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Trellis, rootstock, and nitrogen effects on Sunpreme, a natural dry-on-vine raisin grape variety

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ABSTRACT

From 2021 to 2023, the effects of trellis type (two-wire "T" versus high single wire), rootstock (own-rooted, Freedom, or 1103P), and annual nitrogen fertiliser application rate (45 *versus* 90 kg N/ha) were evaluated in the San Joaquin Valley to determine impacts on Sunpreme productivity, raisin quality and mineral nutrition. The T-trellis increased yield by approximately 10 %, with a slight decrease in raisin quality, compared to the high single-wire trellis. Rootstocks also increased yield by 10 %. The higher N rate did not increase raisin yield, but it reduced raisin quality. None of the treatments tested affected preharvest fruit drop. Petiole and blade nutrient concentrations were affected to some extent by all treatments, but most nutrients, other than potassium (K) and zinc (Zn), were present at concentrations that are generally considered adequate. Vine nutrition was particularly affected by rootstock, with vines on Freedom having the highest levels of boron (B), potassium (K), and nitrogen (TN), and the lowest Zn. Vines on 1103P had the lowest K and highest magnesium (Mg). Own-rooted vines had the lowest NO_3-N, Ca, and Mg, but the highest Zn. Effects of rootstocks on nutrition could have management implications, depending on soil type. The amount of select nutrients in 1 t of raisins was determined. There were approximately 0.0089 kg B, 7.3 kg K, 0.345 kg Mg, 5.8 kg N, and 0.0025 kg Zn in a t of raisins. The quantity of certain nutrients in raisins was most affected by rootstock. Vines on Freedom had the most B and K, and among the most Mg and N. Increasing the N application rate modestly increased yield, and the harvested raisins contained approximately 44.8 to 58.3 kg N/ha, depending on N rate. These values provide practical estimates for nutrient replacement in NDOV vineyards. Overall, yield improvements were achieved with two-wire trellis and rootstocks, while higher N rates increased yield at the expense of quality. Annual applications of 44.8–56 kg N per hectare appear sufficient to sustain yield and maintain raisin quality.

KEYWORDS: dried vine fruit, dry-on-vine, fertilisation, mechanisation, mineral nutrition, natural dry-on-vine

INTRODUCTION

California has been among the top global producers of dried grapes (raisins) for more than a century. For most of this time, California raisin grapes were harvested by hand and dried in the vineyard on trays (Fidelibus, 2014). However, the traditional tray-drying method was the most labour-intensive seasonal farm activity in North America (Calvin & Martin, 2010). The declining availability and increasing cost of labour made tray drying unsustainable for most growers, and intense competition from foreign producers and better financial returns for other crops have all contributed to a substantial decline in the California raisin industry (Fidelibus, 2014; Calvin *et al.*, 2022). As domestic production decreased, raisin prices in the USA have become increasingly dependent on Turkish production and exports (Calvin *et al.*, 2022). To remain competitive in a global marketplace, raisin growers, like other fruit and vegetable producers in the USA, must produce crops more efficiently with fewer labour inputs (Charlton *et al.*, 2025).

To address this problem, most growers have implemented one of two partially mechanised production systems: "continuous tray" (CT) or "dry-on-vine" (DOV) (Fidelibus, 2014). In CT systems, a harvest machine shakes the berries from the vines and deposits them onto tray paper via a tray-laying device (Berg & Striegler, 2002). After drying, a pickup machine retrieves the raisin trays. Many growers have transitioned to a CT system because it is compatible with existing conventional 'Thompson Seedless' raisin vineyards. However, CT is not an ideal solution, as the cane-pruned Thompson Seedless variety is not amenable to mechanised pruning, and tray-drying requires sunlit drying space between rows, which constrains trellis height and row spacing, thereby limiting yield potential. The DOV system was a further advancement in raisin mechanisation (Berg & Striegler, 2002). The DOV system consists of severing grapevine canes bearing clusters of mature fruit, thus separating the clusters from the permanent vine structures, and causing the fruit to DOV (May & Kerridge, 1967). When dry, a mechanical harvester collects the raisins (Fidelibus, 2014). The DOV process takes longer than tray-drying due to the lower temperatures in the trellis as compared to on the ground. Thus, DOV is best suited for vineyards with early-ripening grapevine varieties on expansive trellis systems to ensure timely drying and capitalise on the fact that sunlit row middles are not needed for drying (Fidelibus, 2014).

Studer (2000) observed that the berries of some early ripening table grape varieties, under favourable drying conditions, will naturally DOV (NDOV), without the need for cane-cutting. An NDOV raisin variety with fruitful basal buds would permit mechanisation of harvesting and winter pruning, which would amount to an unprecedented level of mechanisation for raisin grapes (Studer, 2000). Toward that end, Sunpreme, the first NDOV raisin variety, was released in 2015 (Ramming, 2015). Sunpreme's NDOV trait has the potential to transform raisin production, but it also has a notable preharvest fruit drop (shatter) problem, although the impact of preharvest shatter on yield potential has not been determined. Further, factors affecting preharvest shatter or drying of NDOV varieties have received little attention, although Ledbetter and Marini (2016) noted that the berries of NDOV varieties may not dry well in years with particularly heavy crops or poor drying weather.

