Variety Trials

'Sunbelt' as a Possible 'Concord' Juice Grape Partner in a Warming World

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SUMMARY. The juice grape (*Vitis labruscana*) cultivar Sunbelt has been reported to ripen more uniformly than the cultivar Concord in warm climates; thus, 'Sunbelt' might be useful as either a blending partner with or replacement for 'Concord' as global climate change intensifies. We conducted a 4-year field trial to evaluate 'Sunbelt' alongside 'Concord' in arid southeastern Washington. 'Concord' yields were on the average 57% higher than 'Sunbelt' yields because 'Concord' vines produced more shoots of higher fruitfulness and consequently had more clusters. The 31% larger berries of 'Sunbelt' were insufficient to compensate for its lower cluster number. Conversion from hand pruning to minimal (machine) pruning had no consistent influence on yield in either cultivar. Juice soluble solids, titratable acidity (TA), red color intensity, and color hue were significantly higher in 'Sunbelt' than 'Concord', whereas pH and potassium were often similar. Both cultivars cold acclimated in autumn and deacclimated in spring, but hardiness varied during winter depending on prevailing temperatures. With some exceptions, the two cultivars had similar bud, phloem, and xylem hardiness. When differences were significant, 'Sunbelt' was 1 to 4 °C less hardy than 'Concord' and also tended to deacclimate more readily in spring. The results from this study indicate that 'Sunbelt' shows promise as a blending partner with or an alternative to 'Concord' for warm vineyard sites or growing seasons even in regions with cold winters.

The classic American juice-grape cultivar Concord was developed in the mid-1800s in Massachusetts (Cahoon, 1986; Schofield, 1988). Its parentage is predominantly the wild northern fox grape (*Vitis labrusca*), but one male grandparent

was the European wine grape (*Vitis vinifera*) cultivar Sémillon (Huber et al., 2016). In the early 1900s the cultivar was planted in Washington's

Yakima Valley (Irvine and Clore, 1997), which now accounts for nearly half of the national annual juice-grape production. Concentrate from 'Concord' grapes is mainly used to produce juice, jelly, jam, and preserves, whose characteristic "foxy" aroma derives from the volatile ester methyl anthranilate (Shure and Acree, 1994; Wang and De Luca, 2005). Demand for 'Concord' grapes has increased in recent decades after claims that the polyphenols in 'Concord' have beneficial health effects. Owing to its fox grape parentage, 'Concord' is well adapted to northern latitudes but does not cope well with high summer temperatures and under such conditions suffers from uneven ripening within and between clusters, leading to poor juice color (Keller et al., 2004; Moore et al., 1993).

The cultivar Sunbelt originated from a seedling derived from an open-pollinated 'Concord' vine in Arkansas and was released in 1993 (Moore et al., 1993). It has been reported to ripen more evenly than 'Concord' in warm climates, and like 'Concord', it is resistant to important fungal diseases (Moore et al., 1993; Striegler et al., 2002). However, its productivity and winter survival in northern latitudes are unknown. Experiments conducted in Arkansas suggest that low yields may be a concern that could limit adoption by growers (Morris et al., 2007). Nevertheless, global climate change and associated higher frequency of heat waves during the growing season (White et al., 2006) might increase the future significance of 'Sunbelt' for the grape juice industry in the United States. For example, future climate scenarios provided by the University of Washington Climate Impact Group predict a statewide average warming trend by

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
28.3495	oz	g	0.0353
93.0102	oz/ft	g·m ⁻¹	0.0108
2.2417	ton(s)/acre	Mg·ha ⁻¹	0.4461
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

2040 of 1 to 2 °C for the winter season and 1.5 to 3 °C for the growing season (Mote and Salathé, 2010). A 1 °C rise in average temperature will add 214 growing-degree days (base 10 °C) to the April–October growing season (Keller, 2010). It is therefore highly desirable to test alternatives should the quality of ‘Concord’ juice begin to decline.

