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Growth of *Vitis vinifera* L. and *Vitis aestivalis* Michx. as Affected by Temperature

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ABSTRACT. Four European (*Vitis vinifera* L.) winegrape cvs., 'Semillon', 'Pinot Noir', 'Chardonnay', and 'Cabernet Sauvignon', and one American (*Vitis aestivalis* Michx.) winegrape cv. 'Cynthiana', were subjected to three temperature regimes in growth chambers set at 20/15°C, 30/25°C, or 40/35°C, for 16/8 hr day/night to determine the influence of temperatures on vine growth and development. In general, the best temperature for shoot and root growth 28 days after temperature treatments was 20/15°C for 'Semillon', 'Cabernet Sauvignon', and 'Cynthiana', and 30/25°C for 'Pinot Noir' and 'Chardonnay'. Although 40/35°C reduced number of leaves, shoots, tendrils, and internodes, total leaf area (LA), and total shoot biomass of all the cultivars, the reduction was more pronounced in 'Cynthiana' than in the European cultivars. The average reduction in number of leaves at 40/35°C for the European cultivars was 47%, compared with 92% for 'Cynthiana'. The two types of grapes adapted differently to high temperature. Shoot growth in the European cultivars continued under high temperature, whereas growth ceased in 'Cynthiana'. Roots of 'Cynthiana', however, were less susceptible to the adverse effect of high temperatures than were the shoots. This study shows that the European cultivars were relatively more tolerant to high temperature than the American cultivar and they have a potential for production of wine in the climate of south central Kansas.

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KEYWORDS. Leaf area, leaf area ratio, specific leaf weight, 'Semillon', 'Pinot Noir', 'Chardonnay', 'Cabernet Sauvignon', 'Cynthiana'

INTRODUCTION

Grapes are becoming an important specialty crop in Kansas. Before Prohibition, Kansas was ranked among the top 10 states in grape and wine production (Schueneman, 1982). It was not until the early 1980s that grape growing and winemaking experienced resurgence in Kansas. Adequate sunlight and irrigation, fertile soils, and a dry climate provide a good environment for growing grapes. However, high temperature is one of the factors that limits the introduction of new cultivars into Kansas. Heat stress negatively affects grape growth, yield, and berry quality, which reduces the quality of wine and table grapes (Bergqvist et al., 2001; Matsui et al., 1986). Temperatures differ dramatically during the growing season, and those over 35°C are not uncommon in Kansas during the summer.

Photosynthesis, which is closely related to plant growth, is one of the processes most sensitive to high temperature in grapes (Chaumont et al., 1997; Ferrini et al., 1995; Shiraishi et al., 1996b). It is the first process damaged by high temperatures (Henning and Brown, 1986); therefore all stages of vegetative and reproductive development will be negatively affected (Abernethy et al., 1989). Long-term exposure to high temperatures alters plant growth due to the irreversible damage to photosynthesis (Al-Khatib and Paulsen, 1984; Xu et al., 1995). Low yield, due to low plant biomass, is attributed to low assimilation rate, acceleration of plant development, and the diminishing of diurnal temperature range under heat stress (Midmore et al., 1984).

The optimum temperature for photosynthesis has been established for some grape cultivars (Ferrini et al., 1995; Shiraishi, et al., 1996a, 1996b; Song and Ko, 1999), but little information is available regarding the effects of high temperatures on shoot and root growth of winegrape. Although the American type is the dominant winegrape in Kansas, there is always a need for new cultivars, such as the European types, that might have potential in some areas in the state. Considering the importance of introducing new cultivars to Kansas, it is essential to evaluate different cultivars for heat resistance. Genotypes within grape species differ in response to high temperature indicating that there is a substantial genetic variability for the trait. Therefore, this study was conducted to determine the optimum temperature for growth and development of five winegrape cultivars, to evaluate the responses of shoot and root growth to high temperature, and to assess the potential for adoption of the European cultivars in south central Kansas where summer temperatures are between 37 and 40°C.