Production data for Sunpreme are limited. A preliminary study reported that yield averaged approximately 10.8 tons/ha for vines trained to a double-T trellis with 0.91 m and 0.61 m cross-arms and found cane-pruned vines to be as productive as spur-pruned vines (Ramming, 2015; as cited in Ledbetter & Marini, 2016). Subsequent testing with a single cross-arm trellis confirmed that pruning style had little effect on raisin quality, so Ledbetter and Marini (2016) concluded that the variety should be spur-pruned, if not mechanically pruned. Ledbetter and Marini (2016) also showed that deficit irrigation improved raisin drying, but reduced raisin quality. Aside from the preliminary research on pruning and irrigation cited above, there are no other published studies on NDOV cultural practices, so there is a lack of practical insight on trellises, rootstocks, and nutritional needs for NDOV raisin grapes. Quadrilateral trellis systems, which were used for the initial testing of Sunpreme, can be managed with machines, but currently available vineyard mechanisation equipment works best with single curtain trellis systems (Kurtural & Fidelibus, 2021), on which NDOV varieties have not previously been tested.

Likewise, initial testing was conducted on own-rooted vines, but rootstocks are needed in the San Joaquin Valley (SJV) to protect against damaging soil pests. Freedom is the most widely used rootstock for raisin grapes in the SJV, but sudden-vine decline has recently become a serious problem for grapevines on that stock (Eskalen *et al.*, 2022), so growers are increasingly selecting other stocks such as 1103P. Rootstock choice can substantially affect vine mineral nutrition, vegetative growth, berry size, and yield in the SJV (Migicovsky *et al.*, 2021), and is therefore an important consideration for NDOV vineyards.

Nitrogen (N) fertiliser is commonly applied to raisin vineyards across the SJV (Christensen & Peacock, 2000). Vines grafted onto certain rootstocks, including Freedom, have lower N requirements than own-rooted vines, possibly due to the rootstock's more vigorous and explorative root system (Christensen & Peacock, 2000). Sunpreme vineyards should have higher N needs than traditional Thompson Seedless vineyards due to their higher yield potential, but excess N could promote vegetative growth and delay fruit ripening (Christensen & Peacock, 2000; Verdenal *et al.*, 2021), both of which would be undesirable in an NDOV vineyard. Grapevines carrying heavy crop loads are also prone to potassium (K) deficiency, which can delay ripening. Rootstocks differ in their nutrient uptake characteristics; for instance, Freedom is exceptional in accumulating K compared with rootstocks such as 1103P. However, rootstocks with *Vitis champinii* parentage, including Freedom, are also prone to Zn deficiency (Christensen & Peacock, 2000). Consequently, the best rootstock for NDOV varieties in the SJV might depend on trellis design and overall nutritional status.

Petioles have traditionally served as the standard tissue for monitoring grapevine nutrition in California, especially for raisin grapes (Schreiner & Scagel, 2017). However, several mineral nutrients exhibit greater variability in petioles than in blades, suggesting that blades may be a better tissue for nutrient testing (Schreiner & Scagel, 2017; Romero *et al.*, 2013). Moreover, there is growing interest in developing remote-sensing technologies for vineyard nutrition monitoring. Such technologies leverage the principle that leaf biochemical composition influences radiative properties such that remotely sensed spectral data can be used to estimate leaf mineral nutrient content (Farajpoor *et al.*, 2025). For these reasons, tissue test results from both petioles and leaf blades may be useful reference values for growers managing this relatively new variety.

Accordingly, the objectives of this study were to determine the effects of trellis, rootstock, and N fertiliser application rate on tissue nutrient test results and on NDOV raisin grape performance, including preharvest fruit drop, yield, and quality.

MATERIALS AND METHODS

1. Experimental design and vineyard establishment

The experiment was conducted in a vineyard at the University of California Kearney Agricultural Research and Extension Centre, in Parlier, California, USA. The vineyard was planted in late August 2019, with a split-split plot design, where the main-plot factor was trellis (bilateral or quadrilateral), the sub-plot factor was rootstock (own-rooted, Freedom, or 1103P), and the sub-sub plot factor was annual nitrogen application rate (45 or 90 kg/ha). The vineyard was divided into four blocks, each consisting of six consecutive vine rows which were oriented east-west, with 43 vines/row, a 2 m within-row spacing, and a 3.5 m between-row spacing. Each block was divided into two three-row main plots which were randomly assigned to receive a bilateral or quadrilateral trellis system. The bilateral trellis consisted of steel posts at every vine space, each of which extended vertically 1.65 m above the vineyard floor, and to which a single cordon wire was affixed, approximately 5 cm from the tip of the stake. The quadrilateral trellis system consisted of steel posts at every other vine space (alternating with aluminium stakes), with one 0.56 m wide cross arm secured to the steel stakes at 1.40 m above the vineyard floor.

Within each main-plot, entire vine-rows were randomly assigned to each sub-plot factor and were thus planted with either own-rooted vines, or vines grafted to Freedom, or 1103P rootstock. Vines were irrigated through October 2019 and trained and suckered as needed. In December 2019, vines were pruned to a trunk terminating just above the cordon wires. In 2020, all vines were supplied with the equivalent of 22.4 kg N/ha as $Ca(NO_3)_2$, applied through the drip irrigation system in spring and summer. Vine training was completed during this period, and the canes to be retained as cordons were established throughout the vineyard.

Vines were pruned in late January 2021, with two canes retained per vine on the bilateral trellis, and four canes retained per vine on the quadrilateral trellis. In early spring 2021, the two N fertiliser application rate sub-sub plots within each vine row were established (45 or 90 kg N/ha) and maintained for the duration of the study. Each sub-sub plot consisted of 18 adjacent vines, with two to three guard vines between each sub-sub plot and/or at the end of the row. Nitrogen was applied as a mixture of $Ca(NO_3)_2$ and $(NH_4)_2SO_4$, with each annual application consisting of two equal amounts of N (1/2 of the annual allotment), with the first made approximately 1 month after budbreak, and the second at fruit set.

