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Cultivar and Training System Impact Cold-climate Seedless Table Grape Performance in the Northeastern United States

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Abstract. **We grew eight cultivars of seedless table grape in Durham, NH, USA, from 2015 to 2021, using two training systems: Munson and vertical shoot positioning (VSP). We evaluated the vine vigor, prevalence of common diseases, yield, and postharvest fruit weight loss. We observed that cultivar significantly impacted vine vigor and the prevalence of three common diseases. One year after planting, the cultivars Thomcord, Marquis, and Lakemont had significantly less vigor than that of other cultivars, and Thomcord and Marquis both exhibited high mortality (38% and 29%, respectively). 'Marquis' and 'Thomcord' consistently showed among the highest prevalence of most diseases present in the vineyard (powdery mildew, anthracnose, and downy mildew), whereas 'Concord Seedless', 'Canadice', and 'Mars' consistently showed among the fewest symptoms. 'Thomcord' and 'Marquis' were removed from the experiment in 2019. For the six remaining cultivars, the cultivar, year, training system, and all interaction terms significantly affected yield. 'Mars' produced the highest yield throughout the study, reaching a maximum yield of over 15 kg/vine in their seventh season in the vineyard. Overall, yields of vines growing on the Munson training system were greater than those growing on the VSP system ($P < 0.0001$), although the advantages of growing on Munson were greater for some cultivars than for others (e.g., the yield advantages in 2021 were only 8% for 'Lakemont' but reached 90% for 'Concord Seedless' and 74.8% for 'Vanessa'). 'Mars' exhibited the lowest percentage weight loss after 28 days of cold storage, which was significantly lower than that of all cultivars except Reliance. In conclusion, 'Mars', 'Canadice', 'Vanessa', and 'Lakemont' offer potential for commercial production of seedless table grapes in the northeastern United States based on producing moderate to high yields of consistently high-quality fruit; of these, 'Mars' showed the least susceptibility to common diseases and postharvest weight loss.**

Grape (*Vitis* sp.) is a minor but expanding crop in northern New England (northeastern United States). In 2022, 566 acres were grown in New Hampshire, Vermont, and Maine, with 106 of those acres in New Hampshire (US Department of Agriculture, National Agricultural Statistics Service 2024). Nearly all of the reported acreage is used for wine production. In northern New England, winter low temperatures are too cold to permit cultivation of even the most cold-tolerant *V. vinifera* cultivars; therefore, grape cultivation is limited to American species (e.g., *V. labrusca*) and interspecific hybrids. Although nearly all seedless table grape production in the United States takes place in California using *V. vinifera* cultivars, recent decades have seen the release of many interspecific seedless table grape cultivars developed for cold, humid climates that offer a range of flavor profiles, textures, and fruit shapes (Table 1) (Clark 2003; Clark and Moore 2013).

Some winegrape cultivar evaluations have been conducted in cold climates, including in Vermont/zone 5a (Bradshaw et al. 2018; Hazelrigg et al. 2021), Iowa/zone 5a (Schrader et al. 2019), Idaho/zone 7a (Shellie et al. 2014), and New Mexico/zone 7a (Lombard et al. 2013). Although cold-hardy seedless table grape cultivars have been evaluated in Oregon/zones 8b and 9a (Vance et al. 2017) and Utah/zones 6b and 7a (Caron et al. 2021), they have not been systematically evaluated in colder climates. Thus, despite breeding advances, we lack the information necessary to guide those interested in growing table grape.

Grapevine growth is typically modified using one of several training systems that alter leaf area and light exposure to leaves and fruit (Reynolds and Vanden Heuvel 2009). Training systems impact the return on investment because they can influence yield, disease susceptibility, and fruit quality, and they influence the amount of time it takes vines to reach full maturity. There are many named training systems that leverage a variety of strategies, such as single or divided canopies positioned upward or downward, cane or spur pruning, and varied trunk heights. A single-canopy vertical shoot positioning (VSP) system with shoots trained upward from low- or mid-positioned canes or cordons is the standard for European *V. vinifera* vines (Wimmer et al. 2018). Hybrid wine grape vineyards in northern New England commonly use a cane-pruned VSP system with a divided canopy and low trunk. The Munson training system is also a divided canopy system, but it has a high trunk and four canes, with shoots combed downward over support wires. It was originally developed for 'Concord', which has a trailing habit (Munson 1909), and it is now widely recommended and used for table grape production (Zabadal 2002). Information about the optimum training system for specific table grape cultivars in the northeastern United States is currently lacking.

Most horticultural crop producers in the northeastern United States are highly diversified and primarily sell directly to consumers, and high-quality table grape cultivars adapted to this region could represent a novel addition to local markets. Our goal was to evaluate the most promising seedless table grape cultivars suitable for commercial production in New Hampshire under two training systems. We hypothesized that the training system would impact vine performance and yield, and that cultivars might respond differently to training systems. We report the vine vigor, yield, prevalence of common diseases, and postharvest fruit quality of eight cultivars in two training systems evaluated over 7 years.

Materials and Methods

Vineyard planting and maintenance. The research vineyard was established at the New Hampshire Agricultural Experiment Station at Woodman Horticultural Research Farm in Durham, NH, USA (lat. 43°15′N, long. 70°93′W). The site is on Charlton fine sandy loam (coarse loamy, mixed, superactive, mesic Typic Dystrudepts) (US Department of Agriculture, Natural Resource Conservation Service 2016). This site was US Department of Agriculture hardiness zone 5b in 2012; however, it was recategorized as zone 6a in 2023 (US Department of Agriculture 2023).

We selected eight seedless table grape cultivars (Table 1) that performed well in an unreplicated trial vineyard in southern New Hampshire (Lastowka 2014). One-year-old field-grown own-rooted vines (Double A Vineyards,

Table 1. Information about eight table grape cultivars evaluated in Durham, NH, USA.

Cultivar	Fruit color	Slipskin[i]	Resistance[ii]	Susceptibility	Origin[iii]	Reference
Canadice	Red	Yes	PM, DM, BR		NYSAES	Pool et al. (1977)
Concord Seedless	Blue	Yes	PM, DM, BR		Presumed mutant of Concord	Nitsch et al. (1960)
Lakemont	Green	No			NYSAES	Einset (1972)
Marquis	Green	No	Botrytis bunch rot	PM, DM, BR	NYSAES	Reisch et al. (1997)
Mars	Blue	Yes	PM, DM, BR, Anthracnose		Arkansas	Moore (1985)
Reliance	Red	Yes	PM, DM, BR, Anthracnose	Cracking	Arkansas	Moore (1983)
Thomcord	Blue	No		PM	USDA	Ramming (2008)
Vanessa	Red	No		PM	Horticultural Research Institute of Ontario	Fisher and Bradt (1985)

[i] In slipskin fruit, skins separate from the berry flesh.