MATERIALS AND METHODS

Plant Materials and Culture. Four European winegrape cvs., 'Semillon' (white) on clone 5 rootstock 3309, 'Pinot Noir' (red) on clone 667 rootstock 3309, 'Chardonnay' (white) on clone 4 rootstock 3309, and 'Cabernet Sauvignon' (red) on clone 169 rootstock 3309, were compared with 'Cynthiana' (red), the widely grown American winegrape in Kansas. Dormant one-year-old vines were planted in 1:1:1 (by volume) sand:peatmoss:perlite medium soil mix in molded polyethylene pots ($16.25 \times 16.25 \times 12.5\ cm^3$). Each pot had 6 holes at the bottom to facilitate water drainage. Vines were placed in the greenhouse at 21/17 ± 3°C day/night (D/N) temperatures, 50% ± 10% relative humidity, and a 16/8 h day/night photoperiod. The supplemental light intensity was 200 $\mu mol\ m^{-2}\ s^{-1}$ photosynthetically active radiation (PAR) (400-700 nm, measured with LI-188B Integrating Quantum/Radiometer/Photometer and LI-190sB sensor, Li-Cor, Inc., Lincoln, NE, USA). Vines were irrigated as needed and fertilized weekly with a commercial fertilizer containing 300 $\mu g\ L^{-1}$ nitrogen, 250 $\mu g\ L^{-1}$ phosphorus, and 220 $\mu g\ L^{-1}$ potassium (Miracle-Gro soluble fertilizer, Scotts Miracle-Gro Products, Inc., Consumer Products Division, Port Washington, NY 11050).

Experimental Conditions. After 23 days under greenhouse conditions, all vines were pruned to a single shoot. Shoot length (cm) and number of leaves were recorded, then four vines per cultivar for each temperature were transferred to three growth chambers maintained at 20/15°C ± 1, 30/25°C ± 1, or 40/35°C ± 1 D/N temperatures, 16/8 hr D/N photoperiods, or 450 $\mu mol/m^2/s$ PAR for 28 days. Humidity was not regulated but was monitored to be in the range from 40% ± 10 during the day to 70% ± 10 RH during the night. Vines at high temperature were watered twice a day to full capacity to prevent secondary injury due to desiccation.

Plant Growth Measurements. Individual vines were harvested 28 days after temperature treatments, and number of leaves, shoots (main and lateral), tendrils, and internodes, and shoot length (cm) were determined for each temperature regime. Total leaf area (LA) per vine was measured with the LI-3100 Leaf Area Meter (Li-Cor Inc., Lincoln, NE, USA). Major and fine roots were extracted by washing them with water. Roots were placed on a paper towel in the greenhouse for one day. Leaves, shoots (shoots and tendrils), and roots were then dried at 70°C for 72 h and weighed.

Using the above measurements, the growth indices including specific leaf weight (SLW) and leaf area ratio (LAR) were calculated as described by Radford (1966):
SLW (mg/dm^2) = DWL/LA, where LA = Total leaf area (cm^2) and DWL = Dry weight of leaves (mg); LAR (dm^2/g) = LA/DWP, where DWP = Total plant dry weight (g).

