Wine Grape Cultivar Performance in the Four Corners Region of New Mexico in 2010–12

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SUMMARY. Commercial wine grape (Vitis sp.) production in northwestern New Mexico and the greater Four Corners region is now supported by four wineries. The challenges of growing grape vines in northwestern New Mexico include cold winter temperatures and killing spring frosts exacerbated by a semiarid climate and elevations exceeding 1700 m. Nineteen nongrafted European wine grape (Vitis vinifera) and interspecific hybrid wine grape cultivars were planted in 2007 and evaluated between 2010 and 2012. Among European wine grape cultivars, Agria, Malbec, Sangiovese, Viognier, Müller-Thurgau, and Sauvignon Blanc performed poorly or failed altogether. Interspecific hybrid cultivars Baco Noir, Kozma 55, Leon Millot, Chardonel, Seyval Blanc, Siegfried, Traminette, Valvin Muscat, and Vidal Blanc showed greater adaptability to a high-elevation intermountain western U.S. site, yielding on greater than 71% of their vines in each year (except Kozma 55 which only produced on 38% of its vines in 2012 due to severe spring frost damage). We speculate that fruit-bearing shoots on these vines arose from latent buds that survived when primary buds were killed from spring frost events. Once vines were established, grape berry sugar and pH appeared to be within acceptable ranges (3-year mean above 21% soluble solids and juice pH of 3.2), suggesting regional potential to produce favorable wines within acceptable commercial wine grape production ranges. Selection of sites without considerable frost risk and other mesoclimatic variances is critical when considering vineyard establishment at high-elevation locations.

A renaissance in locally produced, locally branded foods is occurring in the Four Corners region, that portion of the southwestern United States where the state boundaries of New Mexico, Arizona, Colorado, and Utah converge. Growers again view fruit crops, including wine grape, as a profitable specialty crop to propel a local agricultural/tourism economy. Current vineyard acreage is 270 ha (Davenport et al., 2008; Keller et al., 2005; Mills et al., 2006); Summerland, BC, Canada (interior), elevation 454 m (Reynolds et al., 2004); and Parma, ID, elevation 750 m (Fallahi et al., 2005; Shelle, 2007). High-elevation trials have been conducted at Willow Creek, NV, elevation 1373 m (Evans et al., 2005) and Grand Junction, CO, elevation 1414 m (Caspari and Montano, 2012; Hamman, 1993; Hamman et al., 1998). Northwestern New Mexico geography and climate closely resembles Grand Junction, CO’s, and northwestern New Mexico growers

Use of trade names does not imply endorsement of the products named nor criticism of similar ones not named.

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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 |
|-----------------------------------|-----------|---------|-----------------------------------|
| 0.4047                            | acre(s)   | ha      | 2.4711                            |
| 29.5735                           | fl oz     | mL      | 0.0338                            |
| 0.3048                            | ft        | m       | 3.2808                            |
| 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                            |
| 2.5900                            | mile2     | km2     | 0.3861                            |
| 1                                 | ppm       | mg kg−1| 1                                 |

\[
(\text{°F} - 32) ÷ 1.8 = \text{°C}
\]

\[
(\text{°C} × 1.8) + 32 = \text{°F}
\]
often reference viticultural work conducted there. As a whole, these studies from low- and high-elevation sites share some similarities with northwestern New Mexico and offer some cultivar performance information for semiarid conditions.

Like Grand Junction, northwestern New Mexico has high solar irradiation, which amplifies minimum–maximum temperatures (Hamman et al., 1998). However, northwestern New Mexico is ~300 m higher in elevation than Grand Junction. A mean temperature decline (temperature lapse rate) of 0.65 °C for every 100 m increase in elevation (Wallace and Hobbs, 2006) can be assumed and temperature lapse rates vary across high-elevation, complex terrain, lee-ward and windward slopes, and valley floors (Minder et al., 2010; Rolland, 2002). Given these site-specific factors, cultivar performance comparisons between sites begin to diverge.

Forgotten in sparsely circulated research reports is the Grape and Wine Production in the Four Corners Region formative work, conducted in the late 1960s and 1970s by Dutt et al. (1981) and Mielke et al. (1980) with cooperators from the New Mexico State University (NMSU) Agricultural Science Center at Farmington (ASC-Farmington). Their work was partially connected to Grand Junction’s early wine grape trials (Mielke et al., 1980). In 1968, the ASC-Farmington trialed 165 wine grape (V. vinifera), fox grape [Vitis labrusca (e.g., ‘Concord’)], muscadine (Vitis rotundifolia), and North American European wine grape, interspecific hybrids, and North American grape cultivars (Table 1) were obtained in Spring 2007 in the form of preredooted cuttings or were propagated at the San Juan College greenhouse (Farmington, NM) from vines located in trials at the NMSU ASCs at Los Lunas and Alcalde, NM. One of the red hybrid cultivars supplied was labeled simply as Kozma without reference to a particular clone. DNA analysis later conducted in June 2013 by University of California Plant Foundation Laboratory (Davis, CA) established that the sample had non-V. vinifera alleles at two of the eight loci tested, indicating a backcross to V. vinifera, perhaps several generations back (J. Dangl, personal communication). Further testing confirmed that the sample matched ‘Kozma csvt 55’, accession number DVTIT 3315, at the National Clonal Germplasm Repository (Davis, CA) and that the DNA profile also showed ‘Pearl of Csaba’ could be a parent, consistent with the published pedigree of ‘Kozma csvt 55’ (Vitis International Variety Catalogue, 2007; J. Dangl, personal communication). Rootstocks were not used in this trial because of the extreme risk of winterkill below the graft union at our high-elevation site.