[ii] Resistance and susceptibility as described in cultivar release publications. BR = black rot; DM = downy mildew; PM = powdery mildew.

[iii] Arkansas = Arkansas Agricultural Experiment Station; NYSAES = New York State Agricultural Experiment Station; USDA = US Department of Agriculture, Agricultural Research Service, Parlier, CA, USA.

Fredonia, NY, USA) were planted on 6 May 2015. Vines were planted 2.4 m apart in rows spaced 3.1 m apart, for a total density of 1344 vines per hectare. Rows were oriented east–west. The experimental design was a split-plot design with four replicates, with training system as the main plot (row) and cultivar as the subplot within each row. Each subplot consisted of three vines.

Before planting, vineyard rows were chisel-plowed to remove any compaction, and existing vegetation was killed using glyphosate and incorporated. During the establishment year, vines were irrigated using overhead irrigation once at planting and twice afterward to avoid drought stress. After that point, the vineyard was not irrigated. In Sep 2017, aisles between the vineyard rows were treated with glyphosate, tilled, and seeded with creeping red fescue to establish a perennial grass strip.

Vines were trained to VSP and Munson training systems (Creasy and Creasy 2009; Munson 1909). Whenever possible, two trunks were maintained for each vine as insurance against physical or winter injury. Once the main trunks were established, four new fruiting canes were selected for each vine each spring, unless four canes were not available because of winter injury or lack of vigor. For the VSP system, the four canes produced a mid-wire (0.76 m) double bilateral canopy with new shoots trained upward using pairs of additional catch wires at 1.1 m and 1.5 m. For the Munson system, the four canes produced a high-wire (1.5 m) double bilateral canopy. A supported wooden crossbar was installed on each pole to support the four high catch wires. The center wires that supported the canes were spaced 15 cm apart, and outer catch wires were spaced 60 cm apart to support shoots that were combed outward.

Vines were pruned in late April of each year according to the protocols described by Domoto (2014); however, lacking cultivar-specific guidelines, we maintained a maximum of 50 buds per vine, depending on vine vigor and winter injury. No fruit or cluster thinning was performed. Hedging was performed during the summer to permit tractor work, maintaining fruiting shoots at least 1.2 m long.

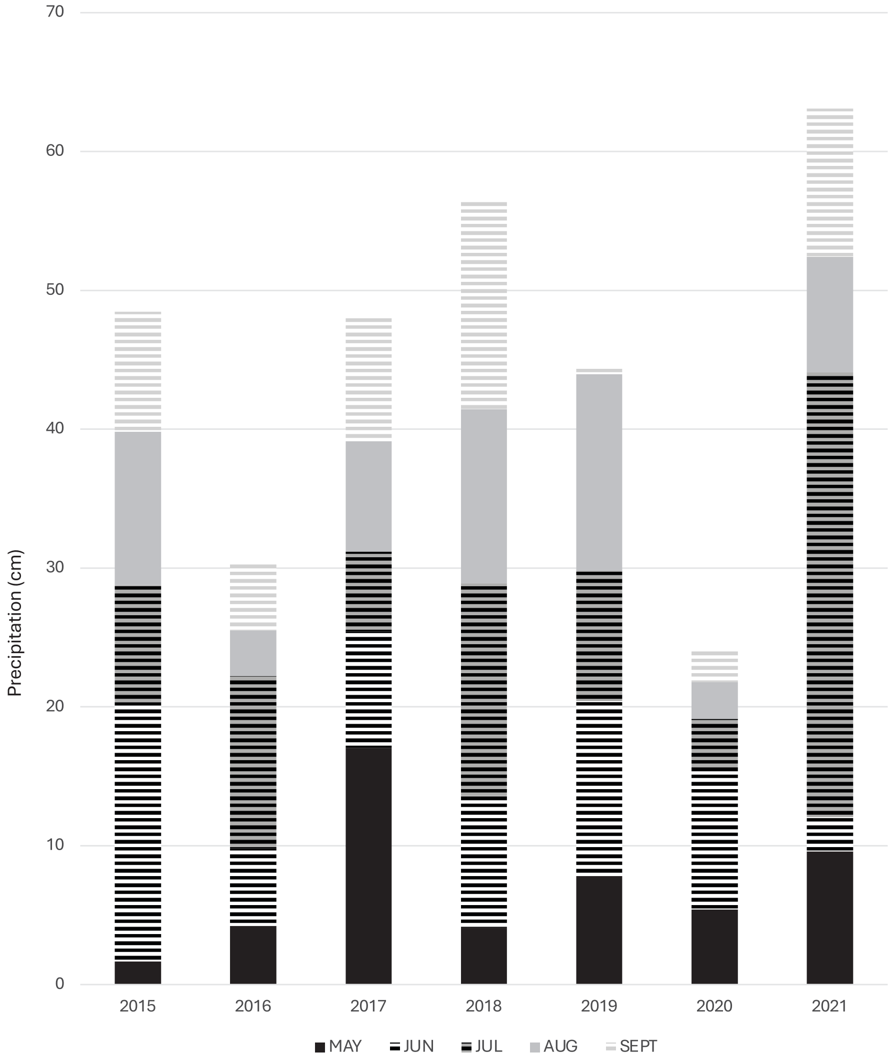

Fig. 1. Total monthly precipitation (in cm) during the growing season (May–September) from 2015 to 2021. Data were obtained from a weather station in the research vineyard at Woodman Horticultural Farm in Durham, NH, USA, after Dec 2016; before that point, data were obtained from neighboring weather stations located in Durham, NH, USA.

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Weed management was accomplished mechanically and through occasional shielded applications of glyphosate or paraquat. Vines were fertilized between budbreak and bloom with 2.8 g actual nitrogen (N) per vine in 2016, 5.7 g actual N in 2017, and 11.3 g actual N in 2019 and 2021 using soybean meal (7N–0.4P–1.7K) in 2016 and NatureSafe (13N–0P–0K) in 2017, 2019, and 2021. Following the recommendations of Christensen (1986), foliar boron (B) was applied in 2019 and 2020 at bloom at a rate of 0.56 kg·ha^{-1} of B using Solubor (Rio Tinto, London, UK) to ensure that B deficiency did not reduce fruit set.