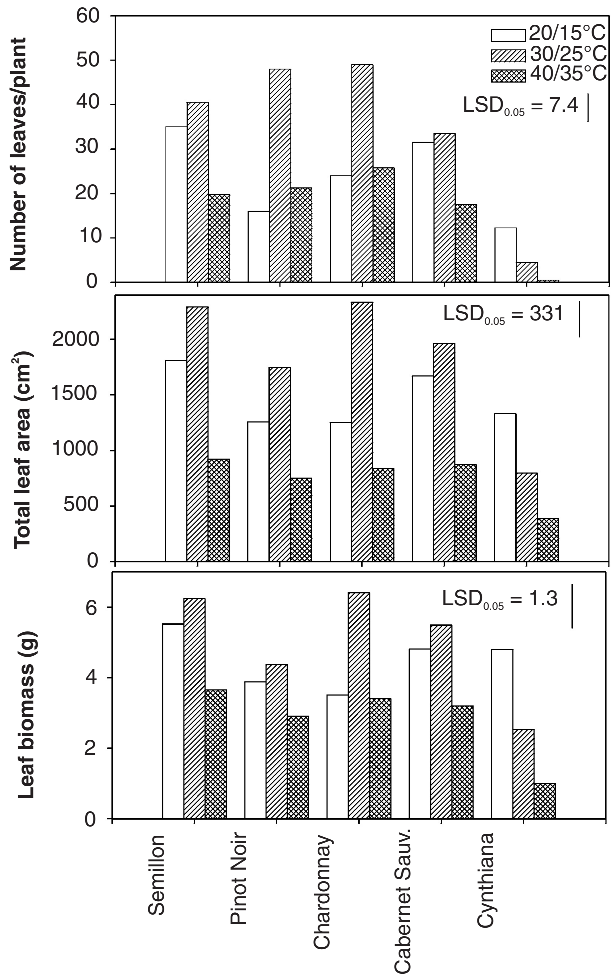
Experimental Design and Data Analysis. Temperature effects on vines were factorial treatments of five cultivars and three temperatures, arranged in a randomized complete-block design. Treatments were replicated four times, and the study was conducted in March and repeated in July 2002. Data will be presented as the average of 8 vines. Treatment effect (plant response) data were analyzed using standard analysis of variance (ANOVA) (SAS Institute, 1990). Data were tested for homogeneity of variance and normality of distribution (Ramsey and Schafer, 1997). Differences among means were tested by Fisher's protected least significant differences (LSD) ($P = 0.05$), and precision was measured by coefficient of variance (CV) percentage. Spearman rank correlation coefficients (r) measured correlation coefficients between parameters were calculated.

RESULTS AND DISCUSSION

At 20/15°C, 'Semillon' and 'Cabernet Sauvignon' had the greatest number of leaves, whereas 'Pinot Noir' and 'Cynthiana' produced the lowest number of leaves (Figure 1A). As temperature increased to 30/25°C, 'Pinot Noir' and 'Chardonnay' produced the most. Leaf production was greatest for 'Semillon' and 'Cabernet Sauvignon' at 20/15°C, whereas 30/25°C was best for 'Pinot Noir' and 'Chardonnay'. Although 'Cynthiana' produced the least number of leaves at 20/15°C compared with the European cultivars, it produced more leaves than 'Cynthiana' vines at 40/35°C; thus, 20/15°C was a better temperature for leaf production for 'Cynthiana'.

Number of leaves was reduced at 40/35°C, and there was significant difference between the two types of grapes. Less reduction was observed in all the European cultivars, compared with the American

FIGURE 1. Number of leaves, total leaf area (LA), and leaf biomass of four European (*Vitis vinifera* L.) winegrape cvs. 'Semillon', 'Pinot Noir', 'Chardonnay', and 'Cabernet Sauvignon', and one American (*Vitis aestivalis* Michx.) winegrape cv. 'Cynthiana' subjected to 20/15ºC ± 1, 30/25ºC ± 1, or 40/35ºC ± 1 D/N temperatures, 16/8 hr D/N photoperiods, and 450 μmol/m^2/s PAR for 28 days. Values are mean of 8 plants (n = 8).



