Sunlight Exposure and Temperature Effects on Berry Growth and Composition of Cabernet Sauvignon and Grenache in the Central San Joaquin Valley of California

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The effects of sunlight exposure on the berry growth and composition of two red wine grape cultivars grown in the central San Joaquin Valley of California (Region V) were examined. Field grown Cabernet Sauvignon and Grenache grape clusters were grown over a range of sunlight exposures (mid-day PAR <10 µmol m^{-2} sec^{-1} [shaded] to >600 µmol m^{-2} sec^{-1} [fully exposed]) from berry set to harvest. Both cultivars were planted in east-west oriented rows, and experimental clusters were evenly distributed between the north (afternoon shaded) and south (afternoon exposed) sides of the canopy. Fruit response to sunlight varied based on cluster location within the canopy, and these results were at least partially due to measured differences in berry temperature. At the same exposure level or PAR (photosynthetically active radiation), mid-day berry temperature was generally 3 to 4°C greater for clusters on the south side of the canopy compared to clusters on the north. Soluble solids initially increased with greater sunlight exposure, then declined when mid-day PAR exceeded 31 to 50 and 51 to 100 µmol m^{-2} sec^{-1}, respectively, for clusters on the north and south sides of the canopy. Titratable acidity generally declined as sunlight exposure increased, with Cabernet Sauvignon clusters on the north side of the canopy maintaining greater acidity at the same exposure level than clusters on the south. Juice pH declined as exposure increased on the north side of the canopy, while sunlight had little effect on juice pH for clusters on the south. Anthocyanins increased linearly as sunlight exposure on the north side of the canopy increased, but declined when cluster exposure on the south exceeded 100µmol m^{-2} sec^{-1}. Total phenolics generally followed a similar pattern. The results suggest that the effects of light on fruit composition are heavily dependent upon the extent to which berry temperature is elevated as a result of increased sunlight exposure. Prolonged exposure of clusters to direct sunlight should be avoided for maximum berry color in the central San Joaquin Valley and other warm regions.

Key words: sunlight exposure, fruit composition

The influence of sunlight on grape berry development and composition has been well documented during the past few decades. Previous studies have found that sunlight-exposed fruits are generally greater in total soluble solids, anthocyanins, and phenolics and lower in titratable acidity, malate, juice pH and berry weight compared to nonexposed or canopy-shaded fruits [3,4,6,7,8,11,15,17,20]. These studies concluded that increased fruit exposure to sunlight generally improved both grape and wine composition. This work has had a profound effect on wine-grape trellising and canopy-management practices throughout the world [19].

Despite this progress, the optimum range or amount of cluster sunlight exposure remains unclear. Much of the previous work compared either fully exposed or canopy-shaded clusters [3,4] or the effects of canopy manipulations, which dramatically altered fruit zone light environment on fruit composition [17,20]. Few studies have compared the relative composition of fruits exposed to the wide range of sunlight exposures typically encountered in commercial vineyards. Previous work indicated that the sunlight exposure of individual clusters on the same vine may vary dramatically, based on cluster location within the canopy [5]. As few clusters within the fruiting zone are exposed to full sunlight or grown in complete canopy shade, the relative effects of a wide range of sunlight exposures on fruit composition should be examined.

Berry temperature in the field is largely regulated by the flux density of absorbed radiation and convective heat loss and has been shown to increase linearly with incident radiation [21]. Kliewer and Lider [11] reported that the temperature of sunlight-exposed Thompson Seedless berries was 3 to 8°C greater compared to berries in the canopy shade. While increased sunlight exposure of clusters is generally believed to improve fruit composition [19], the concomitant increase in berry temperature may be detrimental—especially in warm growing regions such as the San Joaquin Valley. In studies using the fruit of potted vines grown under controlled conditions, where sunlight exposure did not significantly increase berry temperature, high light intensities (>25% ambient sunlight) resulted in maximum skin anthocyanin accumulation [8,10,12]. In contrast, the increased temperature of sunlight-exposed fruits under field conditions

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may lead to reduced berry color, particularly in warm regions [22]. The objective of this study was to determine the optimum sunlight exposure for two red wine-grape cultivars, Cabernet Sauvignon and Grenache, grown in the central San Joaquin Valley of California (Region V [22]).