Pest and disease management. In 2016 and 2017, the vineyard received minimal fungicide applications to control foliar diseases in response to symptoms observed during scouting, resulting in one application on 15 Sep 2016 and two applications in 2017 (on 12 Jun and 29 Jun). In 2018, we switched to a preventative approach and applied dormant lime sulfur (Miller Lime-Sulfur Solution; Miller Chemical and Fertilizer LLC, Hanover, PA, USA) after pruning; we began in-season fungicide applications when vines had 10 to 15 cm of new growth, and again thereafter as needed to maintain coverage in advance of rain events. In most years, this resulted in seven fungicide applications between late May and late July. The specific fungicides used varied between years. Carbaryl (Carbaryl 4L; Loveland Products Inc., Greeley, CO, USA) was applied as one or two applications in years when Japanese beetle caused a significant risk of defoliation. A complete list of pesticides applied is provided in Supplemental Table 1.

Data collection. After Dec 2016, weather data were collected from an on-site weather station and accessed through the Network for Environment and Weather Applications (http://newa.cornell.edu). Before that, they were collected from a weather station located approximately 0.5 miles away and were accessed through the Climate Data Online portal (National Oceanic and Atmospheric Administration 2024).

Vine vigor was evaluated in 2016 and 2018. In 2016, we used a scale of 0 to 4, where 0 represented a dead vine and 4 represented a very vigorous and healthy vine. All dead and nearly dead vines were replaced in May 2017. Those new vines were excluded from analyses. In 2018, we again evaluated vigor using the following modified rating scale: vines received a score of 0 if dead and a score of 0.5 if the trunk was alive but no canes had survived; vines received 1 point for each cane that had one to three viable buds; vines received 2 points for each cane that had four to six viable buds; and vines received 3 points for each cane that had more than six viable buds. This resulted in a maximum score of 12 points per vine for a vine with four healthy canes.

We evaluated susceptibility to pests and diseases when environmental conditions favored their occurrence in the field. We evaluated powdery mildew (*Erisyphe necator*) in 2016, anthracnose (*Elsinoe ampelina*) in 2016 and 2018, and downy mildew (*Plasmopara viticola*) in 2016, 2018, and 2019. For all of these, we used a rating system of 0 to 2, with 0 = no apparent symptoms or injury, 1 = mild symptoms, and 2 = severe symptoms.

Fruit set was not permitted in 2016, the second year of growth. Yield data were collected from 2017 to 2021, when vines were in their third through seventh growing seasons. In each year, bird netting was installed 1 to 2 weeks after veraison. We measured the soluble solids content using a hand-held refractometer (Milwaukee Instruments, Inc., Rocky Mount, NC, USA) to determine harvest maturity, and we began harvesting a given cultivar when the majority of fruit sampled met or exceeded 18°Brix. To collect yield data, all fruit were harvested and weighed separately for each vine.

After harvest in 2019, two clusters from each cultivar grown in each training system were placed in plastic clamshells (SKU#1260; 4-lb clamshells; D&W Fine Pack, Gladwin, MI, USA). ‘Thomcord’ and ‘Marquis’ were excluded from this analysis because of low survival of vines, resulting in few available clusters. Four replicates of each cultivar training system combination ($n = 4$) were used, except M ‘Vanessa’ ($n = 3$) and M ‘Lakemont’ ($n = 2$), because of lack of fruit. Each clamshell was weighed at harvest and again after 7, 14, and 28 d in cold storage (1.1 °C) to calculate the percent of postharvest weight loss of marketable fruit.

Data analysis. Vigor and disease symptom data from different years were analyzed separately because of year-to-year variability in cultivars included. An analysis of variance using a split-plot design was used to evaluate the effects of training system (main plot), cultivar (subplot), year, and all interactions on yield, vigor, and disease ratings. The postharvest weight loss data were subjected to a repeated measures analysis. Block was considered a random effect in all models. When an overall F test was significant ($P < 0.05$), means were compared using Tukey’s honestly significant difference (HSD) test at the $P \leq 0.05$ level. In the case of significant interactions, results are explained or presented separately for all treatment combinations. JMP Pro version 17 (SAS Institute, Cary, NC, USA) was used for all statistical analyses.

Results

Throughout this experiment, the lowest winter temperature each year was below −15 °C, which was expected given the hardiness zone of the site. The coldest temperatures reached in the vineyard from 2016 to 2021 were, in consecutive order, −24.9 °C, −18.3 °C, −23.8 °C, −19.8 °C, −19.3 °C, and −19.8 °C. The amount of rainfall received during the growing season (May through September) varied from 24.2 cm in 2020 to 63.1 cm in 2021 (Fig. 1).

Vigor and disease symptoms. By Spring 2016, 1 year after planting, differences in vine vigor were apparent (Fig. 2), with ‘Thomcord’, ‘Marquis’, and ‘Lakemont’ exhibiting significantly less vigor than that of other cultivars. In 2018, ‘Marquis’ had the lowest vigor, which was significantly less than that of all cultivars except Thomcord and Lakemont (Fig. 2). Effects of cultivar were significant in both years ($P < 0.0001$), whereas effects of training system and the interaction between training system and cultivar were not significant (in 2016: $P = 0.536$ and 0.117, respectively; in 2018:

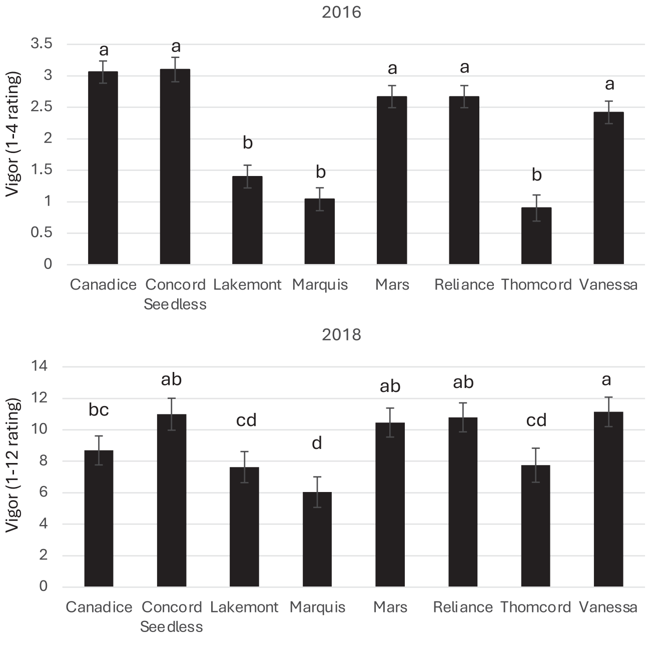

Fig. 2. Grapevine vigor evaluated on 24 Jun 2016 and 2 Jul 2018 in the research vineyard at Woodman Horticultural Farm in Durham, NH, USA. In 2016, 0 = dead vine and 4 = very vigorous and healthy vine. In 2018, 0 = dead vine and 12 = very vigorous vine with four healthy canes. Within a year, bars marked with the same letter are not significantly different (Tukey’s honestly significant difference, $P \leq 0.05$).