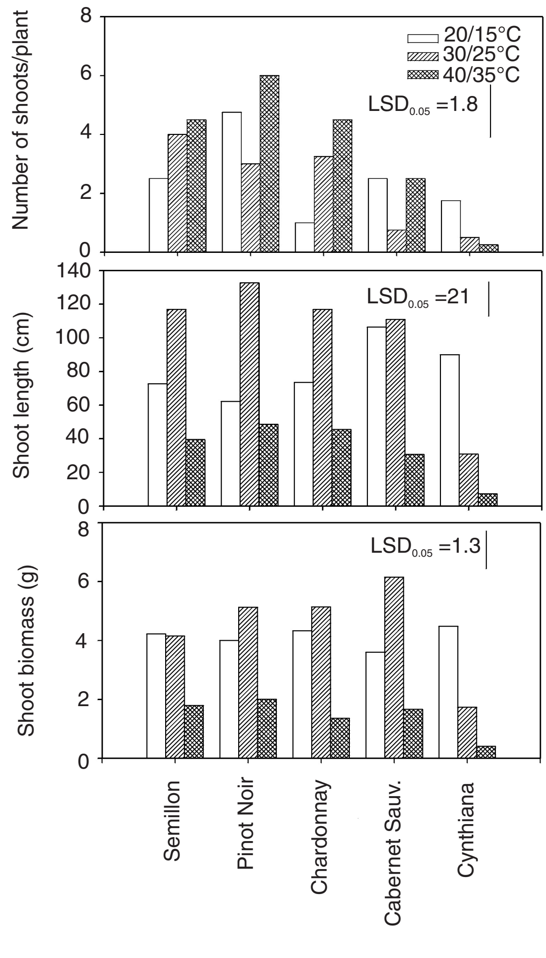
cultivar. The average reduction from the best temperatures for the European cultivars to 40/35°C was 47%, compared with 92% for the American cultivar. These results are in agreement with earlier reports that high temperature reduced leaf growth, compared with low temperature (Shiraishi et al., 1996b).

There were significant differences in total leaf area (LA) and leaf biomass between the five cultivars in response to the treatments (Figures 1B and C). At 20/15°C, 'Semillon' and 'Cabernet Sauvignon' produced the greatest LA, compared with the other cultivars (Figure 1B). As the temperature increased from 20/15 to 30/25°C, LA was the greatest in 'Semillon' and 'Chardonnay' but was the lowest in 'Cynthiana'. At 40/35°C, LA was reduced in all the five cultivars, although there were differences between the cultivars. In general, the European cultivars produced more LA than the American cultivar at 40/35°C. Change in LA is an adaptation mechanism to environmental stresses and directly related to grapevine productivity (Schultz, 1996, 2000). The European cultivars produced more leaves at 40/35°C than the American cultivar. These results disagree with earlier report that reduction of LA of 'Chardonnay' by water stress under field conditions was due to fewer leaves per vine (Gómez del Campo et al., 2002). The discrepancy between the two studies might be due to different environmental conditions under which each study was conducted (heat stress versus drought stress; field versus controlled environmental conditions).

The average leaf biomass of the European cultivars increased by 32% but decreased by 48% for 'Cynthiana' as temperature increased from 20/15 to 30/25°C (Figure 1C). From 30/25°C to 40/35°C, leaf biomass reduction was less in 'Pinot Noir' (34%) compared with 60% reduction in 'Cynthiana.' Leaf biomass of the latter cultivar was significantly reduced by 79% as temperature increased from the optimal, 20/15°C, to 40/35°C. The reduction was mainly attributed to significant decline in LA. Although the influence of temperature on growth parameters was not reported, best temperatures for vine growth in this study agree with earlier reports that optimum photosynthetic rate of the American cultivars is at the range of 15 to 20°C and that of the European cultivars is at the range of 30 to 35°C (Sepulveda and Kliewer, 1986; Shiraishi et al., 1996b). Reduction in photosynthesis by high temperatures reduces all stages of vegetative and reproductive development (Shiraishi et al., 1996a; Song and Ko, 1999).

There were significant differences between the cultivars in number of shoots (Figure 2A). At 40/35°C, more shoots were produced in 'Pinot Noir', 'Semillon', and 'Chardonnay' compared with 'Cabernet Sauvi-

FIGURE 2. Number of lateral and main shoots, shoot length, and shoot biomass (shoots and tendrils) of four European (*Vitis vinifera* L.) winegrape cvs. ‘Semillon’, ‘Pinot Noir’, ‘Chardonnay’, and ‘Cabernet Sauvignon’, and one American (*Vitis aestivalis* Michx.) wine grape cv. ‘Cynthiana’ subjected to 20/15ºC ± 1, 30/25ºC ± 1, or 40/35ºC ± 1 D/N temperatures, 16/8 hr D/N photoperiods, and 450 µmol/m²/s PAR for 28 days. Values are mean of 8 plants (n = 8).