Materials and Methods

Plant materials and vineyard site. The trial was conducted at the University of California Kearney Agricultural Center, located in the central San Joaquin Valley, approximately 50 km southeast of Fresno, CA. Eight-year-old own-rooted Cabernet Sauvignon (UC clone #8) and Grenache (UC clone #1A) grapevines, grown in nearby rows in the same vineyard block, were used in the study. The vines were planted in east-west oriented rows, spaced 2.4 m (between vines) x 3.7 m (between rows), bilateral cordon trained and spur pruned, and trellised to a two-wire vertical system. At the completion of the previous growing season, the mean weight of one-year-old prunings averaged 5.8 and 4.2 kg per vine, respectively, for Cabernet Sauvignon and Grenache.

Treatments and experimental design. Experimental treatments were established one and two weeks after fruit set for Cabernet Sauvignon and Grenache, respectively. Fruit set was defined as the stage of berry development immediately following shatter (average berry diameter approximately 3 mm), corresponding to Stage 29 of the modified Eichhorn and Lorenz system [2]. Eight clusters per vine (one cluster/shoot) were selected for use based on the uniformity of shoot growth and cluster development. Clusters were divided into two groups of four, located on either the east or the west cordon of the vine. Four sunlight exposure categories were assigned to the clusters: (1) full exposure, (2) moderate to high exposure, (3) moderate to low exposure, and (4) shaded. Fully exposed clusters were generally exposed to sunlight throughout the day. High to moderately exposed clusters had one to two leaf layers of shade, while two to three leaf layers shaded clusters in the moderate to low exposure category. Shaded clusters were located deep inside the canopy, with four or more leaf layers. Selected leaf removal, as well as trimming or tying of shoots adjacent to clusters, was performed as necessary to establish desired exposure levels. Experimental clusters were evenly distributed between the north and south sides of the canopy, and positioned to hang freely and parallel to the trellis. Experimental clusters were selected on shoots of similar vigor, with two-thirds or more of their leaves exposed to full sunlight throughout the experiment. The experiment was designed as a randomized complete, split plot with sunlight exposure serving as the main plot and cluster location within the canopy (north versus south side of the vine row) as the subplot. Each treatment was replicated 13 times in both cultivars using single-cluster plots, and all treatments within a replicate occurred on the same vine.

Light measurements. Photosynthetically active radiation (PAR) incident to each cluster was determined at the following stages of fruit development: fruit set (initiation of the experiment), veraison, and several weeks prior to harvest. All measurements were taken near solar noon, on clear, sunny days. PAR was measured using a handheld Li-Cor LI-189 quantum sensor (Li-Cor, Inc., Lincoln, NE), placed in the middle of the cluster, and oriented perpendicular to its plane. Cluster sunlight exposure was expressed as actual PAR with respect to cluster location in canopy (north versus south side of the vine row) and categorized as follows: <10, 10-30, 31-50, 51-100, 101-200, 201-600 and >600 µmol m^{-2} sec^{-1}. No exposure level > 200 µmol m^{-2} sec^{-1} was recorded on the north (shaded) side of the row. Canopy manipulations (leaf removal or shoot positioning) were performed as needed during the growing season to maintain clusters within +/- 10% of their initial sunlight exposure at berry set.

Temperature measurements. Berry temperature was measured between veraison and harvest using a handheld Omega HH 23 temperature monitor with dual hypodermic thermocouples (Omega Engineering, Inc., Stamford, CT). Berry temperature was measured by insertion of the thermocouple probe into the berry center. A shielded probe was placed next to the berry to monitor ambient air temperature. To determine the effects of sunlight exposure on daytime berry temperature, five clusters within each exposure category of both cultivars were selected (all treatments within the same replication). The temperature of three berries on each selected cluster was measured at two-hour intervals from 600 to 2000 hr, Pacific Daylight Time (PDT). Measurements were repeated on the same berries on each cluster throughout the day. To determine the relationship between sunlight exposure and berry temperature, three berries on 10 fully exposed, moderately exposed, and shaded clusters (30 clusters total) were used. Berry temperature and PAR were measured as described above. Berries used for temperature determinations were removed from clusters and discarded at the completion of the measurements.