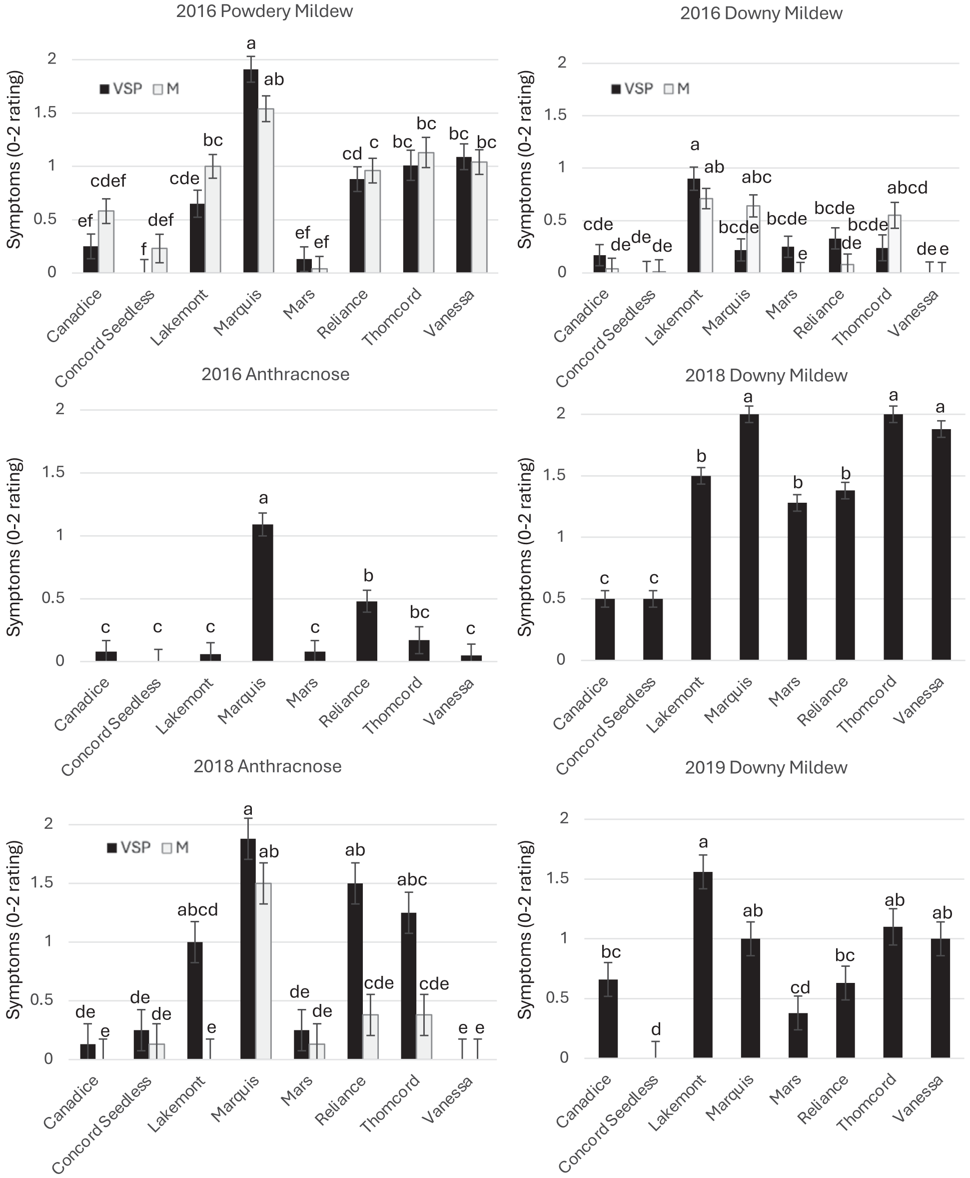

Fig. 3. Symptoms of grapevine powdery mildew, anthracnose, and downy mildew on eight seedless table grape cultivars during years when each disease was present in the research vineyard at Woodman Horticultural Farm in Durham, NH, USA. Mean ± standard error are presented. Rating system: 0 = no symptoms; 1 = mild symptoms; and 2 = severe symptoms. Munson and vertical shoot positioning (VSP) training systems were used. When a significant cultivar × training system interaction was identified, mean ratings are presented for each training system separately. Within a given year/disease combination, bars marked with the same letter are not significantly different (Tukey's honestly significant difference, $P \leq 0.05$).

$P = 0.942$ and 0.183). These low-vigor cultivars also showed relatively high mortality. By Fall 2016, 38% of 'Thomcord' vines and 29% of 'Marquis' vines had died. Fewer 'Lakemont' (17%) vines died, and mortality was 0% to 8% for all other cultivars (data not shown).

In 2016, 2018, and 2019, symptoms of several common foliar diseases of grapevine were observed, and symptoms were rated for each plot (Fig. 3). Trace amounts of black rot affected a few fruit in the vineyard in some years, but symptoms were not widespread enough to permit a systematic evaluation. These and other common grapevine diseases were not observed in the remaining years of the study.

Grapevine powdery mildew (*Erisyphe necator* Schwein) was prevalent in 2016. We observed effects of cultivar ($P < 0.0001$), but not of training system ($P = 0.411$). The cultivar × training system interaction was significant ($P = 0.047$), but the general trends of differences between cultivar were similar across both training systems (Fig. 3). Marquis showed the most severe symptoms, while Mars and Concord Seedless showed significantly fewer symptoms compared to most cultivars.

Grapevine anthracnose (*Elsinoe ampelina* Shear) was observed and rated in both 2016 and 2018 (Fig. 3). In 2016, we observed significant effects of cultivar only ($P < 0.0001$), but not training system or their interaction ($P = 0.342$ and 0.153, respectively). In 2018, cultivar, training system, and their interaction were significant ($P < 0.0001$, $P = 0.003$, and $P = 0.038$, respectively). In both years, 'Marquis' showed the most severe symptoms, followed closely by 'Reliance' and 'Thomcord'. In 2018 only, for many cultivars, vines grown using the VSP system showed significantly more severe symptoms than those grown using the Munson system.