gnon' or 'Cynthiana'. 'Pinot Noir' significantly produced more shoots as temperature increased from 30/25 to 40/35°C, compared with the other cultivars. More than 82% reduction in number of shoots was observed in 'Cynthiana' as temperature increased from 20/35 to 40/35°C. The reduction in number of shoots in 'Cynthiana' may be attributed to reduction of the terminal meristem activity (Gómez del Campo et al., 2002; Kliewer et al., 1983).

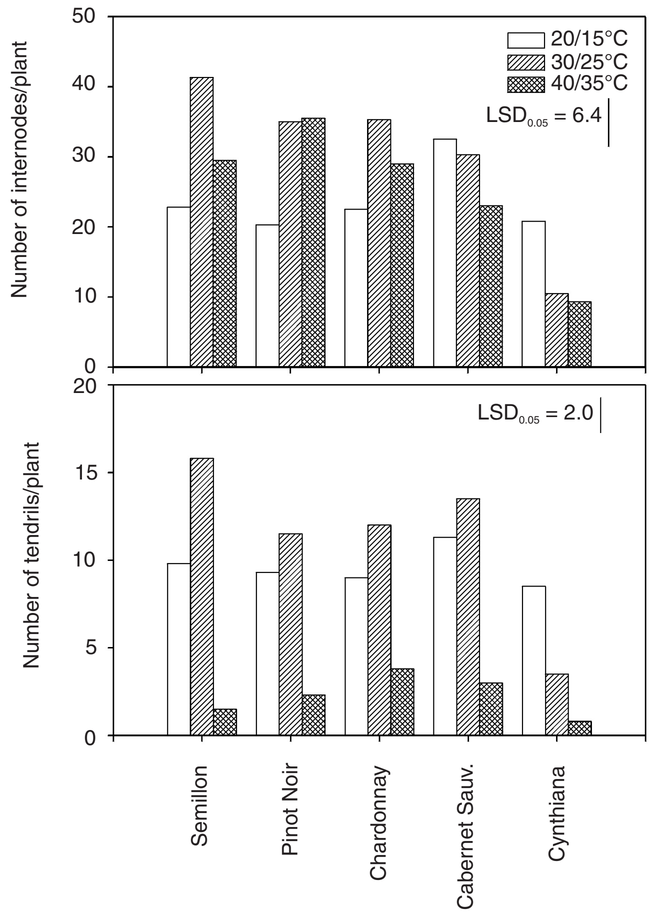
Shoot length increased in all the European cultivars, except 'Cabernet Sauvignon', but decreased in 'Cynthiana' as temperature increased form 20/25 to 30/25°C (Figure 2B). 'Pinot Noir' shoot length increased by 115% compared with 67% reduction in 'Cynthiana'. Significant reduction in shoot length was observed in all the cultivars as temperature increased from 30/25 to 40/35°C. Shoot length was correlated to number of leaves (r = 0.70) (Figure 1A); thus, the decline in number of leaves at 40/35°C in 'Cynthiana' was due to a reduction in shoot length.

Shoot biomass of 'Cabernet Sauvignon' increased by 72% as temperature increased from 20/15 to 30/25°C but decreased by 62% in 'Cynthiana' (Figure 3C). There were no differences in shoot biomass at 40/35°C between the European cultivars, whereas a 76% reduction in 'Cynthiana' was observed compared with that at 30/25°C. Shoot biomass was correlated with total LA (r = 0.74) (Figure 1B) and leaf biomass (r = 0.67) (Figure 1C). A reduction in leaf and shoot biomasses may be attributed to reduction in photosynthesis, leaf senescence (Bravdo et al., 1972; Miller et al., 1996), or lack of movement of photosynthetic assimilates among different sinks (Naor et al., 2002).