Vines were planted 3 July 2007 on 4-ft spacing between vines and 12 ft between rows in a north-south orientation, totaling ~1 acre. Vines were trained to the cordon wire between 2007 and 2009 growing seasons as single trunks using a two-wire vertical trellis (simple curtain) system. This was accomplished by training a single cane to the cordon wire located 5 ft aboveground, bending and tying it along the fruiting wire 4 ft in length and allowing shoots to drop over a foliage support wire located 12 inches above the cordon wire. Drip lines with 1.5 L·h⁻¹ emitters spaced every 2 ft provided irrigation to vines, primarily between flowering and veraison, and postharvest. In 2011, 15 inches total water was applied in 2012, that amount increased to 20 inches. Vines were top dressed with compost (450 mg·kg⁻¹ nitrate) in May 2010. Vines received 20 lb/acre nitrogen in the form of urea ammonium nitrate [UAN (32N–0P–0K)] in 2012.

Vines were hand pruned each year during dormancy between late March and early April. Western bindweed (Convolvulus arvensis) control was attained through periodic spot spraying with glyphosate in 2008. Weed control thereafter was attained by hand cultivation bimonthly between vines and by rototilling between rows monthly during the growing season. Beginning in 2012, weed control between vines was done bimonthly using a tractor-mounted under vine weeder (Clemens Radius; Clemens Technologies, Wittlich, Germany).

**Temperature monitoring.** A National Weather Service maximum and minimum thermometer (Nimbus PL; Sensor Instruments, Concord, NH) housed in a regulation, louvered instrument shelter and located ~20 m from the vineyard was used to calculate growing degree days (GDD). Additional on-site weather data were obtained from the New Mexico Climate Center (NMCC, 2013) weather station located at 375 m from the vineyard and consisting of air temperature, relative humidity, solar radiation, wind speed, wind direction, and rain-depth
sensors wired to a datalogger (CR10; Campbell Scientific, Logan, UT). A temperature-only datalogger (Watchdog model 400; Spectrum Technologies, Plainfield, IL) was mounted within the experimental vineyard at the cor- don wire 5 ft aboveground level and used to corroborate official weather station data.

Growing degree days were calcu-
late
ed using a simple daily average with 
a base of 10 °C and no upper limit 
(Winkler et al., 1974) with the follow-
ing formula (McMaster, 1997):

\[
\frac{T_{\text{MAX}} + T_{\text{MIN}}}{2} - T_{\text{BASE}}
\]

if \( \frac{T_{\text{MAX}} + T_{\text{MIN}}}{2} < T_{\text{BASE}} \),

then \( \frac{T_{\text{MAX}} + T_{\text{MIN}}}{2} = T_{\text{BASE}} \)

where \( T_{\text{MAX}} \) is the maximum daily temperature, \( T_{\text{MIN}} \) is the minimum daily temperature, and \( T_{\text{BASE}} \) is the temperature base of 10 °C. The GDD calculated for each day were summed to obtain monthly and annual totals.

**VINE GROWTH ANALYSIS.** Grape phenology was evaluated using the modified E-L (Eichhorn and Lorenz) system (Coombe, 1995), which covers 47 grape growth stages from dormancy, budbreak, bloom, veraison, and harvest to leaf senescence. Excluding harvest date, modified E-L measurements were performed on 16 sampling dates between 9 Apr. and 17 Aug. 2010, nine sampling points between 18 Apr. and 17 Aug. 2011,