Grapevine downy mildew (*Plasmopara viticola* Berk. & M.A. Curtis) was observed in 2016, 2018, and 2019 (Fig. 3). In 2016, while there was a significant interaction between cultivar and training system ($P = 0.009$), cultivars showed similar responses in both training systems. In 2018 and 2019, only cultivar showed a significant effect ($P < 0.0001$). 'Marquis' and 'Thomcord' (2016, 2018, and 2019), 'Lakemont' (2016 and 2019), and 'Vanessa' (2018 and 2019) showed the most severe symptoms. In contrast, 'Concord Seedless' (2016, 2018, and 2019), 'Canadice' (2016 and 2018), 'Mars' (2016 and 2019), and 'Vanessa' (2016) showed the lowest ratings. Vanessa was the only cultivar that showed an inconsistent response between years because it had the least severe symptoms in 2016, and

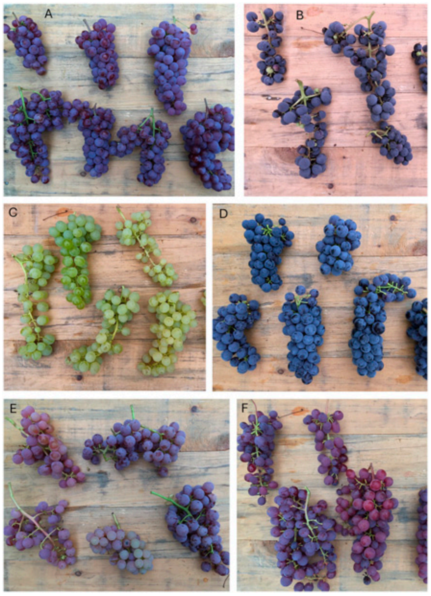

Fig. 4. Representative clusters from the six seedless table grape cultivars grown in Durham, NH, USA: Canadice (**A**), Concord Seedless (**B**), Lakemont (**C**), Mars (**D**), Reliance (**E**), and Vanessa (**F**).

among the most severe symptoms in 2018 and 2019.

Yield. Each year, fruit were harvested over a period of 2 to 4 weeks, from 4 to 20 Sep 2017, 12 Sep to 11 Oct 2018, 15 Sep to 4 Oct 2019, 1 to 24 Sep 2020, and 8 Sep to Oct 2021. Within each growing season, ‘Reliance’ and ‘Canadice’ reached harvest maturity earliest, and ‘Mars’ reached harvest maturity latest. For most cultivars, fruit were relatively uniform, with all fruit ripening in a consistent manner (Fig. 4). The clusters of ‘Canadice’ and ‘Mars’ were tighter than clusters of ‘Lakemont’ and ‘Vanessa’. Later in the season, ‘Lakemont’ and ‘Vanessa’ tended to show berry shattering, with some berries detached from the stem before or during harvest. ‘Reliance’ exhibited uneven ripening, cracking, and shattering in all years, with some fruit detaching before other fruit turned red. ‘Concord Seedless’ also exhibited uneven ripening and cracking, with some fruit cracking and rotting or attracting insects before others turned purple. It was difficult to time the harvest of these two cultivars to maximize yield and fruit quality.

Table 2. Year, training system, and cultivar effects on the yield (kg/vine) of eight seedless table grape cultivars in Durham, NH, USA, during 2017, 2018, and 2019, for vines planted in 2015 as 1-year-old field-grown own-rooted vines ($n = 4$, except for Munson-trained Concord Seedless, for which $n = 3$).

Training system	2017	2018	2019
Munson	1.93	5.91	4.38
Vertical shoot positioning	2.84	4.30	3.51
Cultivar			
Canadice	4.06 a[i]	5.20 ab	7.99 a
Concord Seedless	1.54 ab	5.76 ab	4.04 bc
Lakemont	3.09 ab	3.14 b	0.72 cd
Marquis	1.41 ab	1.18 b	0.22 cd
Mars	3.85 ab	8.31 a	10.27 a
Reliance	3.18 ab	6.08 ab	7.87 ab
Thomcord	0.36 b	5.02 ab	0.75 d
Vanessa	1.60 ab	6.15 ab	0.36 cd
Significance			
Training system		0.2818	
Cultivar		<0.0001	
Training system × cultivar		0.4524	
Year		<0.0001	
Training system × year		0.0024	
Cultivar × year		<0.0001	
Training system × cultivar × year		0.4072	

[i] Within the year, cultivar means sharing a letter are not significantly different according to Tukey’s honestly significant difference test ($P \leq 0.05$).

Yield data were collected from 2017 to 2021. Yield data of all eight cultivars were analyzed from 2017 to 2019 (Table 2). For these three years, cultivar and year significantly impacted yield, but training system did not. A significant cultivar × year interaction was observed. In 2017, ‘Canadice’ produced significantly higher yield than ‘Thomcord’, and it also had the highest average yield of all cultivars. In 2018, ‘Mars’ had the highest average yield of all cultivars (8.3 kg/vine) and significantly greater yield than ‘Lakemont’ (3.1 kg/vine) and ‘Marquis’ (1.2 kg/vine). In 2019, ‘Mars’ (10.3 kg/vine) again produced the highest yield among cultivars, which was statistically comparable to that of ‘Canadice’ (8.0 kg/vine) and ‘Reliance’ (7.9 kg/vine). ‘Concord Seedless’ produced intermediate yield, and ‘Lakemont’, ‘Marquis’, ‘Thomcord’, and ‘Vanessa’ all produced low yields of <1.0 kg/vine.

At the end of 2019, ‘Thomcord’ and ‘Marquis’ were removed from the experiment because most vines, including those replaced in 2017, were dead or very weak. From 2017 to 2021, we analyzed yield data for the six remaining cultivars and found that cultivar, year, and training system, as well as all interaction terms, significantly affected yield (Table 3).

In both training systems, ‘Mars’ consistently produced the highest yield throughout the study (Fig. 5). In some years, yields of ‘Vanessa’, ‘Canadice’, and ‘Reliance’ were not significantly different from those of ‘Mars’, especially in the Munson training system. In general, yield increased over time, reaching the maximum at the end of the study when vines were in their seventh growing season in the vineyard. There were some exceptions to this trend, however. For example, in 2019, ‘Vanessa’ and ‘Lakemont’ in both training systems and ‘Concord Seedless’ in the VSP system produced extremely low yields.

Table 3. Analysis of variance for year, training system, and cultivar effects on yield (kg/vine) of six seedless table grape cultivars in Durham, NH, USA, from 2017 to 2021, for vines planted in 2015 as 1-year-old field-grown own-rooted vines ($n = 4$, except for Munson-trained Concord Seedless, for which $n = 3$).