As temperature increased form 20/15 to 30/25°C, number of internodes increased in 'Semillon', 'Pinot Noir', and 'Chardonnay' by 78, 75, 52%, receptively, but decreased by 50% in 'Cynthiana' (Figure 3A). 'Pinot Noir' produced the most number of internodes at 40/35°C, while 'Cynthiana' produced the least number of internodes. All the European cultivars produced more tendrils at 30/25°C than 'Cynthiana' (Figure 3B). At 40/35°C, 'Chardonnay' produced more tendrils than 'Cynthiana'. The 40/35°C reduced number of tendrils in 'Cynthiana' by 90% compared with vines at 20/15°C.

Differences in LA and leaf biomass between the American and the European cultivars may suggest that the two types of grape, have adapted different mechanisms to survive prolonged exposure to high temperature. 'Cynthiana' meristem activity, as measured by the number of shoots (Figure 2A), shoot length (Figure 2B), and number of internodes (Figure 3A) ceased, which inhibited leaf production. Nevertheless, the European cultivars under high temperature produced leaves on the lat-

FIGURE 3. Number of internodes and tendrils of four European (*Vitis vinifera* L.) winegrape cvs. 'Semillon', 'Pinot Noir', 'Chardonnay', and 'Cabernet Sauvignon', and one American (*Vitis aestivalis* Michx.) winegrape cv. 'Cynthiana' subjected to 20/15°C ± 1, 30/25°C ± 1, or 40/35°C ± 1 D/N temperatures, 16/8 hr D/N photoperiods, and 450 μmol/m²/s PAR for 28 days. Values are mean of 8 plants (n = 8).

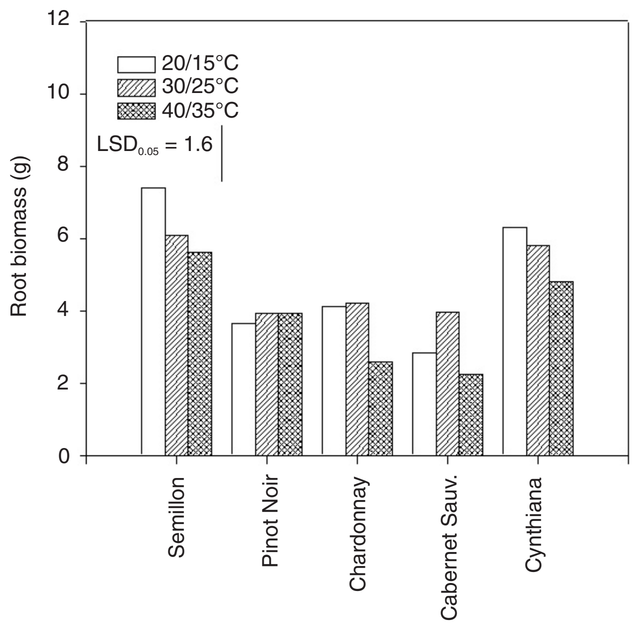


eral and primary shoots. These results suggested that the meristem activity of the European cultivars is relatively less sensitive to high temperature than that of the American cultivar. Vegetative growth of grapevine is due to rapid cell division and enlargement (Vuksanovic, 1984). In this study, high temperature might have a negative effect on cell division and elongation, which caused a reduction in vegetative growth. Leaf morphology of the vines may also have played a role in their response to high temperature. It has been reported that a vine with large leaves is more efficient under water stress than a vine with small leaves (Bravdo et al., 1972). In this study, in spite of significant reduction in number of leaves under high temperature, 'Cynthiana' under field conditions generally produces good yield. This indicates that 'Cynthiana' in the field takes advantage of the early-season mild temperatures, around 20°C, to produce enough vigor and large leaves to survive the late-season high temperatures during which growth ceases. It can be suggested that 'Pinot Noir' with the greatest number of internodes and shoots of at 40/35°C is relatively more resistant to high temperature than the other cultivars.