Despite the overall warming trend, cold damage remains a concern for grape production in northern latitudes. ‘Concord’ is generally cold hardy, especially in midwinter (Ferguson et al., 2011, 2014). Nevertheless, it can occasionally succumb to cold damage during the acclimation and deacclimation periods in the fall and spring, and its early budbreak may be problematic in sites that are prone to spring frosts (Ferguson et al., 2014). Thus, the predicted increase in temperature variation (Semenov, 2012), could be a set-up for cold damage. Therefore, it is also important to determine the dynamic changes in cold hardiness of ‘Sunbelt’ during the dormant season. The aim of this study was to evaluate ‘Sunbelt’ as a potential blending partner with or replacement for ‘Concord’. The study was conducted over 4 years to account for annual climate variation.

Materials and methods

PLANT MATERIAL AND EXPERIMENTAL DESIGN. The experiment was conducted in a vineyard at the Irrigated Agriculture Research and Extension Center near Prosser, WA (lat. 46.29430°N, long. 119.74295°W, elevation 364 m), from 2007 through 2010. The vineyard was planted in 1999 to own-rooted ‘Concord’ grapes at 6 ft between vines in north-south-oriented rows of 60 vines each and spaced 9 ft apart on an about 2% south-facing slope. In 2004, we removed 66 vines and replaced them with own-rooted ‘Sunbelt’ grapes that had been planted in 1999 in a nearby vineyard. This allowed for direct comparison of the two cultivars in the same location. The experiment was designed as a complete randomized block with four within-row replicates of 6–20 consecutive vines each. We used three vines per replicate and cultivar as data vines, pairing ‘Concord’ and ‘Sunbelt’ from adjacent rows.

The soil is a well-drained, uniformly deep (>1 m) Shano silt loam with pH 8.0 and <0.3% organic matter (U.S. Department of Agriculture, 2016). A permanent volunteer-species cover was grown between rows, and a 4-ft herbicide strip was maintained under the vines. No other pesticides were applied during the study period. The vineyard was drip irrigated to avoid plant water stress, using pressure-compensated emitters with a flow rate of 2 L·h⁻¹, spaced 3 ft apart. Nitrogen (N) fertilizer was applied annually as liquid urea ammonium nitrate (UN32) at a rate of 30 lb/acre N by fertigation through the drip system; the rate was split evenly between the six-leaf, bloom, and fruit-set stages. Vines were trained to a bilateral cordon on a single wire 6 ft above the ground and hand-pruned in winter to about 100 buds per vine. In Winter 2008–09, we transitioned the vines to minimal pruning, which consisted of mechanically hedging about 1 ft on either side of the wire and skirting about 1 ft below the wire, whereas no pruning was conducted above the wire.

DATA COLLECTION. Daily weather data were collected from a Washington State University AgWeatherNet (Washington State University, 2017) station located at the same elevation <1 km from the vineyard. We estimated growing-degree days from daily mean temperatures (base 10 °C) from 1 Apr. through 31 Oct. We monitored grapevine phenology separately for the two cultivars. We recorded pruning weights in the two winters before and after the 2007 growing season but not after the transition to minimal pruning; canes were counted each year. We determined yield components as follows: flowers per cluster and percent fruit set were estimated by counting calypters collected in gauze bags (1-mm perforations) and berries on the same clusters (Keller et al., 2001); yield, clusters per vine, and mean berry weight were determined at harvest and used to estimate clusters per shoot and berries per cluster. The two cultivars were always harvested on the same date. We collected samples of 100 berries per replicate at harvest, and weighed and froze them for later analysis of soluble solids, TA, pH, and anthocyanin color as described previously (Keller et al., 2004). Juice

potassium (K⁺) was measured as described by Harbertson and Harwood (2009).