Source of variation	P
Training system	0.0352
Cultivar	<0.0001
Training system × cultivar	0.0020
Year	<0.0001
Training system × year	<0.0001
Cultivar × year	<0.0001
Training system × cultivar × year	0.0107

Overall, vines growing on the Munson training system outyielded those growing on the VSP system ($P < 0.0001$). Figure 6 shows the performance of each cultivar in both training systems. From 2017 to 2021, the two systems performed similarly or Munson outperformed VSP in all cases except for ‘Canadice’ in 2020. This was especially true for ‘Concord Seedless’, which showed significantly higher yield in the Munson system than in the VSP system during three of the five years. In 2021, when vines produced their highest yield, the Munson system yield advantage ranged from 8.4% for ‘Lakemont’ to 90% for ‘Concord Seedless’.

Postharvest weight loss. In 2019, the percent weight loss of berry clusters were measured after 7, 14, and 28 d in cold storage. Repeated measure analyses showed that percent weight loss was affected by cultivar ($P < 0.0001$) and storage duration ($P < 0.0001$), and training system × cultivar ($P = 0.009$) and cultivar × storage duration ($P < 0.0001$) interactions occurred. A three-way interaction between training system × cultivar × storage duration also occurred ($P = 0.032$). In contrast, percent weight loss was unaffected by training system ($P = 0.8697$), and there was no interaction between training system × storage duration ($P = 0.286$).

When exploring the significant training system × cultivar interaction, we found that ‘Concord Seedless’ clusters from the VSP system exhibited a greater percent weight loss than those harvested from the Munson system (data not shown). For all other cultivars, the percent weight loss was comparable between training systems.

The cultivar × storage interaction is illustrated in Fig. 7. In general, fruit from different cultivars lost weight over time in a similar way; however, ‘Mars’ showed less weight loss between 7 and 14 d compared with most cultivars. Overall, ‘Mars’ (3.0%), ‘Reliance’ (3.4%), and ‘Canadice’ (3.9%) maintained the highest percent of their prestorage weight after

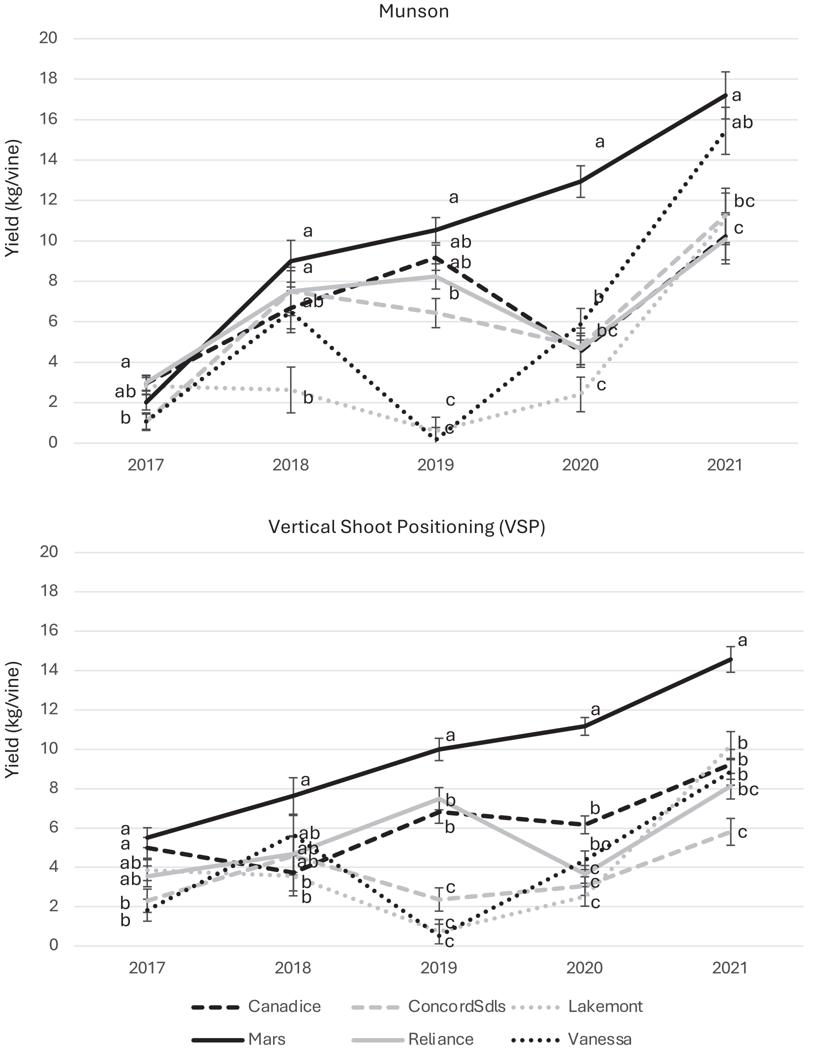

Fig. 5. Yield (kg/vine) from 2017 to 2021 of six seedless table grape cultivars grown in Durham, NH, USA on Munson and vertical shoot positioning training systems. Within a year, values marked with the same letter are not significantly different (Tukey's honestly significant difference, $P \leq 0.05$).

28 d in storage, while 'Concord Seedless' (5.6%), 'Lakemont' (5.2%), and 'Vanessa' (4.5%) lost the highest percent of their prestorage weight (Fig. 7).

Discussion

Of the eight cultivars in our study, Thomcord, Marquis, and Lakemont had the lowest vigor, and Marquis and Thomcord were removed from the experiment after the fifth growing season because of high mortality. Vance et al. (2017) compared Lakemont, Canadice, and Reliance with several other cultivars in Oregon, and they reported that Reliance had lower vigor than that of other cultivars. In contrast, we found that Reliance was among the most vigorous cultivars. Caron et al. (2021) compared Marquis, Canadice, and Reliance with several other cultivars in Utah and found that Marquis plants showed no mortality and produced the highest yield in the trial; additionally, the authors noted that diseases were not present in that experiment, and that *V. vinifera* 'Thompson Seedless' survived, so it is possible that both pathogen and temperature stresses were greater in our experiment, and that these negatively impacted 'Marquis'.

Several fungal diseases limit grape production in the humid northeastern United States, including black rot, powdery mildew, Phomopsis cane and leaf spot, and downy mildew. We began our experiment using an approach that included a very low spray, with no fungicide applications during year 1, one application in year 2, and two applications in year 3. While some vineyards in this region do use minimal fungicide programs or operate no-spray vineyards, use of the most disease-resistant cultivars is critical for that approach. During a cultivar trial, the presence of more susceptible cultivars that can support high inoculum levels makes this ineffective; therefore, we had to switch to a more typical preventative fungicide program, which resulted in approximately seven fungicide applications each year. Regardless, pathogen pressure observed in the early years of this experiment provides important information for producers.