2. Cultural practices

In the dormant seasons preceding the 2022 and 2023 seasons, the vines were spur-pruned by hand, leaving one two-bud spur at each position on vines with quadrilateral cordons, and two two-bud spurs (where possible) at each spur position on vines with bilateral cordons, in an attempt to match the number of nodes per vine. During the growing seasons, the CropManage web tool (https://cropmanage.ucanr.edu/) was used to help schedule irrigations, with a 70 % deficit through veraison, as recommended by Peacock *et al*. (2000). After veraison, an additional deficit was sometimes needed to help control shoot growth, and a pressure chamber was used to monitor mid-day leaf water potential periodically. Approximately 655 mm of water was applied each season, as is typical of raisin grape vineyards with a similar canopy size in the San Joaquin Valley (Peacock *et al.*, 2000). Besides N, all vines were fertigated every year with potassium (K) thiosulfate between bloom and veraison, applying approximately 11.2 to 16.81 kg of K/ha each season. Additionally, in late November 2022, 113 kg of sulfate of potash (48.2 kg actual K) per ha was top-dressed to a 1 m-wide band beneath the vines in each row. No other fertilisers were applied during the study. During each growing season, various herbicides, fungicides, and insecticides were applied to control common grape pests in this region (Bettiga, 2013).

3. Data collection

Paired samples of petioles and leaf blades were collected from vines throughout each plot at bloom and veraison, at sampling dates listed in Table 1. Samples at bloom were collected opposite clusters, whereas samples at veraison were collected from positions having mature, recently expanded leaf blades. After separating the blades from the petioles, the tissues were rinsed in deionised water, surface-dried using a centrifugal spinner, placed in paper bags, and dried to a constant weight in a forced-air oven at 55 °C. Dried samples were ground in a mill and submitted to a commercial laboratory (Valley Tech Ag Laboratory Services, Tulare, CA) to determine macro- and micronutrient content using standard methods (Gavlak *et al.*, 2003).

In late July of each year, replicated berry samples were collected from vines in each plot following standard methods described previously (Fidelibus *et al.*, 2008). Briefly, samples consisting of 100 berries were taken from clusters selected

at random from vines within each treatment replicate. The samples were weighed, and average berry weight was calculated. The berries were then crushed to express juice, which was centrifuged to remove insoluble solids. Soluble solids were measured with a hand-held, temperature-compensating digital refractometer (Palette 101; Atago, Farmingdale, NY, USA). Titratable acidity of the juice was determined by titration with 0.133 N NaOH to an 8.20 endpoint using an automatic titrator (855 robotic titrator; Metrohm USA Inc., Riverview, FL).

TABLE 1. Dates of budbreak, dates that bloom and veraison tissue samples were collected, and raisins harvested, from Sunpreme raisin grapes, Parlier, CA, USA.

	Date			
Year	**Budbreak**	**Bloom**	**Veraison**	**Harvest**
2021	3/5/21	5/5/21	6/14/21	9/15/21
2022	3/7/22	4/28/22	6/15/22	10/6/22
2023	3/12/23	5/22/23	6/26/23	10/4/23

Each year in July, sections of weed mats measuring approximately 0.91 m × 1.14 m were installed beneath randomly selected vines in each plot to catch any abscising berries. The corner of each mat was stapled to wooden stakes which were driven into the ground beneath the vines such that mats were raised approximately 14 cm above the soil surface. After installation, each mat covered a sufficient area of soil beneath vines on either trellis to collect any berries that abscised from a 1 m length of row. The mats were observed one or a few times a week until harvest, and any grapes on the mats were collected, placed into paper bags, and dried. Raisins were harvested when moisture levels were judged to be ≤ 16 %, or the onset of poor drying weather was anticipated, whichever came first. Within a few days of harvest, any remaining berries/raisins on the mats were collected and dried, and then all the raisins in the vine canopy directly above each weed mat were harvested, collected into paper bags, weighed, and then placed in a forced-air oven and dried to a constant weight. The fresh weight of raisins picked from the vine canopies above the weed mats was included in the harvest yield determinations for the plots they came from, and the dry weight of the same raisins was used to determine percent preharvest fruit drop, which was calculated as the ratio of the dry weight of grapes/raisins which fell onto the mats divided by the dry weight of those raisins plus the dry weight of the raisins picked from the vines directly above the mats. The dried raisins picked from above the weed mats were frozen in liquid N to embrittle them, and then they were ground into a fine powder with a mortar and pestle while frozen. Subsamples of dried and finely ground raisins were sealed in plastic vials and submitted to a commercial laboratory for determination of macro- and micronutrient content. The amount of mineral nutrients in a ton of fresh raisins was determined by multiplying the estimated dry matter (0 % moisture) of a ton of raisins by the nutrient concentration (percentage) of the raisins.

At harvest, all remaining clusters of raisins were hand-picked and weighed. Approximately 2 kg of raisins from each plot were collected, manually destemmed, and submitted to the USDA Processed Products Division (Fresno, CA) for moisture and quality determination following official methods (USDA, 2016). Raisins were graded using airstream sorters to determine Grade A and B ("B and better") and substandard. Yield comparisons were made after adjusting raisin weights to 14% moisture (Fidelibus *et al.*, 2008). Yield per hectare was calculated by multiplying the average yield per vine in each plot by the number of vines per hectare.