Cold hardiness of dormant buds and cane vascular tissues was monitored each winter. We sampled sections spanning nodes four to seven of 1-year-old canes weekly or biweekly from late September through early April. We measured cold hardiness by differential thermal analysis (DTA) using the protocol established by Mills et al. (2006). Measurements were taken on four replicates of five buds each or two 3-cm internode sections each. Cold hardiness was expressed as lethal temperature for 50% of the buds (bud LT₅₀), 10% phloem injury (phloem LT₁₀), or 10% xylem injury (xylem LT₁₀).

STATISTICAL ANALYSIS. Data were analyzed using Statistica (version 12; StatSoft, Tulsa, OK). The pH values were converted to H⁺ concentrations for data analysis, and the means were converted back to pH for presentation. Effects of cultivar and year and their interactions were analyzed by two-way analysis of variance (ANOVA). Because interactions were very often significant, cultivar effects within years and year effects within cultivars were analyzed by one-way ANOVA. We used Fisher’s least significant difference test for post hoc means comparisons when year effects were significant. Cold-hardiness data were analyzed using repeated measures ANOVA within each year. Associations between key response variables were tested by correlation analysis, and curves were fitted using the negative exponentially weighted smoothing procedure.

Results and discussion

WEATHER, PHENOLOGY, AND VINE SIZE. Cumulative growing degree days for the 2007, 2008, 2009, and 2010 growing seasons were 1383, 1331, 1479, and 1292 °C, respectively (long-term average 1409 °C). Clearly, 2009 was the warmest growing season during the study period and 2010 the coolest. The lowest temperatures reached during the 2007–08, 2008–09, 2009–10, and 2010–11 dormant seasons were –13.8 °C (24 Jan. 2008), –16.1 °C (23 Dec. 2008), –16.0 °C (8 Dec. 2009), and –16.5 °C (24 Nov. 2010), respectively. Annual precipitation

during 2007, 2008, 2009, and 2010 was 208, 130, 126, and 256 mm, respectively (long-term average 178 mm). Buddbreak typically occurred in the second half of April, bloom and fruit set around the middle of June, and veraison (beginning of ripening) in the second half of August. The harvest date varied from late September (2007) to mid-October (2010). All of these phenological stages occurred simultaneously in ‘Concord’ and ‘Sunbelt’. ‘Sunbelt’ pruning weights (176 g·m⁻¹ of canopy) were only about half those of ‘Concord’ (382 g·m⁻¹) at the beginning of the study but were not significantly different at the end of the 2007 growing season (data not shown), before the vines were converted to minimal pruning. We did not measure pruning weights after the change in pruning method, because they are not a meaningful measure of vine size for minimally pruned vines (Keller et al., 2004).

YIELD AND ITS COMPONENTS. The yield of ‘Concord’ (4-year average 12.7 kg/vine or 25.2 Mg·ha⁻¹) was markedly higher than that of ‘Sunbelt’ (4-year average 8.1 kg/vine or 16.1 Mg·ha⁻¹) in 2 out of 4 years (Table 1). Earlier studies aimed at increasing ‘Sunbelt’ yields had evaluated grafting and increasing shoot numbers by horizontal canopy division (i.e., two fruiting wires instead of one) or mechanical and minimal pruning (Morris et al., 2007; Striegler et al., 2002). Similarly, ‘Concord’ yields generally increased with increasing bud numbers left at pruning and thus were higher with minimal pruning than with hand pruning (Cawthon and Morris, 1977; Keller

et al., 2004; Morris et al., 1983). However, none of those previous studies had compared ‘Sunbelt’ directly with ‘Concord.’ Here we changed the pruning strategy from hand pruning to minimal pruning before the 2009 growing season, and in 2010 the two cultivars had similar yields. Yields varied considerably from year to year, but less so in ‘Sunbelt’ than in ‘Concord’ (Table 1). Nonetheless, there was no evidence of biennial bearing in either cultivar; although yields of individual vines varied from 5 to 24 kg/vine in ‘Concord’ and from 2 to 14 kg/vine in ‘Sunbelt’ (Fig. 1), the correlation between current-year yields and prior-year yields was not significant (‘Concord’: $r = -0.27$, $P = 0.11$) or positive (‘Sunbelt’: $r = 0.38$, $P = 0.02$). An inverse correlation would be expected with a biennial bearing pattern. Moreover, individual yield components varied mostly independently of one another both between cultivars and among years, with the exception that ‘Concord’ had the smallest clusters in 2009 when the switch to minimal pruning led to unusually high cluster numbers per vine (Table 1).

