Evaluation of Cold-hardy Grape Cultivars for North Dakota and the NDSU Germplasm Enhancement Project

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Abstract

The development of cold hardy, *Vitis riparia*-based grape cultivars in the 1990's started a new industry of small vineyards and wineries in the New England, Upper Midwest and northern Plains regions of the United States. A cultivar evaluation study was conducted over a seven-year period to identify cold-hardy hybrid grapes adapted to the harsh environmental conditions of North Dakota. Weather data indicated that grape cultivars must be able to ripen their fruit with as little as 1184 accumulated growing degree day units and with a growing season of only 132 days as observed in 2010. Grape results indicated that three cultivars: 'King of the North', ES 12-6-18, and 'Valiant', were adapted to North Dakota conditions, even though yields were reduced in 2010. Unfortunately, the wine that can be produced from two of the three cultivars: 'Valiant' and ES 12-6-18, fall short of the goals of most winemakers and their potential customers. The high titratable acidity levels of 'King of the North' will greatly limit winemaking styles. 'Marquette', MN1200, and ES 5-4-71 did not have reliable hardiness as each yielded less than an average 770 kg ha^{-1} over the seven-year testing period. The highest yielding white winegrape, when averaged over seven years, was 'Alpenglow' with a yield less than half from the top three yielding cultivars. Therefore, research at NDSU has focused on the development of hardier *V. riparia*-based cold-hardy winegrape cultivars that will survive the harsh North Dakota environment and consistently produce fruit and high quality wine.

INTRODUCTION

The development of cold hardy, *Vitis riparia*-based grape cultivars in the 1990's started a new industry of small vineyards and wineries in the New England, Upper Midwest and northern Plains regions of the United States. In North Dakota, commercial grape growing and the associated wine industry began in 2002 when the first bonded winery making grape wines was established. The North Dakota Department of Commerce Tourism Division currently lists 23 wineries and vineyards on their North Dakota Beer and Wine Trail brochure (Anonymous, 2014). Regulations in North Dakota are meant to stimulate a domestic industry and thus require a majority of North Dakota-grown grapes in commercial wines, although there is a short-term exemption for new wineries. Thus, the greatest difficulty facing new and existing ND wineries is a reliable supply of domestically produced grapes that are suitable for quality wines.

Interest in growing grapes and starting a winery is considerable. Tuck and Gartner (2014) reported that the wine grape and locally-sourced winery industries contributed $1.5 billion to the economy of the 12 states involved in the project, including $409 million of labor and the creation of 28,200 jobs. In addition, winery tourists visiting locally-sourced wineries created $470 million of economic output and 5,300 jobs. The contribution from just cold-hardy grapes alone was approximately one-fourth of the total, but the authors did indicate that results suggest continued growth in the cold-hardy industry.

Cold is a major factor that limits wine grape production in North Dakota. North Dakota shares a cold continental climate with bordering Minnesota, but there are substantial environmental differences between most of North Dakota and south-eastern Minnesota, the location of the University of Minnesota grape breeding program. North Dakota has colder winters, more wind, a shorter growing season, less acidic soil, less rainfall, less humidity and the related pressure from fungal pathogen when compared to Southern Minnesota (NOAA, 2014). Therefore, one cannot assume recent University of Minnesota releases such as ‘Frontenac’, ‘LaCrescent’, and ‘Marquette’ are adapted to North Dakota environmental conditions. Until recently, the two cultivars commonly planted due to their dependable yields in North Dakota were ‘Beta’ and ‘Valiant’; two grape cultivars with wine quality that fall short of the goals of most winemakers and their potential customers (Plocher and Parke, 2008). The objective of this research was to evaluate cold-hardy grape cultivars for their adaptability to North Dakota environmental conditions.

MATERIALS AND METHODS

The trial was establish in 2004 at the North Dakota State Horticulture Research and Arboretum site, near Absaraka, ND, on a Northern Spottswood sandy loam soil with 2.0% organic matter and 7.2 pH. The planting material was purchased from commercial nurseries as ungrafted one-year-old dormant vines. All cultivars were noted as hardy to zones 3 and 4. The cultivars consisted of ‘Alpenglow’, ‘Baltica’, ‘Blue Bell’, ES 5-4-71, ES 12-6-18, ‘Frontenac’, ‘Frontenac Gris’, ‘King of the North’, ‘LaCrescent’, ‘Marquette’, MN 1131, MN 1200, ‘Sabrevois’, ‘Somerset Seedless’, ‘St. Croix’, and ‘Valiant’.