| Cultivar     | Abbreviation | Ancestry                          | Origin              |
|--------------|--------------|-----------------------------------|---------------------|
| **Red**      |              |                                    |                     |
| Agria        | AG           | European cultivar: ‘Bikaver 8’ × ‘Gardonyi Geza’ | Hungary             |
| Baco Noir    | BN           | Interspecific hybrid: ‘Folle Blanche’ × ‘Grand Glabre’ | France              |
| Kozma cvt 55 | KZ           | Interspecific hybrid: ‘Seibel 4986’ × ‘Pearl of Csaba’ | Hungary             |
| Leon Millot  | LM           | Interspecific hybrid: ‘M.G. 101–14 O.P.’ × ‘Goldriesling’ | France              |
| Malbec       | MA           | European cultivar: ‘Magdeleine Noire des Charentes’ × ‘Prunelard’ | France              |
| Pinot Noir   | PN           | European cultivar                   | France              |
| Refosco      | RF           | European cultivar                   | Italy               |
| Regent       | RG           | Interspecific hybrid: ‘Diana’ (‘Müller-Thurgau’ × ‘Silvaner’) × ‘Chambourcin’ | Germany             |
| Sangiovese   | SG           | European cultivar                   | Tuscany, Italy      |
| Zinfandel    | ZN           | European cultivar                   | Croatia             |
| **White**    |              |                                    |                     |
| Chardonel    | CD           | Interspecific hybrid: ‘Seyval’ (‘Seibel 5656’ × ‘Seibel 4986’) × ‘Chardonnay’ | Cornell University, Geneva, NY (Reisch et al., 1990) |
| Müller-Thurgau | MT       | European cultivar: ‘Riesling’ × ‘Madeleine Royale’ | Germany             |
| Sauvignon Blanc | SV      | European cultivar                   | Pouilly France, Upper Loire Valley |
| Seyval Blanc | SY           | Interspecific hybrid: ‘Seibel 5656’ × ‘Seibel 4986’ | France              |
| Siegfried    | SF           | Interspecific hybrid: ‘Oberlin 595 S.P.’ (‘Seibel Millardet’ × ‘Gamay Noir’) × ‘Riesling’ complex cross | Germany             |
| Traminette   | TM           | Interspecific hybrid: ‘Joannes Seyve 23416’ × ‘Gewurztraminer’ | Cornell University, Geneva, NY (Reisch et al., 1996) |
| Valvin Muscat™ | VM       | Interspecific hybrid: ‘Muscat Ottonel’ × ‘Muscat du Moulin’ | Cornell University, Geneva, NY (Reisch et al., 2006) |
| Vidal Blanc  | VB           | Interspecific hybrid: ‘Trebbiano Toscano’ × ‘Rayon d’Or’ (‘Seibel 405’ × ‘Seibel 2007’) | France              |
| Viognier     | VI           | European cultivar                   | France              |
and 16 sampling points between 29 Mar. and 30 Aug. 2012. Budbreak was defined as an E-L 4, when green tips of the first leaf tissue were visible (Coombe, 1995), and was recorded as days of year (DOY) elapsed since the start of the current year.

We evaluated E-L stage directly before and after forecasted spring frost events. Spring frosts occurred on two occasions in 2010 (30 Apr. to 2 May and 12 May), 16 Apr. 2011, and 27 May 2012. On the following day’s assessment, frost-damaged vines greater than E-L 4 stage exhibited brown leaves and wilted shoots. Vines were then scored for frost damage using a simple measure, where 0 = no foliar damage and 1 = foliar damage observed. Vine damage per entry was then expressed as a percentage of the total number of vines planted. The probability of spring frost events occurring at the ASC-Farmington site was also calculated using the frost risk (Frisk) model (Snyder and de Melo-Abreu, 2006) and (from) 44-year historical weather data from NMSU-ASC.

Harvest. Before harvest, ≈10–20 berries were randomly pulled from several vines of a given entry about every other day and pressed in the field with a handheld garlic press to yield ≈2 mL of juice for sugar analysis. Seed color and astringency were also examined. Target harvest criteria were berries having >21% soluble solids, using a handheld digital refractometer (PAL-1; ATAGO, Tokyo, Japan), and dark brown, nonastrin- gent tasting seeds. When these criteria were met, all vines for a particular entry with marketable grapes were counted (to calculate percentage vines harvested) and harvested (up to n = 24 vines per entry). Day of harvest was recorded as elapsed number of days from budbreak. Yield was measured by counting and then weighing the total number of clusters harvested from each vine. Directly after weighing, in the laboratory, a composite sample of berries from each entry was passed through a juicer and ≈50 mL of juice was collected. Grape juice was analyzed again for percent soluble solids using the same handheld digital refractometer described previously and for pH using a bench top pH meter (Accumet AR25; Fisher Scientific, Waltham, MA).

Experimental design and data analysis. The trial was configured as a completely randomized design with four plants of the same cultivar in a plot replicated six times for a total of 24 vines per cultivar. Descriptive statistics were performed on grape phenology E-L stages, percentage vines per entry with foliage damage after a spring frost event, and percentage vines per entry yielding marketable grapes. Remaining data were analyzed with SAS software (version 9.2; SAS Institute, Cary, NC) using PROC MIXED and LSMEANS statements because data were unbalanced due to vine mortality in some entries. Means were compared using the PDMIX612 macro formatting tool developed by Saxton (1998) and a user-specified Tukey’s honestly significant difference comparison test to assign letter groupings. Red and white wine cultivars were analyzed and reported separately.

Results and discussion

Temperature monitoring, vine growth, and budbreak. A cultivar × year interaction prevented data pooling in all categories measured (P < 0.0001), spotlighting the variability of northwestern New Mexico’s climate. Between 1 Apr. and 31 Oct. 2010–12, the coolest growing season was in 2011 (1745 GDD (reported in degree celsius)), whereas the warmest was in 2012 (1976 GDD) (Table 2). Average heat unit accumulation for these three growing seasons (1840 GDD) was 61 units greater than the 44-year average for the ASC-Farmington (1779 GDD) (Table 2). When comparing the ASC-Farmington’s 3-year GDD mean to other intermountain western U.S. sites, heat unit accumulation was greater than Summerland, BC, Canada [1143 GDD between 1993 and 1995 (Reynolds et al., 2004)]; Reno, NV [1277 GDD (Evans et al., 2005)]; Parma, ID [1647 GDD between 2002 and 2005 and 1487 GDD over 78 years (Shellie, 2007)]; and slightly less than Grand Junction, CO [1839 GDD between 1964 and 1990 (Hamman, 1993)].