Root growth of 'Cynthiana' and 'Semillon' was enhanced by 20/15°C compared with roots of the other cultivars (Figure 4). As temperature increased from 30/15 to 40/35°C, root growth of 'Chardonnay' and 'Cabernet Sauvignon' was reduced by 40 and 43%, respectively, whereas no reduction was observed in 'Pinot Noir'. Although root growth of 'Semillon' and 'Cynthiana' at 40/35°C was greater than the other cultivars, the total vegetation to root ratio (data not shown) was smaller than the other cultivars. Root growth was negatively correlated with the total vegetation to root ratio ($r = -0.66$), and the latter was correlated to the number of leaves ($r = 0.50$). These results indicated that roots of 'Cynthiana' and 'Semillon' were less susceptible to high temperature than the shoots.

Specific leaf weight (SLW) of 'Cynthiana' at 40/35°C was the highest among the other cultivars (Table 1). It is reported that changes at the structural levels of photosynthetic apparatus can reduce growth and increase SLW (Kosobrukhov et al., 2004). Leaf area ratio (LAR) at 40/35°C of 'Cynthiana' was significantly lower than that of the European cultivars. A positive correlation between LAR and dry matter was reported (Veneklass et al., 2000). Results of this study showed that the European cultivars generally invested in producing more shoots than roots compared with 'Cynthiana'. This assessment agrees with earlier report that most of the photosynthetic assimilates of plants with a large shoot-to-root ratio is used for shoot growth, rather than root growth (Iersel and Kang, 2002).

FIGURE 4. Root biomass of four European (*Vitis vinifera* L.) winegrape cvs. 'Semillon', 'Pinot Noir', 'Chardonnay', and 'Cabernet Sauvignon', and one American (*Vitis aestivalis* Michx.) winegrape cv. 'Cynthiana' subjected to 20/15°C ± 1, 30/25°C ± 1, or 40/35°C ± 1 D/N temperatures, 16/8 hr D/N photoperiods, and 450 μmol/m²/s PAR for 28 days. Values are mean of 8 plants (n = 8).



CONCLUSIONS AND GROWER BENEFITS

Prolonged exposure to high temperature under controlled environmental conditions significantly reduced vegetative growth of the five cultivars, but the two types of grapes had different growth patterns under heat stress. Meristematic activity and leaf growth of the American cultivar ceased under high temperature, whereas shoot growth of the European cultivars continued, and consequently new leaves were developed on the lateral and primary shoots. Although 'Cynthiana' is a good winegrape, growth and yield reduction can be expected under prolonged high temperature conditions. Therefore, the tested European cultivars in this study have a potential for growth under the summer conditions of south central Kansas. Future studies will examine them under field conditions.

TABLE 1. Specific leaf weight (SLW) and leaf area ratio (LAR) of four European (*Vitis vinifera* L.) winegrape cvs. 'Semillon', 'Pinot Noir', 'Chardonnay', and 'Cabernet Sauvignon', and one American (*Vitis aestivalis* Michx.) wine grape cv. 'Cynthiana' subjected to 20/15°C ± 1, 30/25°C ± 1, or 40/35°C ± 1 D/N temperatures, 16/8 hr D/N photoperiods, and 450 μmol/m^2/s PAR for 28 days. Values are mean of 8 plants (n = 8).

Cultivar	SLW ($mg.dm^{-2}$)	LAR ($dm^{-2}.g^{-1}$)
	------------20/25°C D/N------------	
Semillon	304a	1.88a
Pinot Noir	310a	1.60b
Chardonnay	318a	1.81ab
Cabernet Sauvignon	298a	1.66b
Cynthiana	335a	1.70ab
	------------30/25°C D/N------------	
Semillon	272bc	2.24a
Pinot Noir	249c	1.88bcd
Chardonnay	273abc	2.06abc
Cabernet Sauvignon	277abc	1.73d
Cynthiana	314a	1.96b
	------------40/35°C D/N------------	
Semillon	394b	1.74a
Pinot Noir	383b	1.75a
Chardonnay	414b	1.77a
Cabernet Sauvignon	384b	1.80a
Cynthiana	525a	1.16b

Mean separation was performed by Fisher's LSD test ($P < 0.05$)

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