For statistical analysis, the experimental design was considered a split-split-split plot, with year as the main-plot factor, trellis (high single-wire versus T-trellis) as the subplot factor (replicated four times), rootstock (own-rooted, Freedom, or 1103P) as the sub-sub plot factor, and annual N application rate (45 or 90 kg N/ha) as the sub-sub-sub plot factor. Statistical analyses were performed using SAS (SAS 9.4, SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

1. Tissue test results

Year, trellis, rootstock, and annual N application rate all affected petiole and leaf nutrient content at bloom and veraison with relatively few and minor interaction effects, so the main effects are summarised in Tables 2–5. Annual variation in petiole and leaf blade nutrient content is common, due to various factors including the dynamic nature of tissue nutrient content during the course of the season (Christensen, 1984; Romero *et al.*, 2013; Wolpert *et al.*, 2005), fertiliser application timing, amount, and type, irrigation practice, phenology, weather, sample collection timing, and crop load (Robinson, 2005). Despite annual variability, concentrations of N, K, Mg, Zn, and B, the five minerals most likely to require supplementation in San Joaquin Valley raisin vineyards, were within the sufficient or normal range in petioles at bloom each year, based on reference values for Thompson Seedless raisin grapes as reported in Christensen and Peacock (2000). Christensen and Peacock (2000) did not indicate critical values for B, N, Mg, or Zn at veraison. However, they suggested K should exceed 0.5 %, a level reached each year (Table 2).

Petioles generally had higher K and Mg, but lower B, Ca, Cu, Fe, and N than leaf blades (Tables 2–5), and Robinson (2005) suggested a higher threshold for "normal" levels of certain nutrients in leaf blades compared to Christensen and Peacock's (2000) recommendation for petioles. Assessing our leaf blade data using Robinson's (2005) critical values, Zn was deficient at bloom, and Zn and K were below normal to deficient at veraison. However, grapevine tissue test results frequently fall outside ranges currently considered normal or adequate in published standards (Arrobas *et al.*, 2014), and Christensen and Peacock (2000) and Robinson (2005) noted that plant tissue analysis is best used with other approaches, especially visual observation. No obvious symptoms of Zn

deficiency were observed in our study (Fidelibus, personal observations), though K deficiency symptoms were sometimes observed after veraison.

Together, tissue test results and observations indicate that most nutrients were likely present at sufficient levels, except for Zn and K, which were marginally sufficient. Mineral nutrient content of petioles or leaves, measured at bloom or veraison, was not strongly correlated with raisin yield or quality (results not shown). This lack of correlation could suggest that the vines were adequately nourished overall, or that none of the factors affected the content of any individual nutrient such that a measurable effect on yield or quality was significantly affected as a result.

Interestingly, trellis type consistently affected tissue nutrient content. At bloom, vines trained to high single-wire trellises had higher N, P, Mg, Zn, Mn, Fe, Cu, and B content in petioles and leaf blades (Tables 2 and 4) compared to vines with quadrilateral cordons on two-wire trellises. Trellis effects diminished by veraison, at which time vines on two-wire trellises continued to have lower N but higher Mn (Tables 3 and 5). The underlying reasons for trellis effects on tissue nutrient content are uncertain but might be due to differences in vine size and crop load, which could have resulted in growth dilution or differential sink-strength effects.

Rootstocks had typical effects observed in other studies (Wolpert *et al.*, 2005). Vines on Freedom had the highest B,

TABLE 2. Main effects of year, trellis, rootstock, and annual nitrogen application rate on nutrient content of Sunpreme grapevine petioles at bloom, Parlier, California, 2021–2023.

	Mineral nutrient content										
	(%)					(ppm)					
Factor	**N**	**P**	**K**	**Ca**	**Mg**	**NO_3-N**	**Zn**	**Mn**	**Fe**	**Cu**	**B**
Year											
2021	0.86 b[z]	0.24 b	1.90 b	1.76 a	0.71 a	-[y]	39 a	68	26	49 b	36 a
2022	1.03 a	0.47 a	2.40 a	1.74 a	0.49 b	1365 b	28 b	67	14	58 a	34 b
2023	0.87 b	0.23 b	2.28 a	1.27 b	0.49 b	1853 a	30 b	75	28	18 c	33 c
Trellis											
Bilateral	0.99 a	0.32	2.15	1.58	0.55 b	1861 a	31	67	21	40 b	34
Quadrilateral	0.84 b	0.31	2.23	1.60	0.58 a	1358 b	34	74	25	43 a	34
Rootstock											
Own-rooted	0.83 c	0.29 b	2.31 b	1.44 c	0.39 c	1313 b	36 a	62 b	25	48 a	32 b
Freedom	1.02 a	0.28 b	2.57 a	1.61 b	0.61 b	1834 a	30 b	80 a	22	36 c	39 a
1103P	0.90 b	0.37 a	1.70 c	1.72 a	0.69 a	1681 a	31 ab	69 b	22	41 b	32 b
Nitrogen (kg/ha)											
45	0.83 b	0.32	2.19	1.59	0.56	1152 b	33	60 b	24	43	34
90	1.00 a	0.31	2.19	1.59	0.56	2066 a	32	80 a	21	41	34
Significance (Pr > F)											
Year (Y)	<.0001	<.0001	<.0001	<0.001	<.0001	<.0001	<.0001	0.1202	0.1865	<0.001	<.0001
Trellis (T)	0.0006	0.2740	0.5111	0.1160	0.0054	0.0036	0.1772	0.0491	0.5296	<0.001	0.6183
Rootstock (R)	<.0001	<.0001	<.0001	<0.001	<.0001	<.0001	0.0027	0.0133	0.1873	<0.001	<.0001
Nitrogen (N)	<.0001	0.1553	0.7802	0.6217	0.9107	<.0001	0.2297	<0.001	0.6081	0.0466	0.5534
N x T	0.4408	0.8134	0.1103	0.0146	0.4180	0.1003	0.5234	0.2555	0.3366	0.5070	0.7825
N x R	0.1371	0.7383	0.0195	0.0737	0.5748	0.0861	0.0010	0.3887	0.2572	0.4744	0.3372
T x R	0.5455	0.5489	0.0611	0.3173	0.0186	0.0575	0.4098	0.0830	0.1873	0.0239	0.0001
T x R x N	0.7408	0.3768	0.8912	0.4502	0.8141	0.7638	0.4376	0.7558	0.3229	0.9520	0.8741

[z] Values are treatment means. Means followed by a different letter, within columns and factors, are significantly different.