Like other intermountain western U.S. sites, large diurnal temperature swings (around 20 °C difference between minimum and maximum daily temperatures) were observed at the ASC-Farmington throughout the study period as illustrated for 2010 (Fig. 1). Although these warm/cool fluctuations are desirable during berry ripening, temperature extremes during fall, winter, and spring do not permit slow acclimation and deacclimation of vines into and out of winter dormancy, making tissue and buds susceptible to winterkill and spring frost damage (Dani et al., 2012; Fennell, 2004; Mills et al., 2006). Further, although frost period periods at lower-elevation intermountain western U.S. sites, even at higher latitudes, ASC-Farmington’s frost risk period extends well into May (Fig. 1). Opposing forces presented by northwestern New Mexico’s high-elevation extreme diurnal temperature fluctuation and early season heat unit accumulation at northwestern New Mexico’s lower latitude, work to both stimulate budbreak and cause bud mortality in the event of a spring frost event.

Historical data show average frost-free period for the ASC-Farmington is between 20 Apr. and 21 Oct. or 184 frost-free days (Table 2). Using the ASC-Farmington’s 44-year historical weather data and the Frost Risk model (Snyder and de Melo-Abreu, 2006), data indicated a 96% probability of a spring frost (≤–2.2 °C) occurring on 1 Apr. (≈92 DOY) tapering to 56% on 30 Apr. (≈121 DOY), 11% on 15 May (≈136 DOY), down to 0% by 30 May (≈151 DOY). Indeed, vines breaking dormancy before 30 Apr. 2010 (120 DOY), 2 May 2011 (122 DOY), and 27 May 2012 (148 DOY) (Fig. 2 and Table 3) were damaged by frost, particularly early budding cultivars Baco Noir, Kozma 55, Leon Millot, Siegfried, Valvin Muscat, and Chardonel (Fig. 2). Average budbreak dates for red cultivars were 19 Apr. 2010 (109 DOY), 4 May 2011 (124 DOY), and 9 Apr. 2012 (100 DOY) (Table 3). Average budbreak dates for white cultivars were 21 Apr. 2010 (111 DOY), 6 May 2011 (124 DOY), and 12 Apr. 2012 (103 DOY) (Table 3). There was ≈23 to 24 d between average budbreak for red and white grape cultivars, respectively, in 2011 (latest year for budbreak) when compared with 2012 (earliest year for budbreak) due to about a 12.5% difference in heat unit accumulation in 2012 when compared with 2011 (Table 2).

Harvest was completed before occurrence of fall frost, and ‘Leon Millot’ was one of the earliest harvested
among red cultivars while there was less consistency among white grape cultivars (Table 3). Hybrids yielded consistently and on more vines when compared with European wine grape cultivars (Fig. 2 and Table 3) because these vines are capable of yielding a partial crop on canes derived from latent, secondary buds. For instance, among red cultivars, Baco Noir and Leon Millot managed to yield on greater than 88% of their vines, whereas among white cultivars Siegfried, Vidal Blanc, Seyval Blanc, Chardonel, Traminette, and Valvin Muscat produced on >75% of their vines in all years studied (Fig. 2). Yielding in 2010 and 2011, 'Kozma 55' suffered 74% spring frost foliar damage in 2012 and consequently produced grapes on only 38% of its vines that year (Fig. 2 and Table 3). European wine grape cultivars fared much worse than interspecific hybrids. Among red cultivars, Malbec and Sangiovese failed to produce fruit in 2010 and 2011 (Fig. 2 and Table 3) and were removed from the analysis in 2012. 'Agria' yielded in 2010 but failed in 2011 and was also removed from the study in 2012. 'Pinot Noir' and 'Refosco' did not yield in 2010 but managed to produce light crops on surviving vines in 2011 and 2012 (Fig. 2 and Table 3). Among white cultivars, Sauvignon Blanc failed to produce fruit in 2010 and 2011 and was removed from the study in 2012, whereas Viognier and Müller-Thurgau produced only in 2012 (Fig. 2 and Table 3).

Four Corners region winter temperatures sometimes drop below −20 °C for short periods. From 2010 to 2012, extreme winter temperatures recorded at the ASC-Farmingtom were −15.6 °C on 3 Jan. 2010, −21.1 °C on 3 Feb. 2011, and −14.0 °C on 13 Jan. 2012 (Table 2). The coldest winter temperatures recorded during 44 years of measurement at the station were −28.0, −25.6, and −26.7 °C in Jan. 1971, Feb. 1989, and Dec. 1990, respectively (D. Smeal, unpublished data). The years 2010 and 2012 were somewhat similar because vines presumably sustained more damage related to spring frost events than to winter kill. The year 2011 stands out because winter temperatures were colder than 2010 and 2012 and the 2011 spring was generally cooler, permitting a slower deacclimation of vines than in 2010 or 2012. This is probably why vine damage due to spring frost was less problematic in that year than winter-kill. Spring E-L measurements and frost damage assessments combined with lack of harvest data for 'Agria', 'Malbec', 'Müller-Thurgau', 'Sangiovese', and 'Sauvignon Blanc' suggest these cultivars suffered spring frost damage in 2010 and winter budkill during the 2011 winter (Fig. 2 and Table 3). Many of these vines had to

