sugars, anthocyanins, and phenolics, and demonstrate that canopy division and shoot orientation are major determinants of bunch exposure. Whole-canopy gas exchange and training-system comparisons indicate