K, and N (NO_3-N and TN), and the lowest Zn (Tables 2–5). Vines on 1103P had the lowest K but the highest Mg (Tables 2–5). Own-rooted vines had the lowest NO_3-N, Ca, and Mg, but the highest Zn (Tables 2 and 3). Rootstock-driven differences in nutrient content may be relevant under specific soil or environmental conditions, as they could influence management decisions (Ibacache *et al.*, 2020).

The amount of certain nutrients in a ton of raisins was calculated to estimate nutrients removed by the raisin harvest. A ton of raisins contained approximately 0.0089 kg B, 7.3 kg K, 0.345 kg Mg, 5.8 kg N, and 0.0025 kg Zn (Table 6). These values may help estimate nutrient replacement.

Requirements in fertilisation programs, consistent with the nutrient-removal approach described by Arrobas *et al*. (2014). In contrast to petioles and leaves, the nutrient content of raisins was relatively stable from year to year, except for N, which generally increased annually (Table 6).

Thompson Seedless raisin grapes typically accumulate approximately 1.5 kg of N per t of fresh grapes (Christensen & Peacock, 2000). The drying ratio of Sunpreme raisin grapes has not been determined, but Thompson Seedless raisin grapes are typically dried after attaining 20 °Brix, at which point their drying ratio is approximately 4.25:1 (Christensen & Peacock, 2000), indicating that 4.25 t of fresh grapes at

TABLE 3. Main effects of year, trellis, rootstock, and annual nitrogen application rate on nutrient content of Sunpreme grapevine petioles at veraison, Parlier, California, 2021–2023.

	Mineral nutrient content										
	(%)					(ppm)					
Factor	**N**	**P**	**K**	**Ca**	**Mg**	**NO_3-N**	**Zn**	**Mn**	**Fe**	**Cu**	**B**
Year											
2021	0.58 b[z]	0.19 a	0.98 c	2.41 a	1.13 b	-[y]	28 a	212 a	28 a	11 b	34 a
2022	0.45 c	0.18 b	1.49 b	2.08 b	0.85 a	1089 b	23 c	177 b	11 c	14 a	28 b
2023	0.65 a	0.13 c	1.71 a	1.79 c	0.86 a	1600 a	27 b	168 b	21 b	9 c	34 a
Trellis											
Bilateral	0.58 a	0.18	1.43	2.05 b	0.92	1375	24	173 b	19	11	33
Quadrilateral	0.54 b	0.16	1.35	2.13 a	0.98	1314	28	198 a	21	12	32
Rootstock											
Own-rooted	0.57	0.19 a	1.58 a	1.80 b	0.69 c	1141 b	27 a	128 b	20	11	30 c
Freedom	0.57	0.14 b	1.48 a	2.28 a	1.01 b	1472 a	24 b	214 a	23	11	35 a
1103P	0.54	0.18 a	1.11 b	2.21 a	1.14 a	1420 a	27 b	214 a	17	11	32 b
Nitrogen (kg/ha)											
45	0.51 b	0.18 a	1.43	2.08	0.94	1026 b	25	139 b	21	12	32
90	0.61 a	0.16 b	1.36	2.10	0.95	1662 a	27	232 a	19	11	32
Significance (Pr > F)											
Year (Y)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Trellis (T)	0.03	0.13	0.46	<0.05	0.08	0.57	0.09	0.07	0.54	0.38	0.28
Rootstock (R)	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.22	0.20	<0.01
Nitrogen (N)	<0.01	0.01	0.26	0.59	0.62	<0.01	0.87	<0.01	0.43	0.25	0.51
N × T	0.14	0.29	0.17	0.52	0.23	0.54	0.21	0.97	0.35	0.22	0.78
N × R	0.47	0.57	0.19	0.28	0.84	0.53	0.47	<0.01	0.52	0.99	0.53
T × R	0.61	0.40	0.16	0.06	0.35	0.91	<0.05	0.93	0.69	0.14	<0.01
T × R × N	0.75	0.33	0.97	0.93	0.42	0.97	0.39	0.71	0.37	0.59	0.64

[z] Values are treatment means. Means followed by a different letter, within columns and factors, are significantly different.
[y] Data not collected.

20 Brix are needed to make 1 t of raisins. Therefore, 1 t of Thompson Seedless raisins should typically contain 6.38 kg of N, an amount that falls within the range observed in our study. Likewise, Christensen and Peacock (2000) noted that 1 t of Thompson Seedless raisins will contain approximately 8.5 kg of K, a value comparable to our estimate for Sunpreme (Table 6). Trellis type did not affect the nutrient content of raisins, but rootstocks affected N and K content (Table 6). The quantity of certain nutrients in raisins was mostly affected by rootstock. Raisins from vines on Freedom had the most B and K, and among the most Mg and N. Doubling the amount of N applied increased the N content of raisins by approximately 11 %, but according to Christensen and Peacock (2000), the accumulation of N in raisins is of "no value".

2. Fruit and raisin quality and yield

Grapes generally achieve maximum soluble solids content at approximately 23 °Brix (Casciato & Keller, 2025), and raisin yield and quality are typically optimal when grapes are allowed to amass at least 20 % soluble solids before drying (Parpinello *et al.*, 2012). Because the relationship between soluble solids and the onset of drying in NDOV varieties like Sunpreme has yet to be determined, we collected replicated berry samples when berries were close to 20 °Brix (Table 7), so that treatment effects on fresh berry physical and chemical characteristics would likely reflect treatment effects on mature berries.