| Growing degree days* | 2010 | 2011 | 2012 | 44-yr (1969–2012) mean |
|----------------------|------|------|------|----------------------|
| April                | 64   | 43   | 98   | 61                   |
| May                  | 148  | 131  | 226  | 183                  |
| June                 | 359  | 351  | 424  | 337                  |
| July                 | 444  | 454  | 439  | 442                  |
| August               | 377  | 443  | 434  | 406                  |
| September            | 290  | 254  | 272  | 261                  |
| October              | 117  | 69   | 83   | 89                   |
| Season (April–October) | 1799 | 1745 | 1976 | 1779                 |
| Average minimum and maximum temp. range (°C)* | | | | |
| January              | −8.7 to 2.6 | −10.3 to 1.5 | −7.3 to 8.1 | −7.2 to 5.0 |
| February             | −4.7 to 6.3 | −7.2 to 7.0 | −4.3 to 9.3 | −4.4 to 8.9 |
| March                | −3.0 to 13.1 | −0.7 to 16.0 | −1.4 to 29.5 | −1.4 to 13.9 |
| April                | 1.0 to 18.7 | 1.8 to 18.6 | 3.2 to 21.4 | 2.1 to 18.7 |
| May                  | 3.8 to 23.0 | 5.3 to 22.4 | 7.7 to 26.9 | 7.1 to 24.3 |
| June                 | 12.1 to 30.4 | 11.7 to 30.8 | 12.2 to 34.1 | 12.0 to 30.3 |
| July                 | 15.9 to 32.0 | 16.2 to 33.4 | 16.0 to 32.3 | 15.8 to 32.8 |
| August               | 14.4 to 29.9 | 15.9 to 32.5 | 16.0 to 32.0 | 15.1 to 31.1 |
| September            | 10.5 to 28.2 | 11.0 to 26.2 | 10.8 to 27.3 | 10.7 to 26.8 |
| October              | 4.8 to 20.2 | 3.9 to 19.0 | 3.0 to 20.8 | 4.2 to 19.7 |
| November             | −4.6 to 10.8 | −1.9 to 11.6 | −0.9 to 14.3 | −2.0 to 11.7 |
| December             | −2.2 to 8.7 | −7.1 to 5.1 | −6.2 to 5.6 | −6.5 to 5.8 |
| Extreme minimum temp/date (°C) | −15.6/3 Jan. | −21.1/3 Feb. | −14.0/13 Jan. | −28/7 Jan. 1971 |
| Spring frost date     | 30 Apr. and 12 May | 2 May | 27 May | 20 Apr. |
| Fall frost date (≤−2.2 °C)  | 26 Oct. | 28 Oct. | 25 Oct. | 21 Oct. |

*Growing degree days are calculated using a simple daily average with a base of 10 °C and no upper limit (Winkler et al., 1974). We calculated GDD in °C; 1.8 × GDD (°C) = GDD (°F).

(1.8 × °C) + 32 = °F.
be retrained, which is why frost damage assessments especially for these European wine grape cultivars is potentially misleading. We did not control the condition of primary buds before bud swell nor after spring frost events. In retrospect, we see such information is valuable for being able to clearly differentiate between buds that were winterkilled or damaged in spring.

Budkill in grape varies by genotype (Mills et al., 2006; Rombough, 2002; Wolf and Cook, 1994). Rombough (2002) reports European wine grape vines are generally hardy to \( \approx -20 ^\circ \text{C} \) with some cultivars from northern Europe reported to withstand temperatures down to \(-29 ^\circ \text{C} \). For two European wine grape cultivars, Mills et al. (2006) reported 94% phloem damage and 30% xylem damage at \(-18 ^\circ \text{C} \) in Chardonnay, and 80% phloem damage at \(-20 ^\circ \text{C} \) and 28% xylem damage at \(-23 ^\circ \text{C} \) in Cabernet Sauvignon. Dami et al. (2012) reported European wine grape cultivars to be most sensitive to subfreezing temperatures, sustaining 93% bud injury at \(-26 ^\circ \text{C} \), whereas hybrids sustained only 12% to 35% primary bud injury. Lisek (2012) reported similar findings in a survey of 40 wine grape cultivars grown in Poland experiencing a winter low of \(-28.1 ^\circ \text{C} \): cultivars Auror, Delaware, Leon Millot, Marechal Foch, Siberia, Saphira, and Seyval received rankings of very resistant or resistant to subfreezing winter temperatures. Similar findings have been reported in western Colorado (Colorado State University, 1996). Reynolds et al. (2004) noted that ‘Kozma 55’ had good potential in Summerland, BC, Canada, whereas Masabni and Wolfe (2007) reported moderate winter injury in the same clone planted in Kentucky.

Because European wine grape cultivars performed so poorly, no further discussion is made for these cultivars in the current report.