Crop yields were mostly driven by cluster numbers per vine (Fig. 1A), and these in turn were mostly driven by shoot numbers per vine (Fig. 1B), in agreement with earlier observations in ‘Concord’ (Cawthon and Morris, 1977; Keller et al., 2004; Morris et al., 1983). Consequently, yield increased as the number of shoots increased in both ‘Concord’ ($r = 0.55$, $P < 0.001$) and ‘Sunbelt’ ($r = 0.68$, $P = 0.01$). In ‘Concord’, moreover, cluster numbers per shoot

were as important as shoot numbers in influencing the overall variation in yield ($r = 0.51$, $P < 0.001$), but cluster numbers were less important in ‘Sunbelt’ ($r = 0.36$, $P = 0.01$). Across cultivars, the shoot number was a somewhat stronger determinant of yield ($r = 0.69$, $P < 0.001$) than was the number of clusters per shoot ($r = 0.50$, $P < 0.001$). Cluster weight was of minor importance for yield in ‘Sunbelt’ ($r = 0.33$, $P = 0.02$) and had no effect in ‘Concord’ ($r = 0.03$, $P = 0.86$) and across cultivars ($r = -0.001$, $P = 0.99$). Unlike in ‘Concord’, there was no further increase in ‘Sunbelt’ cluster numbers above about 60 shoots/vine. Moreover, in ‘Sunbelt’ but not in ‘Concord’, there was a trend toward declining cluster numbers per shoot above 60 shoots/vine (33 shoots/m of canopy). These results suggest that high canopy density might impair bud fruitfulness in ‘Sunbelt’ but not ‘Concord’. Therefore, decreasing pruning severity by minimal pruning might have only limited potential to increase ‘Sunbelt’ yields in the long term.

Thus the higher cropping potential of ‘Concord’ was mainly because of its propensity to grow more shoots than ‘Sunbelt’. In addition, in 2 of the 4 years ‘Concord’ also had higher bud fruitfulness (i.e., more clusters per shoot) than did ‘Sunbelt’ (Table 1). These two factors led to 83% more clusters per vine in ‘Concord’ on the average. Each year, the mean cluster number per vine in ‘Concord’ was higher than 150, whereas in ‘Sunbelt’ the mean was always below 150 (Table 1). ‘Sunbelt’ tended to have bigger flower clusters (i.e., more flowers per inflorescence) but lower fruit set

Table 1. Yield and yield components of field-grown ‘Concord’ and ‘Sunbelt’ juice grapes at Prosser, WA, from 2007 through 2010.

	Concord				Sunbelt			
	2007	2008	2009	2010	2007	2008	2009	2010
Yield (kg/vine) ^z	14.2* a ^y	10.1 b	16.2* a	10.2 b	4.8 b	8.6 a	10.1 a	8.8 a
Shoots (no./vine)	63* c	57* c	103* a	80* b	38 c	44 bc	69 a	52 b
Clusters (no./vine)	173* b	162 b	328* a	187* b	70 b	137 a	132 a	124 a
Clusters (no./shoot)	2.6* ab	2.7 ab	3.0* a	2.4 b	1.9 c	3.0 a	2.0 c	2.4 b
Cluster wt (g) ^z	86* a	63 b	51* c	57* bc	71 ab	63 b	76 a	72 ab
Flowers (no./cluster)	n.d. ^x	145 ab	156 a	121* b	n.d.	167	164	173
Fruit set (%)	n.d.	29* a	12 b	28* a	n.d.	16	14	18
Berries (no./cluster)	33* a	26* b	20 c	22 bc	21	20	20	22
Berry wt (g)	2.63*	2.44*	2.60*	2.67	3.39 b	3.14 b	3.81 a	3.23 b

^z1 kg = 2.2046 lb, 1 g = 0.0353 oz.