TABLE 4. Main effects of year, trellis, rootstock, and annual nitrogen application rate on nutrient content of Sunpreme grapevine leaf blades at bloom, Parlier, California, 2021–2023.

	Mineral nutrient content									
	(%)					(ppm)				
Factor	**N**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Fe**	**Cu**	**B**
Year										
2021	3.22 a[z]	0.23 b	0.83 b	2.12 a	0.41 a	19 b	149 b	131 a	225 b	53 b
2022	3.08 b	0.34 a	1.09 a	1.98 b	0.33 b	20 b	163 a	96 b	329 a	44 c
2023	2.82 c	0.21 b	1.06 a	2.11 a	0.41 a	22 a	165 a	91 c	75 c	59 a
Trellis										
Bilateral	3.08 a	0.27 a	0.99	2.14	0.39 a	22 a	166 a	111 a	225 a	55 a
Quadrilateral	3.00 b	0.25 b	1.00	2.00	0.37 b	19 b	152 b	101 b	195 b	49 b
Rootstock										
Own-rooted	3.05	0.25 b	1.17 a	1.77 c	0.29 c	19 b	148	109 a	220 a	46 c
Freedom	3.05	0.24 b	1.02 b	2.09 b	0.42 b	20 ab	165	108 a	227 a	58 a
1103P	3.02	0.29 a	0.79 c	2.36 a	0.44 a	22 a	164	101 b	182 b	51 b
Nitrogen (kg/ha)										
45	2.97 b	0.26	1.00	2.06 a	0.38	21	148 b	107	210	52
90	3.11 a	0.26	0.98	2.08 b	0.39	20	170 a	105	209	52
Significance (Pr > F)										
Year (Y)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Trellis (T)	<0.01	<0.01	0.68	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01
Rootstock (R)	0.63	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
Nitrogen (N)	<0.01	0.84	0.49	0.66	0.15	0.54	<0.01	0.46	0.93	0.96
N x T	0.02	0.76	0.27	0.50	0.35	0.87	0.89	0.12	0.60	0.83
N x R	0.69	0.66	0.08	0.41	0.99	0.20	0.10	0.30	0.84	0.67
T x R x N	0.90	0.49	0.55	0.81	0.95	0.73	0.59	0.40	0.82	0.19

[z] Values are treatment means. Means followed by a different letter, within columns and factors, are significantly different.

Average berry fresh weight ranged from 1.58 to 2.38 g/berry across years (Table 7), values comparable to those reported for first-generation DOV raisin varieties (Fidelibus *et al.*, 2008). Heavier berries were generally associated with lower soluble solids, and vice versa. These results could suggest that the lighter berries were already beginning to desiccate when the samples were collected, as desiccation would reduce berry fresh weight while increasing soluble solids. Therefore, treatment effects on berry weight and soluble solids may indicate effects on maturation rate and/or the onset of drying.

Trellis design also influenced berry development. Vines on bilateral trellises produced heavier berries with higher titratable acidity than vines trained to T-trellises (Table 7), suggesting a slight delay in berry maturation under the bilateral system. Rootstock also affected berry development. Own-rooted vines produced larger berries with lower soluble solids and titratable acidity than vines on rootstocks (Table 6). Vines on either Freedom or 1103P rootstocks had lighter berries than own-rooted vines, and vines on Freedom had berries with the highest soluble solids. Annual N application rate had no detectable effects on berry size or composition (Table 7).

Preharvest fruit drop was nearly 25 % of the potential crop in 2021 but declined substantially in 2022 and 2023, and was unaffected by trellis, rootstock, or annual applied N (Table 8). Yield was lowest in 2021, the vineyard's first crop, doubled in 2022, and decreased slightly in 2023 (Table 8). Yields in 2022 and 2023 were nearly twice the yields typically obtained in vineyards designed for tray-drying, which average approximately 4.48 t/ha (Vasquez *et al.*, 2006), and were only 20 % lower than yields reported for first generation dry-on-vine vineyards trained to open-gable (Fidelibus *et al.*, 2008)

TABLE 5. Main effects of year, trellis, rootstock, and annual nitrogen application rate on nutrient content of Sunpreme grapevine leaf blades at veraison, Parlier, California, 2021–2023.

	Mineral nutrient content									
	(%)					(ppm)				
Factor	**N**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Fe**	**Cu**	**B**
Year										
2021	2.84 b[z]	0.22 a	0.49 b	2.98 a	0.60 a	15 a	128 b	142 a	28 a	48 a
2022	2.60 c	0.19 b	0.28 c	2.78 b	0.46 b	14 b	141 a	91 b	35 a	39 c
2023	3.02 a	0.19 b	0.64 a	2.81 b	0.46 b	15 a	144 a	64 c	9 b	42 b
Trellis										
Bilateral	2.84	0.20	0.48	2.86	0.50	15	135 a	99	23	46 a
Quadrilateral	2.80	0.20	0.45	2.86	0.51	15	141 b	100	25	40 b
Rootstock										
Own-rooted	2.90 a	0.21 a	0.57 a	2.31 c	0.37 c	14.7 ab	109 b	100	20	38 c
Freedom	2.80 b	0.19 c	0.43 b	3.08 b	0.54 b	14.2 b	152 a	98	24	48 a
1103P	2.76 b	0.20 b	0.40 b	3.19 a	0.61 a	15.1 a	152 a	100	28	43 b
Nitrogen (kg/ha)										
45	2.76 b	0.20	0.47	2.85	0.51	15	120 b	99	25	43
90	2.88 a	0.20	0.46	2.87	0.50	15	155 a	99	23	43
Significance (Pr > F)										
Year (Y)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Trellis (T)	0.39	0.12	0.06	0.87	0.35	0.20	<0.01	0.74	0.63	<0.01
Rootstock (R)	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.56	0.21	<0.01
Nitrogen (N)	<0.01	0.29	0.58	0.60	0.83	0.29	<0.01	0.99	0.71	0.51
N × T	0.29	0.64	0.27	0.57	0.22	0.25	0.89	0.34	0.90	0.64
N × R	0.86	0.77	0.45	0.74	0.87	0.96	0.09	0.68	0.97	0.64
T × R × N	0.71	0.78	0.06	0.83	0.82	0.36	0.59	0.98	0.95	0.77