Harvest. As vines matured, average clusters per vine ranged from 8.7 in 2010 to 36.6 in 2012 among red cultivars and 21.1 (2010) to 30.7 (2012) among white cultivars (Table 4). Mean total yield per vine ranged from 0.5 kg/vine (2010) to 1.3 kg/vine (2012) for red cultivars, and 1.9 kg/vine (2010) to 1.0 kg/vine (2012) for white cultivars (Table 4). ‘Vidal Blanc’ and ‘Seyval Blanc’ produced fewer clusters and had lower yield weights in 2012 than the previous year possibly due to low N inputs in 2012 in combination with clusters formed from secondary buds. Reynolds et al. (2004) reported declining yield differences in their experimental vineyard treated under certified organic conditions mainly due to low N inputs.

Target soluble solids content was reached in most entries in 2010 and 2011 and to a lesser extent in 2012 (Table 5). Because 2012 sustained above-average temperatures in May and June (Table 2), many cultivars were harvested early in 2012 to prevent widespread sunscald damage. For top-performing red cultivars, percent soluble solids by year (2010, 2011, and 2012, respectively) follows: Bacó Noir (28.0%, 23.4%, and 21.8%), Kosma 55 (26.3%, 21.6%, and 22.9%), and Leon Millot (22.6%, 22.8%, and 18.1%) (Table 5). Percent soluble solids (3-year mean) for white cultivars ranged from 19.9% (Vidal Blanc) to 24.6% (Chardonnel), and ‘Chardonnel’ consistently had the highest sugar content (Table 5). Most cultivars fell within acceptable ranges for juice pH (between 3.0 and 3.8) as reviewed by Kodur (2011). Red cultivar juice pH ranged from 3.3 to 3.4 in 2010, 3.1 to 3.5 in 2011, and 2.9 to 3.2 in 2012. For white cultivars, Traminette had the lowest pH in all 3 years (2.9–3.0) compared with Valvin Muscat (pH 3.4–3.5).

Cultivar recommendations alone are insufficient to avoid risk of crop and/or vine losses due to freeze injury, especially at high elevations like northwestern New Mexico. Excellent resources pertaining to preventing or managing freeze damage risk in vineyards have been published and should also guide growers who have already
Fig. 2. Descriptive statistics for modified Eichorn and Lorenz [E-L (Coombe, 1995)] evaluations for 19 red and white European and interspecific hybrid wine grape cultivars evaluated 2010–12 at the New Mexico State University Agricultural Science Center at Farmington, NM [elevation 1720 m (5643.0 ft)] with percentage vines recording foliar frost damage and percentage vines yielding in parenthesis. Excluding harvest date, modified E-L measurements were performed on 16 dates in 2010, 9 dates in 2011, and 16 dates in 2012. Refer to Table 1 for cultivar abbreviations. Modified E-L 4 (dashed line) indicates budbreak. Percentage frost damage (first number in parentheses) indicates the number of vines out of total vines in a cultivar entry recording foliar damage when measured after 30 Apr. and 12 May 2010, 2 May 2011, and 27 May 2012 frost events. Percentage vines yielding (second number in parentheses) indicates the percentage number of vines out of total vines in a cultivar entry recording grape clusters at harvest.
planted grape vines or who are considering a vineyard. Strategies to mitigate risk associated with winter kill and spring frost include late season irrigation to replenish the root zone after harvest (Davenport et al., 2008; Moyer et al., 2011), training multiple canes from the ground to increase survival potential (Howell, 2003), and late season pruning leaving more buds which are then removed after the last danger of frost (Dami et al., 2012; Howell, 2003). Other strategies include burying canes during winter for bud and cane protection (Kaiser et al., 2008), air mixing using fans and/or overhead sprinklers when temperatures hover at 0°C (Davenport et al., 2008; Snyder et al., 2005), and use of topical foliar sprays before a spring frost event (Francko et al., 2011). Each of these strategies carries an associated cost in terms of time and money invested, and may be cost prohibitive to small-scale producers.

On the other hand, choosing upland sites with good air drainage is the single most important and least expensive method of frost protection (Davenport et al., 2008; Hamman et al., 1998; Howell, 2003; Moyer et al., 2011; Snyder et al., 2005). Even so, we experienced spring frost damage and winter kill between 2010 and 2012 at an upland site. Northwestern New Mexico growers in irrigated valleys, where frost damage and colder winter temperatures are even more likely to occur because of the presence of frost pockets (Moyer et al., 2011), are cautioned to choose sites very carefully before selecting cultivars.

**Conclusion**

This work was conducted at an intermountain western U.S. site above 1700 m. Interspecific hybrids outperformed European wine grape cultivars in establishment and yield. Weather data show northwestern New Mexico begins accumulating heat units in early spring yet late spring freeze events like ones we observed in May in all three measurement years pose a high crop loss risk. Site selection to avoid frost pockets is of utmost importance (along with soil testing for pH, salinity and nutrient content). Every high-elevation grower

### Table 3. Budbreak and harvest for 19 red and white European and interspecific hybrid wine grape cultivars evaluated 2010–12 at the New Mexico State University Agricultural Science Center at Farmington, NM [elevation 1720 m (5643.0 ft)]. Cultivars within berry color are listed in order of average (2010–12) budbreak day of year.