^yAsterisk indicates significant difference between cultivars within years (analysis of variance, $P < 0.05$); different letters indicate significant differences among years within cultivars (Fisher’s least significant difference test, $P < 0.05$).

^xNot determined.

than ‘Concord’ (Table 1). In both cultivars, percentage fruit set was negatively correlated with the number of flowers per inflorescence ($r = -0.71$, $P < 0.001$). Consequently, the number of berries per cluster varied independently of flower number, and ‘Concord’ only had more berries per cluster than ‘Sunbelt’ when the vines were hand-pruned but not when they were minimally pruned. Although ‘Sunbelt’ had 31% larger berries (average 3.4 g) than ‘Concord’ (average 2.6 g), this did not compensate for the lower cluster number of the former.

FRUIT COMPOSITION. Grape juice from ‘Sunbelt’ generally had higher soluble solids, TA, red color intensity, and color hue (redness) than did ‘Concord’ juice, whereas the pH was similar, and K^+ varied from much lower to slightly higher in ‘Sunbelt’ (Table 2). Because the two cultivars were harvested on the same day, the higher soluble solids of ‘Sunbelt’ berries could partly be attributed to lower yields. Indeed, soluble solids and yields were negatively correlated

both within and across cultivars (Fig. 2), and the lowest soluble solids in ‘Concord’ but not ‘Sunbelt’ (Table 2) were recorded in the year with the heaviest crop after conversion to minimal pruning (Table 1). Higher yields tend to delay or slow down sugar accumulation and are often associated with slower fruit ripening (Cawthon and Morris, 1977; Keller, 2015). Consequently, heavily cropped juice grapes may require some extra time to achieve adequate fruit maturity (Keller et al., 2004; Morris and Cawthon, 1980; Morris et al., 1983).

However, the other juice quality parameters were unaffected by yield. On the contrary, the lower-yielding ‘Sunbelt’ had higher TA than did ‘Concord’ despite the higher soluble solids of the former (Table 2). Because advanced fruit maturity is generally associated with low TA (Keller, 2015), the cultivar difference in TA indicates that ‘Sunbelt’ either produces more organic acids than ‘Concord’ or is better able to retain (malic) acid during ripening. Indeed, the pH

of ‘Sunbelt’ juice was mainly driven by TA ($r = -0.82$, $P = 0.001$) rather than K^+ ($r = 0.28$, $P = 0.50$). By contrast, the pH of ‘Concord’ juice was much more dependent on K^+ ($r = 0.66$, $P = 0.005$) instead of TA ($r = -0.23$, $P = 0.47$). In ‘Concord’ but not in ‘Sunbelt’ the intensity of juice color because of anthocyanins increased as soluble solids increased ($r = 0.66$, $P = 0.005$). A similar sugar dependence of anthocyanin accumulation was previously noted for ‘Concord’ (Keller et al., 2004). However, the 78% higher color of ‘Sunbelt’ juice is especially noteworthy because it occurred independently of any variation in yield or soluble solids, and because ‘Sunbelt’ berries were almost one-third larger than ‘Concord’ berries and thus had a lower skin:juice ratio. Indeed, juice color was not correlated with berry weight within either cultivar, and the correlation was positive rather than negative across cultivars ($r = 0.61$, $P < 0.001$). This indicates that ‘Sunbelt’ has a much greater capacity for anthocyanin biosynthesis in the berry skin than does ‘Concord’. Therefore, ‘Sunbelt’ may be an interesting blending cultivar to improve the color of grape juice. Moreover, because juice processors often pay higher prices for grapes with higher soluble solids (over the last 10 years, quality bonuses paid in Washington have varied from about \$3.30 to \$8.20 per ton for each 1% increment in soluble solids), the lower yield of ‘Sunbelt’ could be partially offset by higher returns per unit crop. The higher soluble solids also would require less energy input during processing to produce juice concentrate. A field trial conducted in California found that juice produced from