[z]Values are treatment means. Means followed by a different letter, within columns and factors, are significantly different.

or overhead arbor (Fidelibus, 2021) trellises, both of which are substantially larger than the trellises evaluated in this study. Approximately 10 % higher yields were produced on T-trellis than on high single-wire trellises (Table 8). Because identical vine spacing was used for all trellis systems, high single-wire trellises, which are narrower than T-trellises, could be established at closer row spacing, which could increase vineyard-level yield and reduce the modest yield advantage of the T-trellis.

Either rootstock increased yield by approximately 10 % compared to own-rooted vines, but the N treatments did not affect yield (Table 8). Raisin moisture at harvest was lowest in 2021, increased in 2022, and was unacceptably high in 2023, a year with particularly poor drying weather. Lack of direct control over the drying process is a disadvantage of NDOV varieties. Research is needed to understand the physiology of the NDOV trait better and to develop cultural practices that increase the likelihood of reliable drying. A preliminary study by Ledbetter and Marini (2016) suggested that deficit irrigation treatments could improve drying, possibly at the expense of raisin quality. Our research suggests that rootstocks, especially 1103P, can improve drying, and raisins from vines on T-trellises dried slightly better than raisins from vines on high single-wire trellises (Table 8). Additional research is needed to develop canopy management and irrigation practices that optimise drying while maintaining or improving raisin quality.

TABLE 6. Main effects of year, trellis, rootstock, and annual nitrogen application rate on raisin mineral nutrient content, Parlier, California, 2021–2023.

	Mineral nutrient content (kg/t)[z]									
Factor	**N**	**P**	**K**	**Ca**	**Mg**	**Zn**	**Mn**	**Fe**	**Cu**	**B**
Year										
2021	4.50 c	1.04 a	7.40 a	0.60 b	0.30 c	0.0034 a	0.0034 a	0.0176 c	0.0040 c	0.0098 a
2022	4.95 b	0.92 b	6.83b	0.76 a	0.36 b	0.0028 b	0.0036 a	0.0221 a	0.0058 a	0.0082 b
2023	7.81 a	0.90 b	7.69 a	0.73 a	0.40 a	0.0015 c	0.0028 b	0.0193 b	0.0053 b	0.0086 b
Trellis										
Bilateral	6.02	0.99 a	7.60	0.69 b	0.36	0.0024	0.0032	0.0200	0.0051	0.0091 a
Quadrilateral	5.60	0.93 b	7.08	0.73 a	0.34	0.0027	0.0032	0.0189	0.0048	0.0087 b
Rootstock										
Own-rooted	5.44 b	0.96 b	7.03 b	0.69 b	0.32 b	0.0029 a	0.0029 b	0.0177 b	0.0059 a	0.0079 c
Freedom	5.97 a	0.90 c	7.80 a	0.70 b	0.35 a	0.0022 b	0.0034 a	0.0200 a	0.0040 c	0.0097 a
1103P	6.02 a	1.00 a	7.20 b	0.74 a	0.37 a	0.0026 ab	0.0033 a	0.0208 a	0.0051 b	0.0090 b
Nitrogen (kg/ha)										
45	5.50 b	0.95	7.36	0.70	0.34	0.0026	0.0029 b	0.0191	0.0049	0.0089
90	6.12 a	0.97	7.32	0.72	0.35	0.0025	0.0036 a	0.0199	0.0051	0.0089
Significance (Pr > F)										
Year (Y)	<.0001	<0.001	<.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Trellis (T)	0.0653	0.008	0.0956	0.0065	0.2942	0.1335	0.9696	0.1337	0.3753	0.0217
Rootstock (R)	<.0001	<0.0001	<.0001	0.0333	<0.001	0.0082	0.0016	0.0005	<0.001	<0.0001
Nitrogen (N)	<.0001	0.0828	0.7119	0.2907	0.7444	0.5067	<0.0001	0.1549	0.9484	0.6848
N × T	0.3227	0.8889	0.5427	0.6732	0.8362	0.8531	0.8544	0.2186	0.3000	0.1401
N × R	0.5412	0.8703	0.3422	0.0325	0.4904	0.7541	0.0012	0.8654	0.8721	0.3661
T × R	0.0587	0.0757	0.0136	0.2263	0.2624	0.2026	0.3210	0.1160	0.4302	<0.0001
T × R × N	0.4570	0.1619	0.0231	0.8529	0.1523	0.9959	0.3522	0.0413	0.8612	0.7147

[z] Kilograms of mineral nutrients per ton of raisins, assuming raisin moisture content was 14 %.