Fruit analyses. At harvest, berries from the exterior plane (berries facing outward, toward the middle of the row) of the clusters were removed, placed in sealed plastic bags, and stored on ice. One hour after harvest, the berries were taken to the laboratory and randomly separated into two subsamples. The first sample consisted of eight berries and was used for anthocyanin and total phenolic determinations, while the remaining berries were reserved for pH, titratable acidity, and total soluble solids determinations. The size of this sample ranged from 15 to 70 berries for Grenache and 10 to 63 berries for Cabernet Sauvignon. All samples were weighed and stored in sealed plastic bags at -20°C until analyzed. Frozen berry samples were thawed at room temperature, placed between two layers of muslin, and macerated using a mortar and pestle. The juice was collected in plastic tubes and soluble solids (°Brix) determined using a handheld temperature-compensated refractometer. Following soluble solids determinations, 5 mL of juice from each sample was placed into a 20 mL vial to which 10 mL of distilled water was added. Titratable acidity was determined by titration with 0.1N of NaOH to a pH 8.2 end point and expressed as g 100 mL^{-1} of tartaric acid. The pH of undiluted juice of each sample was determined using a pH meter. For anthocyanin and phenolic analyses, samples were removed from the freezer and thawed at room temperature. Berry skins were removed from the pulp by hand, rinsed with tap water, rinsed with distilled water, and then blotted dry with paper towels. The skins were weighed on an analytical balance, placed in centrifugation tubes containing 50 mL of acidified methanol (1% HCl, v/v), and stored in darkness for 48 hours. After appropriate dilution with acidified methanol, the absorbance of a 5 mL aliquot of the extract was determined at 520 nm using a spectrophotometer (Spectronic, Rochester, NY). Anthocyanin concentration (expressed as mg pigment g^{-1} berry skin) was determined using the molecular weight (529) and molar absorbance (28,000) values for malvidin-3-glucoside (1). A 10 mL aliquot of the above extract was collected for the determination of the total phenol content by the modified Folin-Ciocalteu method [18]. Total phenol content was expressed as mg of gallic acid g^{-1} of berry skin.

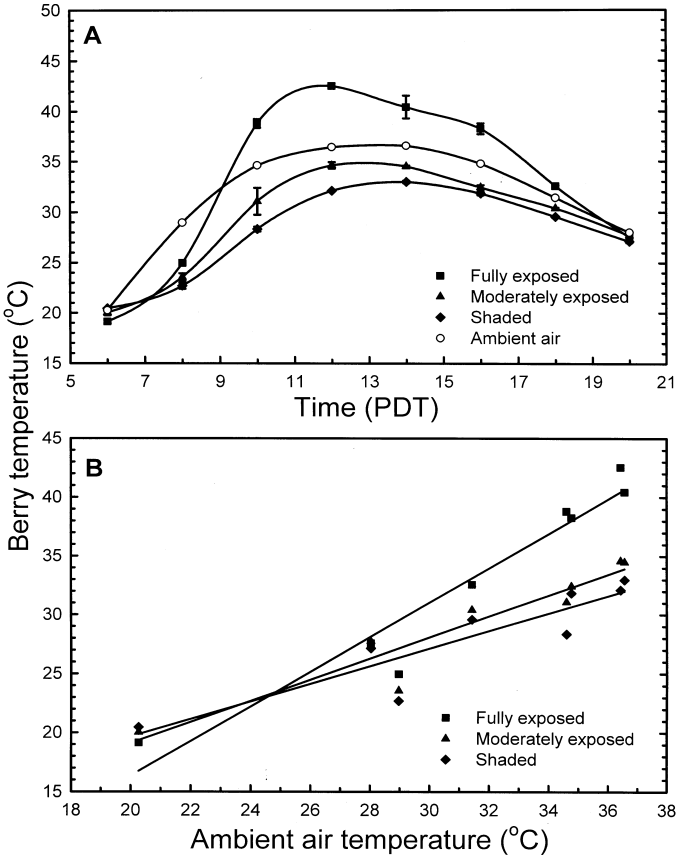

Fig. 1 (**A**) Diurnal variation in the daytime ambient air and berry temperature of fully exposed, moderately exposed, and shaded Cabernet Sauvignon grape clusters approximately two weeks prior to harvest. Each data point represents the mean of three single-berry measurements per cluster. Vertical bars represent the standard mean error (+/-). (**B**) Relationship between ambient air temperature and berry temperature of fully exposed, moderately exposed, and shaded Cabernet Sauvignon grape clusters approximately three weeks prior to harvest. Each data point represents the mean of three single-berry measurements per cluster. Data were fitted to the following equations: fully exposed y =-12.9 + 1.4x, r^2=0.9344; moderately exposed y = 1.2 + 0.8x, r^2 = 0.9032; shaded y = 4.7 + 0.7x, r^2 = 0.8273.

Statistics. Relationships among cluster light exposure and berry temperature, growth, and composition were examined using general linear modeling and curve fitting procedures in SAS (SAS Institute, Cary, NC). Homogeneity tests in SAS were used to determine if regression relationships differed significantly ($p < 0.05$) for clusters on the north and south sides of the canopy.