All weather data was recorded at a weather station that is part of the North Dakota Agriculture Weather Network (NDAWN, 2014). Growing-degree day (GDD) heat unit accumulation was calculated for each year of the study using the simple average daily maximum and minimum temperatures with a base temperature of 10 °C and a 30 °C upper temperature limit.

The trial experimental design was a randomized complete block with cultivars planted in four-vine experimental units and four replications. Rows were oriented north-to-south with 3 m between rows and 2.4 m between vines. Vines were initially grown with a single trunk and trained to form a bilateral cordon arm that was approximately 1.2 m long and located 1.8 m above the soil surface. Each cordon arm was dormant pruned annually to retain approximately 15 buds or 30 buds per vine for 0.5 kg of pruning weight. Vines with 1 kg of pruning weight had a total of 40 buds retained with a maximum of 50 buds per vine if pruning weight exceeded 1.5 kg.

Vines were irrigated as needed only during the establishment year. Alleyways were seeded with creeping red fescue (*Festuca rubra* subsp. *rubra*) in 2005. Canopy and nutrient management, weed removal, and pesticide applications were performed according to extension recommendations (Bordelon et al., 2014; Dami et al., 2005).

Vine phenology was characterized by recording in Julian Days when 50% of the buds or clusters on a vine had reached budbreak, bloom, and veraison (Coombe, 1995). Each cultivar was harvested when juice from a random sample of berries had a soluble solids concentration (SSC) of ≈20% for white-skinned grapes and ≈22 to 24% for red-skinned grapes and a pH of at least 3.0. The SSC was used as the primary harvest indicator, but harvest was delayed if pH was not at the target level. If a freeze occurred before berries reached their target level, all fruit was harvested the following day. All clusters were counted during harvest and were weighed to determine yield per vine. Immediately after harvest, six random clusters from each experimental unit were taken for cluster, berry, and juice evaluations. Each cluster sample was individually weighed. Average berry weight was calculated by dividing cluster weight by the number of berries per cluster. The Ravaz Index (RI) for each treatment was calculated by dividing the yield per vine by the dormant pruining weights collected. In addition, a random 100-berry weight was recorded. The 100-berry sample was used to measure SSC, pH, and titratable acidity (TA) as described by Kristic et al., 2003.

Data for phenology, yield, and berry composition were analysed using analysis of variance procedures using the general linear model and mixed model procedures in SAS at $\alpha = 0.05$ (version 9.3; SAS Institute, Cary, NC), with replication, replication by cultivar, and replication by year as random variables. The mixed model type III mean squares were computed when missing data occurred from vine injury, which prevented fruit production. Means without missing data were separated where appropriate using Fisher's least significant difference test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Environmental Conditions

The minimum daily winter temperature for each year was at least 7 °C lower than the 30-year average minimum temperature (Table 1). This generally occurred early- to mid-January with the main exception during the winter of 2007-08 when the coldest temperature occurred mid-February. The coldest month was January except during the winter of 2009-10 when February was the coldest month. The day of the year when the first ≤ 0 °C event occurred was at least 5 d earlier than the 30-year average with the earliest event occurring 11 September, 2007. Similarly, the day of the year when the last ≤ 0 °C event occurred was at least 8 d later than the 30-year average with the latest event occurring 17 May, 2009.

Daily temperature extremes that have a temperature range above and below 0 °C have been suggested as a major cause for winter injury (Caspari and Larson, 2013).

Surprisingly, the most extreme diurnal temperature range above and below 0 °C occurred at least 10 d after the first fall ≤ 0 °C event with the exception of 2012-13 where the temperature went from a high of 18 °C to -4 °C in less than 24 h only 5 d after the first fall ≤ 0 °C event (Table 1). The greatest winter injury during the 7-year evaluation period occurred after the winter of 2009-10 with trunk and cordon replacement for several cultivars. Unfortunately, winter conditions during this period were similar to other years with the exception that the month with the mean coldest temperature was February instead of January. Five of the seven years had growing season heat unit accumulation below the 30-year average. The 2010 growing season had only 1184 accumulated growing degree days (AGDD), 229 growing degree days (GDD) below the 30-year average.