Fig. 1. Relationship between cluster number per vine and yield (A), and between shoot number and cluster number per vine (B) of field-grown ‘Concord’ and ‘Sunbelt’ juice grapes at Prosser, WA. Data from 2007 through 2010 were pooled; all correlations were significant at $P < 0.001$ ($n = 48$); 1 kg = 2.2046 lb.

Table 2. Fruit composition at harvest of field-grown ‘Concord’ and ‘Sunbelt’ juice grapes at Prosser, WA, from 2007 through 2010.

	Concord				Sunbelt			
	2007	2008	2009	2010	2007	2008	2009	2010
Soluble solids (%)	16.6* a ^y	17.9 a	14.3* b	17.8* a	21.8 a	18.6 b	19.7 b	19.4 b
Titrate acidity (%) ^z	1.10* c	1.37* a	1.26 b	1.36* ab	1.41	1.52	1.46	1.50
pH	3.21 a	3.07 b	2.96 c	3.25 a	3.15 a	2.97 b	2.97 b	3.17 a
K^+ (%)	0.10 b	0.17* a	0.21* a	0.21* a	n.d. ^x	0.15 b	0.24 a	0.10 c
Red color (A_{520}) ^z	8.3*	9.2*	7.6*	10.0*	13.3 b	15.1 b	14.6 b	19.9 a
Color hue (A_{520}/A_{420})	1.0* b	2.2* a	1.2* b	2.1* a	2.4 a	2.4 a	1.8 b	2.6 a

^zValues given as $A_{\text{subscript}}$ refer to absorbance at the wavelength shown in the subscript; 1% = 10 g·L⁻¹.

^yAsterisk indicates significant difference between cultivars within years (analysis of variance at $P < 0.05$); different letters indicate significant differences among years within cultivars (Fisher's least significant difference test at $P < 0.05$).

^xNot determined.

minimally pruned ‘Sunbelt’ grapes was preferred over that from mechanically and manually pruned vines (Striegler et al., 2002).

COLD HARDINESS. Each year both cultivars showed typical patterns

Fig. 2. Relationship between yield and fruit soluble solids of field-grown ‘Concord’ and ‘Sunbelt’ juice grapes at Prosser, WA. Data from 2007 through 2010 were pooled; correlations were significant at $P < 0.01$ ($n = 16$); 1 kg = 2.2046 lb.

of autumn cold acclimation (mid-October through mid-December), midwinter hardiness (mid-December through early February), and spring deacclimation (early February through early April). During the acclimation phase, the buds were up to 10 °C less hardy than the xylem, but this difference decreased by midwinter (Fig. 3). The phloem was typically 7 to 10 °C less hardy than the xylem (data not shown). Grapevines can recover from severe phloem injury, but xylem injury is generally lethal (Keller, 2015; Keller and Mills, 2007). Hardiness levels in midwinter reached about –31 °C for bud LT₅₀, –22 °C for phloem LT₁₀, and –33 °C for xylem LT₁₀. During the autumn acclimation period, there were no differences in bud LT₅₀ in the first 3 years and on only one sample date in the last year, when ‘Sunbelt’ was less hardy than ‘Concord’ (Fig. 3). In midwinter, bud LT₅₀ differences were recorded