Hazelrigg et al. (2021) rated disease incidence for several interspecific wine grape hybrids grown without fungicides in Vermont and found that the disease incidence varied among cultivars, and that cultivar ratings were not always consistent between years. Furthermore, not all diseases were present in both years of their study. We also found this to be the case, thus highlighting the importance of multiyear experiments to evaluate disease susceptibility of specific cultivars.

'Marquis' and 'Thomcord' consistently showed the most susceptibility to all diseases present in our vineyard (powdery mildew, anthracnose, and downy mildew), while 'Concord Seedless', 'Canadice', and 'Mars' consistently showed the least susceptibility. This is consistent with cultivar release notes that suggest that 'Canadice' and 'Mars' have moderate resistance to powdery and downy mildews, and that 'Mars' also has resistance to anthracnose (Moore 1985; Pool et al. 1977). 'Marquis' and 'Thomcord' are reportedly susceptible to powdery mildew, and 'Marquis' is also susceptible to downy mildew (Ramming 2008; Reisch et al. 1997).

We observed that 'Lakemont' and 'Reliance' had intermediate susceptibility to all three diseases, and that 'Vanessa' showed moderate susceptibility to powdery and downy mildew, but ratings varied among years. Consistent with our results, Vance et al. (2017) found that 'Canadice' had low, 'Lakemont' had intermediate, and 'Reliance' had high "disease susceptibility," which included susceptibility to botrytis bunch rot and powdery mildew. In contrast, Moore (1983) reported that 'Reliance' has moderate resistance to black rot, anthracnose, powdery mildew, and downy mildew; however, this finding was not consistent with our observations. We concluded that more careful attention to pathogen management than that for 'Concord Seedless', 'Canadice', and 'Mars' may be required for success with 'Marquis' and 'Thomcord', and that a medium level of attention may be required for 'Lakemont', 'Reliance', and 'Vanessa'. Importantly, we did not observe meaningful levels of black rot, Phomopsis, or botrytis bunch rot during our experiment; therefore, we cannot comment on susceptibility to these common diseases.

In our study, the highest yield was observed for all cultivars in the final year of the experiment, when vines were in their seventh growing season. In many production budgets, grapevines are expected to reach full production by year 4 (Gómez and Tang 2014; Noguera et al. 2005); however, others suggest that yield continued to increase until year 6 (Fidelibus et al. 2018). California table grape yield in recent years has averaged between 17.5 and 20.8 $t{\cdot}ha^{-1}$ (US Department of Agriculture, National Agricultural Statistics Service 2024), and a range of 13.5 to 26.9 $t{\cdot}ha^{-1}$ has been reported as typical for American hybrid grapes (Dami et al. 2005). Yields observed in the last year of our trial were within these ranges (from 13.7 $t{\cdot}ha^{-1}$ for 'Reliance' and 'Canadice' to 23.1 $t{\cdot}ha^{-1}$ for 'Mars'). We did observe surprisingly low yields for 'Vanessa' and 'Lakemont' in 2019, and we

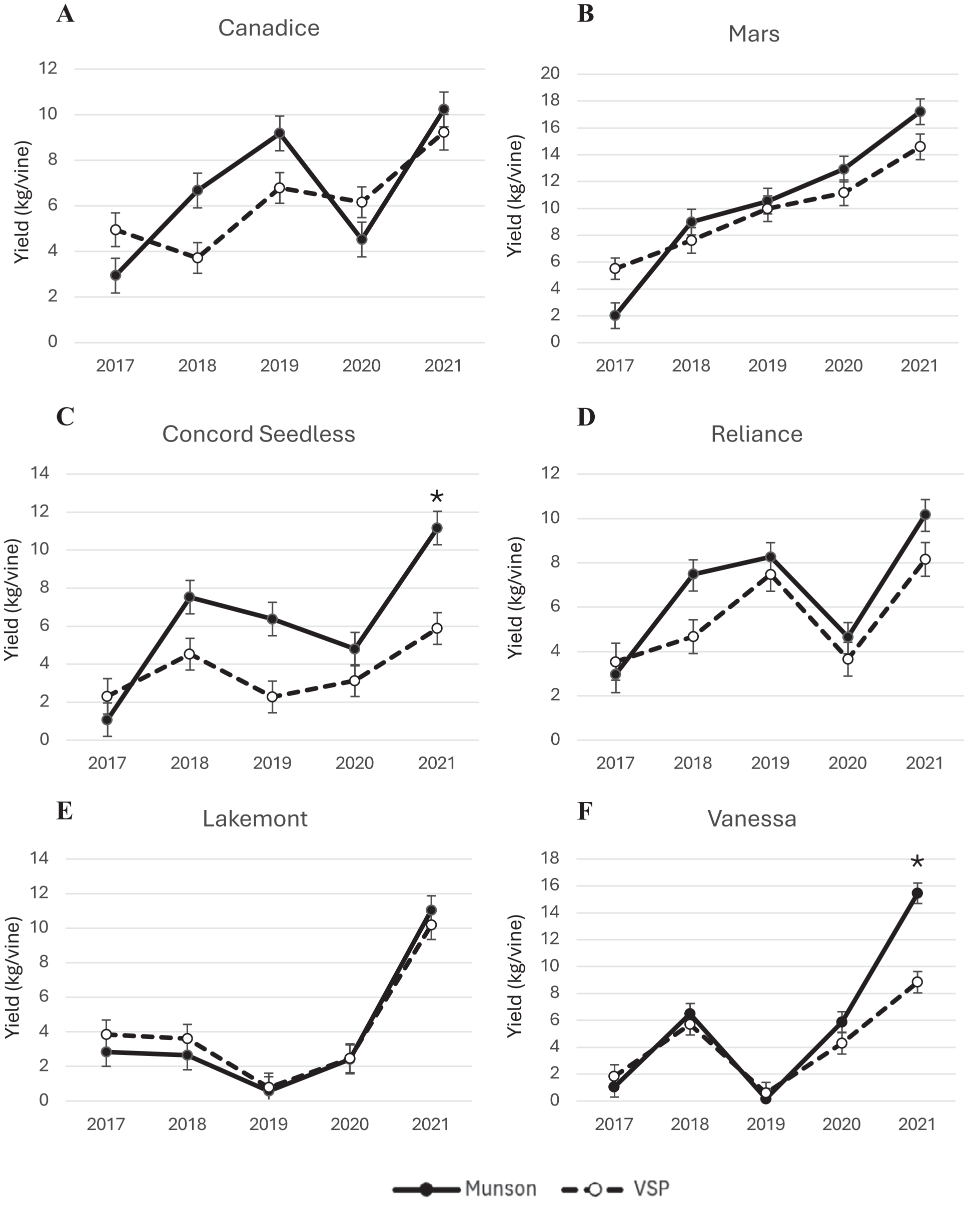

Fig. 6. Yield (kg/vine) from six seedless table grape cultivars grown in Durham, NH, USA, on Munson and vertical shoot positioning (VSP) training systems from 2017 to 2021. *Years in which mean values differed significantly between training systems (Tukey's honestly significant difference, $P \leq 0.05$).

hypothesized that these low yields may have been attributable to the unusually wet year in 2018, which favored downy mildew and defoliation of some cultivars that reduced fruitfulness the following year.