Results

As expected, daytime berry temperature was greatest for fully exposed clusters and lowest in shaded clusters (Fig. 1a). The mid-day temperature of fully exposed berries exceeded ambient air temperature by 7°C, and that of shaded berries by

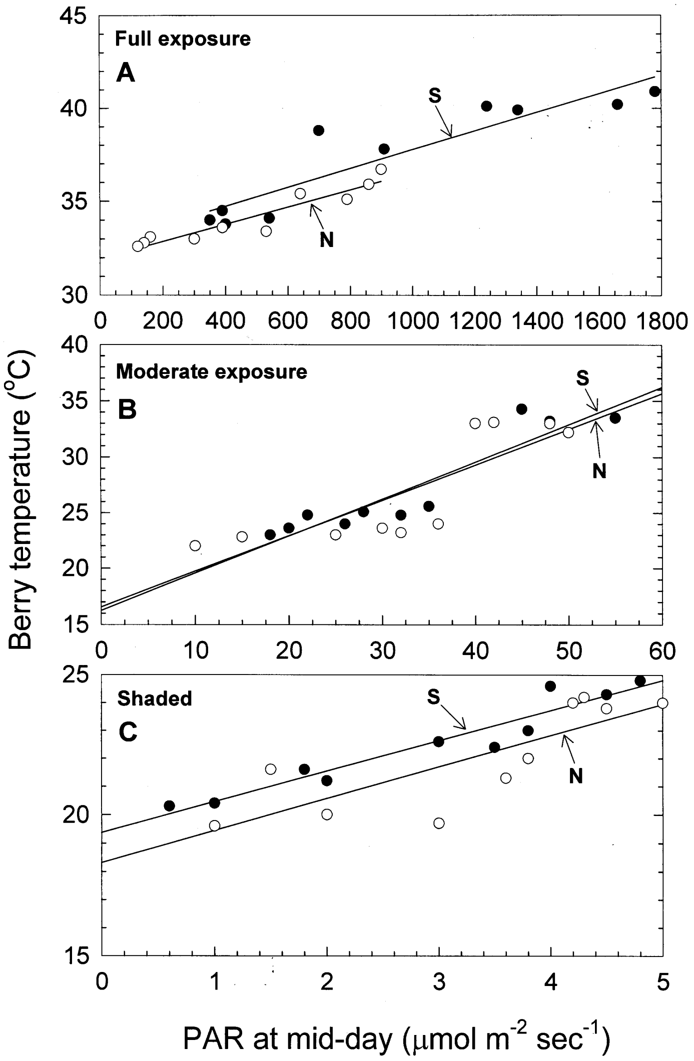

Fig. 2 Relationship between PAR and the berry temperature of fully exposed (**A**), moderately exposed (**B**), and shaded (**C**) Cabernet Sauvignon clusters located on the north (N) or south (S) side of canopy at mid-day two weeks prior to harvest. Each data point represents the mean of three, single berry measurements per cluster. Data were fitted to the following equations: fully exposed N: y=32.7 + 5.0x, r^2=0.8420; fully exposed S: y=32.0 + 4.6x, r^2=0.8880; moderately exposed N: y=16.2 + 0.3x, r^2=0.8662; moderately exposed S: y=16.5 + 0.3x, r^2=0.6964; shaded N: y=19.4 + 1.1x, r^2=0.9219; shaded S: y=18.3 + 1.1x, r^2=0.6683.

nearly 10°C. Fully exposed clusters exhibited the largest fluctuation in daytime berry temperature among the treatments, and shaded clusters exhibited the least. Berry temperature of all sunlight exposure classes correlated closely with air temperature near the cluster (Fig. 1b). The berry temperature of fully exposed clusters increased more quickly with ambient air temperature than moderately exposed or shaded clusters, reflecting the greater radiation incident to their surface. Berry temperature increased linearly with incident PAR for clusters in all exposure classes (Fig. 2). When fully exposed or shaded clusters received the same sunlight exposure, mid-day berry temperature was significantly greater for clusters on the south side of the canopy compared to those on the north ($p \leq 0.05$; Figs. 2a and 2c). In contrast, the berry temperature of moderately exposed clusters on the north and south sides of the canopy rose similarly as PAR increased (Fig. 2b). Similar data were collected for Grenache (data not presented).