on 2, 1, 0, and 1 sampling dates in 2007–08, 2008–09, 2009–10, and 2010–11, respectively. Bud LT₅₀ showed more differences during the deacclimation period in spring, when on 46% of the sampling dates ‘Sunbelt’ buds were 1 to 4 °C less hardy than ‘Concord’ buds. Xylem LT₁₀ of ‘Sunbelt’ was significantly higher than that of ‘Concord’ on 1, 0, 2, and 2 sampling dates during the 2007, 2008, 2009, and 2010 acclimation phases, respectively (Fig. 3). In midwinter, xylem LT₁₀ was different on 1, 1, 0, and 2 sampling dates in 2007–08, 2008–09, 2009–10, and 2010–11, respectively. Similar to the buds, more differences in xylem LT₁₀ were recorded during the deacclimation period: across years values were significantly different on 35% of sampling dates. Phloem LT₁₀ of ‘Sunbelt’ was significantly higher than that of ‘Concord’ on only 1, 3, 2, and 1 sampling dates during the 2007–08, 2008–09, 2009–10, and 2010–11 dormant seasons, respectively (data not shown). When differences in xylem or phloem hardiness did occur, ‘Sunbelt’ was generally 1 to 2 °C less hardy than ‘Concord.’

Despite its reputation as a warm-climate ‘Concord’-type grape (Moore et al., 1993; Striegler et al., 2002), ‘Sunbelt’ was almost as cold-hardy as ‘Concord’. The two cultivars generally had LT values that were within about 2 °C of each other, and they differed mainly during the deacclimation period in spring. Rates of deacclimation and time of budbreak during this period have been shown to be influenced by geographic origin of grape cultivars. Although more southerly and coastal cultivars tend to be more vulnerable to winter damage compared with more northerly and inland cultivars, the latter have a propensity to deacclimate and break bud earlier in spring (Ferguson et al., 2014). In general, however, buds and cane vascular tissues were so hardy that no cold damage was observed in this study. The only exception occurred in late 2010 after an unusually warm autumn, when the vines had not fully acclimated to withstand the –16.5 °C registered on 24 Nov. (Fig. 3). The lethal temperature (LT₅₀) for both ‘Concord’ and ‘Sunbelt’ buds measured just before this cold event was –15.8 °C. Bud dissection revealed

Fig. 3. Dormant-season changes in minimum/maximum daily air temperatures (gray area) and cold hardiness (symbols), measured as lethal temperatures (LT) for 50% of buds and 10% of cane xylem, of field-grown ‘Concord’ and ‘Sunbelt’ juice grapes at Prosser, WA, from 2007 through 2011. Values are means ($n = 4$); asterisks above LT values indicate significant cultivar effect on buds; crosses below LT values indicate significant cultivar effect on xylem ($P < 0.05$); $(^{\circ}\text{C} \times 1.8) + 32 = ^{\circ}\text{F}$.

a range of 15% to 25% primary bud damage with no significant difference between cultivars, thus confirming the DTA measurements. The surviving buds and cane vascular tissues of both cultivars responded to this cold event with a very rapid gain in cold hardiness (Fig. 3).

Conclusion

In a juice grape field trial conducted in arid eastern Washington, 'Concord' produced a significantly heavier crop than 'Sunbelt' in 2 of 4 years. The average yield was 57% higher in 'Concord', largely due to its greater cluster numbers that resulted from higher shoot numbers and higher bud fruitfulness. 'Sunbelt' had much larger berries than 'Concord' but not large enough to compensate for the lower cluster number. Although conversion from hand pruning to minimal (machine) pruning was only partially successful in improving 'Sunbelt' yields, this cultivar had less year to year variation in yield than did 'Concord'. Moreover, juice soluble solids, TA, color intensity, and color hue were generally higher in 'Sunbelt' than 'Concord'. Cold hardiness was slightly lower in 'Sunbelt' than 'Concord', especially during the deacclimation period in early spring, but both cultivars acclimated sufficiently to withstand all but the most extreme temperatures during the dormant season. Thus, 'Sunbelt' might be an interesting blending partner that could supplement 'Concord' to maintain juice color in a warming world that may be associated with more frequent heat waves during the growing season even in regions where winter injury remains a concern.

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