For all cultivars, early yield (year 3) was higher for vines trained to the VSP system than that for those trained to the Munson system, likely because the Munson system requires the establishment of a higher trunk, which takes longer to grow, before establishing fruiting canes. Despite the comparatively slow start and longer time to fruit for the Munson system compared with the VSP system, Munson vines eventually tended to outyield VSP vines. While we did not directly evaluate fruit quality in this study, in a separate study using these vines, we found that 'Mars' fruit grown in the Munson training system had higher soluble solids content, higher total phenolics, and higher antioxidant potential compared with fruit from the VSP system (Lima et al. 2022). Despite the advantages of the Munson system, we should note that dormant pruning, shoot placement, leaf removal, cluster thinning, and harvesting practices all require working with the arms overhead when using the Munson system, and members of our research team found these practices tiring.

Couvillon and Nakayama (1970) showed that 'Concord' had more even ripening when grown in a modified Munson system compared to that grown in a four-arm Kniffin system. Similarly, we observed more even ripening for 'Concord Seedless' grown in a Munson system compared with that grown in a VSP system. On VSP-trained vines, many clusters had several small berries that remained green that were interspersed with full-size berries that ripened normally; however, we did not observe this on Munson-trained vines. This phenomenon is known as "millerandage" (Collins and Dry 2009), and its effects are evident in the yield data, which showed significantly lower yield for VSP-trained compared with Munson-trained vines during three of the five years when we collected data.

Table grapes have a narrow harvest window to avoid losses caused by fruit drop, cracking, and a variety of pests. Typically, table grapes are stored for up to 8 to 10 weeks at –1 to 1 °C (Creasy and Creasy 2009; Crisosto and Smilanick 2016). Along with other postharvest practices, cold storage is used to prolong the marketing season by limiting postharvest weight loss, which causes fruit softening and shriveling, fruit shattering, and stem drying and browning. Weight loss during storage has been associated with quality decline and reduced firmness in grape (Mencarelli et al. 2015). Because American consumers are most familiar with the crisp texture of *V. vinifera*

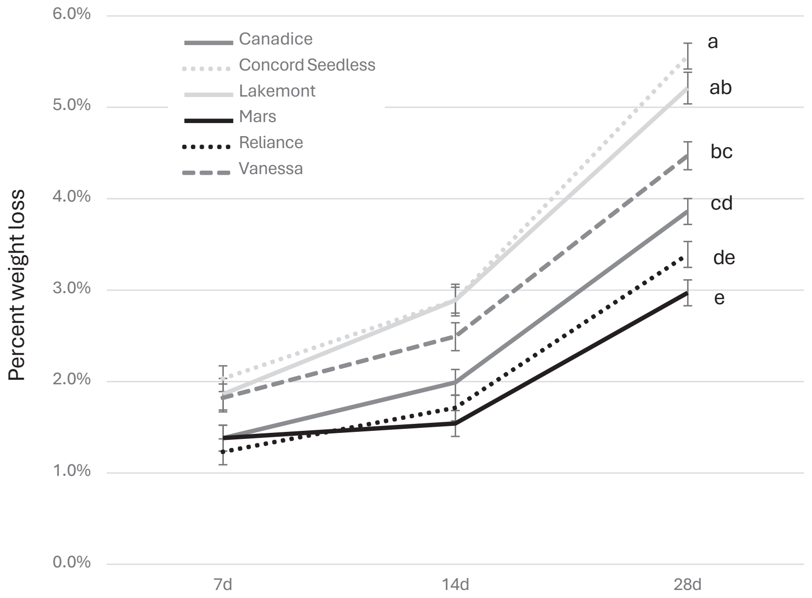

Fig. 7. Percent weight loss for berry clusters of six seedless table grape cultivars following the 2019 harvest. Fruit were kept in cold storage (1.1 °C) in clamshell containers for 28 d and weighed at harvest and after 7, 14, and 28 d of storage. Mean ± standard error are presented. For 28-d weight loss, values sharing a letter are not significantly different according to Tukey's honestly significant difference test ($P \leq 0.05$) [$n = 4$, except Munson 'Vanessa' ($n = 3$) and Munson 'Lakemont' ($n = 2$)].

table grapes, and because the hybrid grapes in our study generally have a softer fruit texture, minimizing weight loss during storage may be key to consumer acceptance. When stored at 1 °C, fruit of all cultivars remained marketable throughout the experiment (28 d), but we did observe significant differences in postharvest weight loss. This suggests that some cultivars (e.g., Mars, Reliance, Canadice) may be held and marketed for longer than other cultivars (Lakemont, Concord Seedless), and that producers can use this information to select cultivars or prioritize sales.

Conclusions

The cultivar Mars consistently produced the highest yield throughout the experiment. 'Canadice', 'Lakemont', and 'Vanessa' produced lower yield, but the fruit quality of all four of these cultivars was excellent. The fruit quality of 'Reliance' and 'Concord Seedless' was not consistently excellent because of uneven ripening and cracking, and 'Marquis' and 'Thomcord' showed high mortality and low vigor. With all table grapes, growers may need to focus special attention on harvest timing to avoid shattering and fruit loss to pests while maximizing fruit quality and yield. We conclude that 'Mars', 'Canadice', 'Lakemont', and 'Vanessa' offer potential for commercial seedless table grape production in southeastern New Hampshire and areas with a similar climate. Of these, postharvest weight loss over the month following harvest was lowest for 'Mars' and 'Canadice' and higher for 'Lakemont' and 'Vanessa'. 'Mars' and 'Canadice' also showed less susceptibility to the diseases present in our study compared to other cultivars, including Lakemont and Vanessa, simplifying pest-management operations.

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