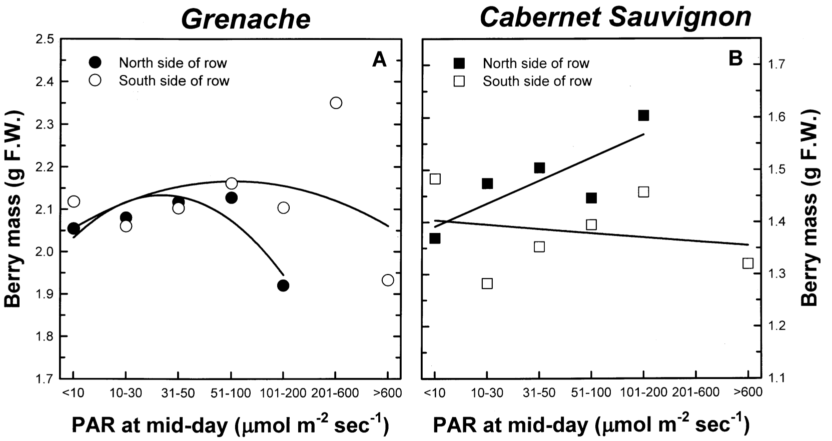

Fig. 3 Influence of cluster sunlight exposure on berry mass of Grenache (**A**) and Cabernet Sauvignon (**B**). Clusters were grouped according to the following sunlight exposure classes: <10, 10-30, 31-50, 51-100, 101-200, 201-600 and >600 μmol m^{-2} sec^{-1} PAR. Data were fitted to the following equations: Grenache: north side of row $y = 2.034 + 0.119x - 0.035x^2$, $r^2=0.800$; south side of row $y = 2.055 + 0.073x - 0.012x^2$, $r^2=0.130$. Each data point represents the mean of at least two replicates, except for exposure class 201 to 600 μmol m^{-2} sec^{-1}, which has only one. Cabernet Sauvignon: north side of row $y = 1.392 + 0.044x$, $r^2=0.661$; south side of row $y = 1.404 - 8.528 \times 10^{-3}x + 7.542 \times 10^{-5}x^2$, $r^2=0.049$. Each point represents the mean of at least three replicates; no clusters were present in the 201-600 μmol m^{-2} sec^{-1} exposure class on the south side of the canopy.