| Cultivar     | Budbreak (day of yr)* | Harvest (days after budbreak) |
|--------------|------------------------|-------------------------------|
|              | Avg 2010–12 2010 2011 2012 | Avg 2010–12 2010 2011 2012 |
| Red          |                        |                               |
| Baco Noir    | 103 105 d 109 c 95 b   | 138 150 a 132 a 131 ab        |
| Kozma 55     | 103 105 d 112 c 93 b   | 140 146 b 137 a 136 a         |
| Sangiovese   | 106 106 d —           | —                             |
| Leon Millot  | 107 106 d 115 c 100 ab | 123 125 d 122 b 122 b         |
| Agria        | 109 109 bcd —        | 141 141 c —                   |
| Refosco      | 112 106 d 131 b 98 ab | 136 — 134 a 137 a             |
| Pinot Noir   | 114 108 cd 130 b 105 a| 124 — 119 b 129 ab            |
| Malbec       | 114 114 a —          | —                             |
| Zinfandel    | 117 112 abc 134 ab 106 a| 132 146 b 115 b 136 a         |
| Regent       | 120 113 ab 141 a 106 a| 124 147 ab 101 c 123 b        |
| Mean         | 111 109 124 100       | 132 142 123 131               |
| Cultivar (CV) P value | <0.0001 <0.0001 <0.0001 <0.0001 | <0.0001 <0.0001 <0.0001 <0.0001 |
| Year (Y) P value | <0.0001               | <0.0001                       |
| CV × Y P value | <0.0001               |                               |
| White        |                        |                               |
| Viognier     | 106 113 ab — 99 bc    | 144 — — 144 bc                |
| Müller-Thurgau| 107 110 ab — 103 bc  | 158 — — 158 a                 |
| Valvin Muscat™| 108 110 ab 117 c 97 c| 137 147 a 118 a 147 b         |
| Siegfried   | 110 105 b 121 bc 103 bc| 133 147 a 99 b 154 a         |
| Chardonnel  | 112 111 ab 125 bc 101 bc| 132 140 a 117 a 140 c         |
| Sauvignon Blanc | 113 113 ab — — — — — — |                               |
| Seyval Blanc | 113 114 a 122 bc 104 b| 123 123 b 118 a 128 d         |
| Vidal Blanc | 116 115 a 129 ab 104 b| 135 141 a 125 a 138 c         |
| Traminette  | 119 113 ab 134 a 111 a| 121 142 a 91 b 129 d          |
| Mean         | 113 111 124 103       | 131 140 111 142               |
| Cultivar (CV) P value | <0.0001 0.0069 <0.0001 <0.0001 | <0.0001 <0.0001 <0.0001 <0.0001 |
| Year (Y) P value | <0.0001               | <0.0001                       |
| CV × Y P value | <0.0001               |                               |

*Conversion from day of year to calendar date is based on National Aeronautics and Space Administration (2013).

*Means within a column followed by the same letter are not significantly different according to Tukey’s honestly significant difference (HSD) pairwise comparison test at \( P \leq 0.05 \).
Table 4. Yield characteristics of top performing red and white interspecific hybrid wine grape cultivars evaluated 2010–12 at the New Mexico State University Agricultural Science Center at Farmington, NM [elevation 1720 m (5643.0 ft)]. Cultivars within berry color are listed in order of average clusters/vine in 2010–12.

| Cultivar      | Yield (clusters/vine) | Yield (kg/vine) |
|---------------|-----------------------|-----------------|
|               | Avg 2010−12  | 2010 | 2011 | 2012 | Avg 2010−12  | 2010 | 2011 | 2012 |
| Red           |             |       |      |      |               |       |      |      |
| Regent        | 10.7        | 4.0 b | 4.6 c | 23.6 b | 0.7           | 0.4 b | 0.7 a | 1.1 ab |
| Kozma 55      | 17.6        | 15.5 a| 17.3 b| 20.1 b | 0.8           | 1.1 a | 0.7 a | 0.5 b  |
| Leon Millot   | 27.0        | 4.9 b | 27.1 ab| 49.1 a | 1.1           | 0.3 b | 1.2 a | 1.9 a  |
| Baco Noir     | 32.9        | 10.3 ab| 36.4 a| 52.1 a | 1.1           | 0.4 b | 1.1 a | 1.7 ab |
| Mean          | 22.1        | 8.7   | 21.3  | 36.2  | 0.9           | 0.5   | 0.9   | 1.3   |
| Cultivar (CV) P value | <0.0001 | <0.0001 | <0.0001 | 0.0005 | 0.1120        | <0.0001 | 0.1679 | 0.0415 |
| Year (Y) P value | <0.0001 | <0.0001 | <0.0001 | 0.0001   | <0.0001 | 0.0010 | 0.2168 |
| CV × Y P value | <0.0001 | <0.0001 | <0.0001 | <0.0001   | <0.0001 | <0.0001 | <0.0001 |