Raisin quality was highest in 2021 and decreased thereafter, as evidenced by a reduction in per cent "B and better", the highest grade, and an increase in "substandard", an unacceptable grade (Table 8). The "B and better" grades observed in this study were sufficient to meet incoming inspection standards, although the substandard grades observed in this study would incur some dockage (Kagawa, 2000). Trellises did not affect raisin quality, but rootstock did, with vines on Freedom having the highest "B and better" grades and the lowest "substandard" grades. The N application rate also affected raisin quality, with the higher rate reducing "B and better" and increasing "substandard" grades. It should be noted that the raisins in this study were harvested by hand, retaining all the raisins picked, but in a commercial vineyard, NDOV raisins would most likely be harvested by a machine having cleaning fans (Kurtural & Fidelibus, 2021) that should reduce, if not eliminate, substandard raisins in the harvest stream. The relatively small trellises used in this study would be compatible with a variety of harvest machines that are widely used in California vineyards, whereas open gable and overhead arbour trellises used for the first generation of DOV varieties require specialised harvest machines (Fidelibus, 2014).

TABLE 7. Main effects of year, trellis, rootstock, and annual nitrogen application rate on Sunpreme grape berries, before the onset of drying, Parlier, California, 2021–2023.

	Berry			
	Fresh weight	Soluble solids	pH	Titratable acidity
Factor	(g/berry)	(°Brix)		(g/L)
Year				
2021	2.07 b[z]	19.9 b	.	.
2022	1.58 c	22.9 a	3.55	5.16 a
2023	2.38 a	18.9 c	3.58	4.95 b
Trellis				
Bilateral	2.09 a	20.6	3.58 a	5.07
Quadrilateral	1.92 b	20.5	3.54 b	5.05
Rootstock				
Own-rooted	2.21 a	20.0 b	3.52 b	5.00
Freedom	1.87 b	21.2 a	3.60 a	5.02
1103P	1.94 b	20.4 b	3.57 a	5.15
Nitrogen (kg/ha)				
45	2.02	20.6	3.56	5.06
90	1.99	20.5	3.57	5.05
Significance (Pr > F)				
Year (Y)	<.0001	<.0001	0.06	0.01
Trellis (T)	0.0141	0.7230	0.02	0.83
Rootstock (R)	<.0001	0.0024	<0.01	0.24
Nitrogen (N)	0.4894	0.4183	0.62	0.92
N x T	0.9189	0.6561	0.72	0.83
N x R	0.9566	0.3494	0.90	0.61
R x T	0.2039	0.7096	0.19	0.46
T x R x N	0.7338	0.8805	0.74	0.83

[z] Values are treatment means. Means followed by a different letter, within columns and factors, are significantly different.

TABLE 8. Main effects of year, trellis, rootstock, and annual applied nitrogen on preharvest drop, yield, moisture content, and quality grades ("B and better" and "Substandard") of Sunpreme raisins.

	Preharvest drop	Yield[z]	Moisture content	B and better	Substandard
Factor	(%)[y]	(t/ha)	(%)	(%)	(%)
Year					
2021	24 a	4.00 c	12 c	83 a	6 c
2022	9 b	9.22 a	14 b	67 b	8 b
2023	9 b	8.52 b	17 a	65 b	12 a
Trellis					
Bilateral	13	6.89 b	14.46 a	73	8
Quadrilateral	14	7.59 a	13.84 b	70	9
Rootstock					
Own-rooted	15	6.79 b	14.66 a	71 ab	11 a
Freedom	15	7.39 a	14.05 b	75 a	6 b
1103P	12	7.56 a	13.72 c	69 b	9 a
Nitrogen (kg/ha)					
45	14	7.12	14	74 a	7 b
90	13	7.36	14	70 b	10 a
Significance (Pr > F)					
Year (Y)	<0.01	<0.01	<0.01	<0.01	<0.01
Trellis (T)	<0.37	0.03	<0.01	0.05	0.14
Rootstock (R)	0.20	<0.01	<0.01	<0.01	<0.01
Nitrogen (N)	0.26	0.12	0.14	<0.01	<0.01
N × T	0.10	0.12	0.33	0.64	0.12
N × R	0.22	0.09	0.12	0.49	0.91
T × R	0.47	0.56	0.06	0.37	0.52
T × R × N	0.75	0.96	0.79	0.70	0.32

[z] Harvested raisins, not including any that may have abscised.
[y] Percent of potential yield that was abscised before harvest.

In conclusion, Sunpreme's fruitful basal buds and NDOV trait make it uniquely suited for mechanised winter pruning and eliminate the need for cane severance to initiate drying. Together, these traits position Sunpreme as the first raisin variety capable of fully mechanised production. While NDOV varieties, like Sunpreme, offer significant promise for reducing production costs and labour inputs, research on their optimal management practices remains limited. Therefore, this study provides important data on how trellis type, rootstock selection, and nitrogen fertiliser rates affect tissue nutrient levels and Sunpreme performance to improve Sunpreme management.

We showed that Sunpreme is highly productive on high single-wire or T-trellises, with either trellis producing raisins of acceptable quality. Additionally, rootstocks significantly affected tissue nutrient levels and raisin quality. Vines on Freedom had the highest levels of B, K, and TN, and the lowest Zn. Vines on 1103P had the lowest K and highest Mg. Own-rooted vines had the lowest NO_3-N, Ca, and Mg, but the highest Zn. These findings may help in rootstock selection, depending on a vineyard's specific soil, pest, and environmental conditions. We also found that annual applications of 44.8–56 kg N per hectare are sufficient to sustain yield and raisin quality. The leaf tissue tests and visual observations indicate that induced K deficiency, due to high crop loads, could be a concern, especially on 1103P rootstock. The fact that petiole tests did not indicate K deficiency suggests that leaf blade analysis, particularly at veraison, may be preferable to petiole tests, and that critical values of certain nutrients, particularly K, may differ from Thompson Seedless.

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