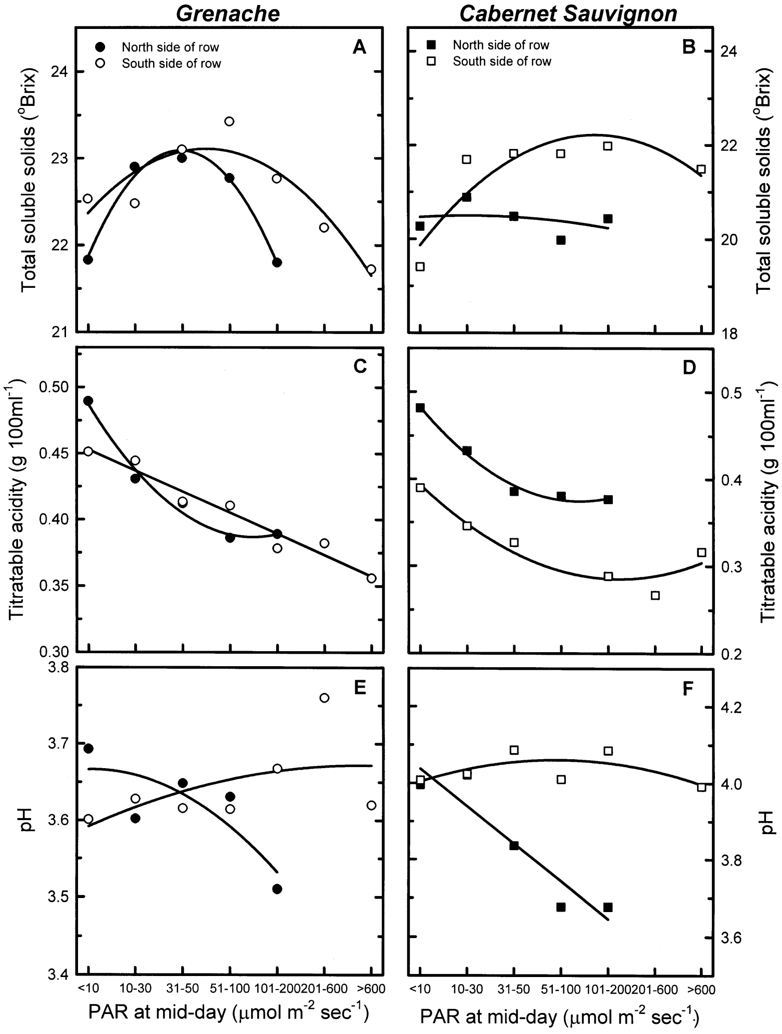

Fig. 4 Influence of cluster sunlight exposure on total soluble solids, titratable acidity, and juice pH of Grenache (**A**, **C**, and **E**, respectively) and Cabernet Sauvignon (**B**, **D**, and **F**, respectively) grape berries. Refer to Fig. 3 for explanation of PAR exposure classes. Data were fitted to the following equations: Total soluble solids—Grenache: north side of row $y = 21.867 + 1.242x - 0.315x^2$, $r^2=0.985$; south side of row $y = 22.362 + 0.596x - 0.119x^2$, $r^2=0.833$. Cabernet Sauvignon: north side of row $y = 20.456 + 0.061x - 0.030x^2$, $r^2=0.105$; south side of row $y=19.865 + 1.260x - 0.169x^2$, $r^2=0.804$. Titratable acidity—Grenache: north side of row $y = 0.487 - 0.058x + 8.302 \times 10^{-3}x^2$, $r^2=0.984$; south side of row $y = 0.453 - 0.016x$, $r^2=0.954$. Cabernet Sauvignon: north side of row $y = 0.483 - 0.064x + 9.5456 \times 10^{-3}x^2$, $r^2=0.989$; south side of row $y = 0.393 - 0.051x + 6.027 \times 10^{-3}x^2$, $r^2=0.916$. pH—Grenache: north side of row $y = 3.667 + 1.489 \times 10^{-3}x - 8.796x^2$, $r^2=0.669$; south side of row $y = 3.592 + 0.028x - 2.410 \times 10^{-3}x^2$, $r^2=0.297$. Cabernet Sauvignon: north side of row $y = 4.037 - 0.098x$, $r^2=0.874$, south side of row $y = 4.004 + 0.039x - 6.76 \times 10^{-3}x^2$, $r^2=0.443$.

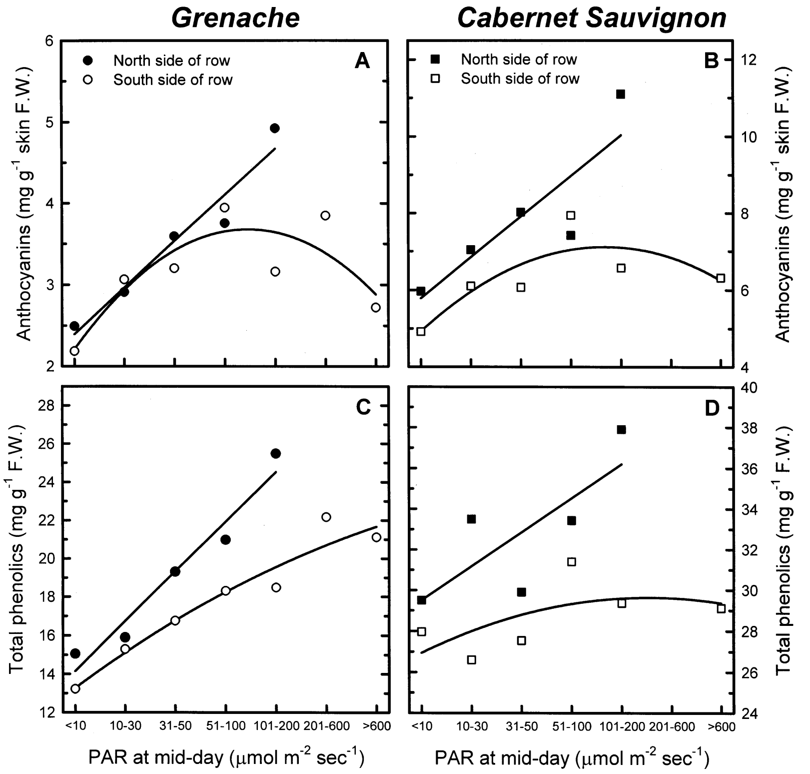

Fig. 5 Influence of cluster sunlight exposure on the anthocyanin and total phenol concentrations of Grenache (**A** and **C**, respectively) and Cabernet Sauvignon (**B** and **D**, respectively) grape berry skins. (See Fig. 3 for PAR exposure classes.) Data were fitted to the following equations: Anthocyanins—Grenache: north side of row $y = 2.394 + 0.570x$, $r^2=0.942$; south side of row $y = 2.211 + 0.848x - 0.123x^2$, $r^2=0.722$. Cabernet Sauvignon: north side of row $y = 5.782 + 1.064x$, $r^2=0.757$; south side of row $y = 4.928 + 1.186x - 0.161x^2$, $r^2=0.693$. Total phenolics—Grenache: north side of row $y = 14.147 + 2.595x$, $r^2=0.952$; south side of row $y = 13.279 + 1.910x - 0.085x^2$, $r^2=0.938$. Cabernet Sauvignon: north side of row $y = 29.492 + 1.674x$, $r^2=0.607$; south side of row $y = 26.940 + 1.182x -0.130x^2$, $r^2=0.367$.