White

| Cultivar      | Juice soluble solids (%) | Juice pH |
|---------------|--------------------------|---------|
|               | Avg 2010−12  | 2010 | 2011 | 2012 | Avg 2010−12  | 2010 | 2011 | 2012 |
| Red           |             |       |      |      |               |       |      |      |
| Regent        | 20.9        | 25.5 b| 19.2 b| 18.0 c | 3.2           | 3.4 a | 2.9 b | 3.2 a  |
| Leon Millot   | 21.2        | 22.6 c| 22.8 a| 18.1 bc| 3.3           | 3.3 b | 3.5 a | 3.1 ab |
| Kozma 55      | 23.6        | 26.3 b| 21.6 ab| 22.9 a | 3.2           | 3.3 b | 3.1 b | 3.1 ab |
| Baco Noir     | 24.4        | 28.0 a| 23.4 a| 21.8 ab| 3.1           | 3.3 b | 3.1 b | 2.9 b  |
| Mean          | 22.5        | 25.6  | 21.8  | 20.2  | 3.2           | 3.3   | 3.2   | 3.1   |
| Cultivar (CV) P value | <0.0001 | <0.0001 | <0.0016 | 0.0028 | 0.0400        | 0.0038 | <0.0001 | 0.0028 |
| Year (Y) P value | <0.0001 | <0.0001 | <0.0001 | <0.0001   | <0.0001 | <0.0001 | <0.0001 |
| CV × Y P value | <0.0001 | <0.0001 | <0.0001 | <0.0001   | <0.0001 | <0.0001 | <0.0001 |

White

| Cultivar      | Juice soluble solids (%) | Juice pH |
|---------------|--------------------------|---------|
|               | Avg 2010−12  | 2010 | 2011 | 2012 | Avg 2010−12  | 2010 | 2011 | 2012 |
| Red           |             |       |      |      |               |       |      |      |
| Regent        | 19.9        | 21.7 bc| 19.0 b| 19.0 c | 3.1           | 3.2 ab | 3.0 bc | 3.2 bc |
| Leon Millot   | 20.8        | 21.4 c| 19.9 b| 21.0 abc| 3.1           | 3.0 b  | 3.1 bc | 3.3 ab |
| Kozma 55      | 21.1        | 19.8 c| 20.5 ab| 22.9 ab| 3.2           | 3.2 ab | 3.2 ab | 3.3 ab |
| Baco Noir     | 21.2        | 23.6 b| 20.7 ab| 19.4 bc| 3.4           | 3.4 a  | 3.4 a  | 3.5 a  |
| Mean          | 21.5        | 23.1  | 20.4  | 21.1  | 3.2           | 3.2   | 3.1   | 3.2   |
| Cultivar (CV) P value | <0.0001 | <0.0001 | <0.0001 | 0.0020 | <0.0001 | 0.0008 | <0.0001 | <0.0001 |
| Year (Y) P value | <0.0001 | <0.0001 | <0.0001 | <0.0001   | <0.0001 | <0.0001 | <0.0001 |
| CV × Y P value | <0.0001 | <0.0001 | <0.0001 | <0.0001   | <0.0001 | <0.0001 | <0.0001 |

*Means within a column followed by the same letter are not significantly different according to Tukey's honestly significant difference (HSD) pairwise comparison test at P≤0.05.

Table 5. Juice composition of top performing red and white wine interspecific hybrid grape cultivars evaluated 2010–12 at the New Mexico State University Agricultural Science Center at Farmington [elevation 1720 m (5643.0 ft)]. Cultivars within berry color are listed in order of average juice percent soluble solids in 2010–12.

| Cultivar      | Juice soluble solids (%) | Juice pH |
|---------------|--------------------------|---------|
|               | Avg 2010−12  | 2010 | 2011 | 2012 | Avg 2010−12  | 2010 | 2011 | 2012 |
| Red           |             |       |      |      |               |       |      |      |
| Regent        | 21.5        | 23.1  | 20.4  | 21.1  | 3.2           | 3.2   | 3.1   | 3.2   |
| Leon Millot   | 21.6        | 24.9 ab| 19.8 b| 20.2 abc| 2.9           | 3.0 b  | 2.9 c  | 2.9 d  |
| Kozma 55      | 21.0        | 27.5 a| 22.3 a| 23.9 a | 3.1           | 3.1 ab | 3.1 bc | 3.0 cd |
| Mean          | 21.5        | 23.1  | 20.4  | 21.1  | 3.2           | 3.2   | 3.1   | 3.2   |
| Cultivar (CV) P value | <0.0001 | <0.0001 | <0.0001 | 0.0020 | <0.0001 | 0.0008 | <0.0001 | <0.0001 |
| Year (Y) P value | <0.0001 | <0.0001 | <0.0001 | <0.0001   | <0.0001 | <0.0001 | <0.0001 |
| CV × Y P value | <0.0001 | <0.0001 | <0.0001 | <0.0001   | <0.0001 | <0.0001 | <0.0001 |

*Means within a column followed by the same letter are not significantly different according to Tukey's honestly significant difference (HSD) pairwise comparison test at P≤0.05.
should evaluate their risks and markets carefully in relation to climate, soil, and what they can afford before planting any crop, including wine grape. Should decisions to pursue grape production be made, then Four Corner regional growers are encouraged to select cultivars capable of sustaining periodic winter temperatures below −20 °C yielding on canes originating from latent, secondary buds after a spring frost event. In this study, these cultivars were interspecific hybrids. These data form the basis of ongoing testing and future reports to inform agricultural producers in the Four Corners region and similar high-elevation intermountain western U.S. sites. Evaluating winter bud status will permit a clearer understanding of bud survival activity. Evaluating titratable acidity and wine sensory attributes will permit greater inferences on grape juice quality.

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