Berry mass of Grenache increased as mid-day PAR increased up to 51- 100 μmol m^{-2} sec^{-1}, then declined for clusters on both the north and south sides of the canopy (Fig. 3a). In contrast, the mass of Cabernet Sauvignon berries increased linearly with sunlight exposure for clusters on the north side of the canopy (Fig. 3b). Berry mass on the south side of the canopy declined slightly with increased sunlight exposure and was lower compared to berry mass on the north side ($p \leq 0.05$).

Soluble solids concentrations of Grenache increased with greater sunlight exposure, then declined when mid-day PAR exceeded 31-50 and 51-100 μmol m^{-2} sec^{-1}, respectively, for clusters on both sides of the canopy (Fig. 4a). Compared to clusters on the north, soluble solids concentrations were higher for clusters on the south side of the canopy when mid-day PAR exceeded 51-100 μmol m^{-2} sec^{-1} ($p \leq 0.05$). Soluble solids of Cabernet Sauvignon clusters on the south side increased sharply when mid-day PAR increased from <10 μmol m^{-2} sec^{-1} to 10-30 μmol m^{-2} sec^{-1}, then leveled off (Fig. 4b). In contrast, sunlight exposure had little effect on the soluble solids of Cabernet Sauvignon clusters on the north side of the canopy, and the fruit was generally lower in percent soluble solids compared to clusters on the south ($p \leq 0.05$).

Titratable acidity of Grenache clusters on the south side of the canopy declined linearly as mid-day PAR increased (Fig. 4c). In comparison, the titratable acidity of clusters on the north side of the canopy declined as mid-day PAR increased from <10 μmol m^{-2} sec^{-1} to 51-100 μmol m^{-2} sec^{-1}, then leveled off. At the same exposure level, titratable acidity was similar for Grenache clusters on both sides of the canopy. In contrast, Cabernet Sauvignon clusters on the north side of the canopy maintained greater acidity at the same exposure level than clusters on the south side ($p \leq 0.05$; Fig. 4e). Cabernet Sauvignon clusters on both sides of the canopy followed a similar pattern, with titratable acidity decreasing sharply as mid-day PAR increased from <10 μmol m^{-2} sec^{-1} to 51-100 μmol m^{-2} sec^{-1}, then leveling off.

Compared to clusters on the south side of the canopy, the juice pH of clusters on the north side declined significantly ($p \leq 0.05$) with increased sunlight exposure in both cultivars (Figs. 4e and 4f). Juice pH declined slightly (Grenache), or remained relatively constant (Cabernet Sauvignon), with increased sunlight exposure on the south side.

For clusters on the north side of the canopy, skin anthocyanins increased linearly with increased sunlight exposure for both cultivars (Figs. 5a and 5b). For clusters on the south side of the canopy, the anthocyanin concentrations of both cultivars increased initially, then declined when PAR exceeded 51-100 μmol m^{-2} sec^{-1} at mid-day. For Grenache, clusters on north and south sides of the canopy had similar anthocyanin levels until mid-day PAR reached this level. At the same exposure level, Cabernet Sauvignon clusters on the north side of the canopy had greater anthocyanin concentrations than clusters on the south side ($p \leq 0.05$). Total phenol concentrations in the skins of both cultivars increased linearly with mid-day PAR for clusters on the north side of the canopy (Figs. 5c and 5d). Total phenol concentrations increased more gradually with sunlight exposure for clusters on the south side of the vine. At the same exposure level, clusters on the north side of the canopy were greater in total phenolics than clusters on the south ($p \leq 0.05$).

Discussion

As suggested previously by Smart and Sinclair [21], berry temperature increased linearly with sunlight exposure in this study. The mid-day temperature of fully exposed berries was 9 to 10°C greater compared to shaded berries. When accumulated during the entire fruit development period, this difference likely accounts for a significant portion of the compositional variation reported between sunlight-exposed and shaded fruits [7,9,11,13]. Temperature differences also explain why fruit response to sunlight varied due to cluster position within the canopy. Direct sunlight heats plant tissues more efficiently than diffuse light [21]. Fully and moderately exposed clusters on the south side of the canopy received direct sunlight in the afternoon, while clusters on the north side of the canopy received mostly indirect or diffuse light during this period. At similar sunlight exposure levels, the mid-day berry temperature of clusters on the north side of the canopy was 3 to 4°C lower than that of clusters on the south. It should be noted that temperature differences between sunlight-exposed and shaded berries reported here, for a warm climate (Region V), may be less pronounced in a cooler climate (such as Region I or II [22]).

Dokoozlian reported that the berry growth of Cabernet Sauvignon increased as cluster exposure to sunlight was increased under controlled conditions, but light exposure had no effect on berry temperature in that study [5]. The gradual decline in the berry mass of Grenache with increased sun exposure reported here may have resulted from the effects of elevated berry temperatures on berry cell division or elongation as well as increased fruit transpiration rates and subsequent berry dehydration [4,7,11]. A similar explanation can be made for the lower mass of Cabernet Sauvignon berries on the south side of the canopy. Contrary to this trend, the berry mass of Cabernet Sauvignon increased linearly with increasing exposure for clusters on the north side of the vine. Berry growth may therefore be enhanced by increased exposure to indirect light, as long as fruit temperatures are not elevated beyond the optimum for development [7,13].

Soluble solids reached their maximum when mid-day cluster exposure ranged between 31-50 µmol m^{-2} sec^{-1} for Grenache and 51-100 µmol m^{-2} sec^{-1} for Cabernet Sauvignon. The increased temperature of fruits exposed beyond these levels may have inhibited ripening, as previous work indicated that cluster temperatures >37°C inhibited sugar accumulation [10]. The decline in titratable acidity with increasing sunlight exposure agrees with previous work [3,11,17,20] and was attributed to increased malic acid degradation due to the higher temperatures of exposed fruit [9,11,14]. Increased sunlight exposure had little effect on the juice pH of clusters on the south side of the canopy, likely because their elevated temperature was a more important factor influencing pH than light exposure [7,9,10]. In contrast, results for fruit on the north side of the canopy were similar to previous studies reporting that exposed clusters have lower juice pH than shaded clusters [19,20]. These studies also implied that foliage exposure to sunlight may regulate fruit pH; however, all experimental shoots were exposed to similar levels of sunlight. It should be noted that analyses were performed on previously frozen berries, thus pH may have been elevated as a result of tartrate precipitation [1].

While increased exposure to light generally stimulates anthocyanin accumulation in grape berries, high temperatures inhibit color formation [8,10,12]. In this study the anthocyanin concentration of both cultivars increased linearly as sunlight exposure increased on the north side of the canopy. In contrast, a quadratic relationship was found on the south side, where maximum coloration occurred when berries were exposed to 51-100 µmol m^{-2} sec^{-1} PAR at mid-day. Pirie [16] reported the optimum temperature range for anthocyanin accumulation was between 17 and 26°C. The lower anthocyanin concentration of clusters exposed to >100 µmol m^{-2} sec^{-1} PAR at mid-day on the south side of the canopy is likely a consequence of their elevated temperature, as implicated by earlier studies [10,12]. Lower total phenolic concentrations of fruit on the south side of the canopy were likely a result of this same interaction.

Conclusions

In addition to regulating photosynthesis and photo-morphogenesis, sunlight provides radiant energy, which heats plant surfaces. Berry composition is influenced by both the direct (light quantity and light quality) and the indirect (temperature mediated) effects of sunlight exposure. Cluster location within the canopy had a significant influence on the relationship between sunlight exposure and berry temperature in this study. It is generally accepted that, as fruit exposure to sunlight increases, fruit composition and wine quality improve [19]. Results of this study were in agreement with the above for clusters located on the north, or afternoon shaded, side of the canopy. However, when clusters were located on the south or afternoon sun exposed side of the canopy, concomitant increases in berry temperature were likely a major factor regulating fruit responses to increased sunlight exposure. Berry color, in particular, was negatively affected by excessive sunlight exposure in this study.

The results indicate that canopy management practices that provide high amounts of diffuse light in the fruiting zone, rather than direct sunlight exposure, are best suited to warm regions such as the San Joaquin Valley. Training and trellising systems, row orientation, and canopy management practices should be considered carefully in order to avoid prolonged fruit exposure to direct sunlight in such regions.

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