Phenology

Cultivar budbreak, bloom, veraison, and harvest varied with year. Most cultivars reached 50% budbreak by mid-May (data not shown). When graphed, most cultivars responded similarly to varying environmental conditions each year. However, if one cultivar reached 50% budbreak 3 d earlier than another cultivar, the next year the sequence may have been reversed. There was no pattern for cultivar budbreak except that 'Sabrevois' 50% budbreak date was at least 1 d later than the other cultivars (data not shown). Similarly, graphing the interaction of the day when a cultivar reached 50% bloom with year did not provide a pattern except that when the bloom period was longer, such as 2012, several *V. riparia*-based cultivars including 'Frontenac', 'Frontenac Gris', and MN1131reached 50% bloom approximately seven days earlier than most of the other cultivars (data not shown). 'Baltica' clearly reached veraison earlier than other cultivars regardless of the year (Fig. 1). 'Baltica' reached veraison at least 7 d earlier than other cultivars and during years when fruit ripening was delayed for many cultivars, such as 2009, 'Baltica' reached veraison 14 d earlier than the next closest cultivar. However, 'Baltica' harvest occurred earlier than other cultivars only during 2012 and 2013, when AGDDs were greater than 1400 (Fig. 2). 'Somerset seedless' had similar early harvest dates in 2012 and 2013.

Yield components

Yield was converted from a per vine basis to a per area basis in order to reflect inconsistent fruit production. Cultivar yield, pruning weight, and Ravaz index (RI) varied with year (Table 2). Clusters harvested per vine for each cultivar also varied with year, but data collection was not initiated until 2008 (data not shown). The number of clusters harvested per vine reinforced yield results and thus will not be discussed. Additionally, since RI is the ratio between yield and pruning weight and is used to estimate crop load, pruning weight data will not be presented (Howell, 2001). Consistent fruit production is essential for the grape grower as well as the wineries in North Dakota. During good growing conditions (i.e. AGDD > 1400) and less challenging winters such as 2012 and 2013, most of the cultivars evaluated produced a modest crop. Although the yields were less than the expected yields of 6,500 to 11,000 kg ha^{-1} for commercial vineyards discussed by Dami et al., (2005), growers would accept yields between 1,000 and 2,000 kg ha^{-1} if this yield was consistent. Only two cultivars, 'King of the North' and 'Valiant' approached the lower range of this yield goal over the seven years of evaluation with an average yield of 961 and 923 kg ha^{-1}, respectively (Table 2). The third most productive grape was ES 12-6-18 with an average yield of 853 kg ha^{-1}. 'Frontenac' was next with an average yield of 721 kg ha^{-1} and would be considered the best winegrape in the group. 'Alpenglow' was the highest yielding white-skinned winegrape, when averaged over seven years, with an average yield less than half of the top three yielding cultivars. Yield from other cultivars was consistent except in 2010 when extreme winter conditions occurred (Table 1).

Crop load management sustains vegetative grapevine growth while optimizing yield, fruit composition, and primary bud cold hardiness. A RI range of 5 to 10 kg yield per kilogram of pruning weight has been shown to be optimal while maintaining vine capacity in a warm climate (Terry and Kurtural, 2011). None of the cultivars maintained this RI range suggesting that vine balance was not achieved (Table 2). O'Daniel et al., (2012) suggested that the ability of a vine to enter a dormant state and to withstand freezing may be directly linked to the ratio between reproductive sinks and vegetative sources. Our results suggest that more research must be done with balanced pruning formulas and cluster thinning in order to determine a RI range for vines in a cold climate.

Cluster weight, berry cluster weight, the number of clusters per vine, and the number of berries per cluster varied for each cultivar by year. Only cultivar 100-berry weight did not vary by year. However, since a cultivar's ability to adapt to a location should include years of good fruit set and fruit ripening conditions as well as years where fruit set and fruit ripening were poor, an average over years was discussed unless graphed interaction could be explained. 'Bluebell' and ES 5-4-71 had the heaviest clusters and berries (Fig. 3). This was expected as the berries are much larger than berries from other cultivars. The 100-berry weight was the least with MN1200 but did not differ from 'Frontenac Gris', ES 12-6-18, or MN 1131. MN 1200 average individual cluster weight was the least and never reached above 55 g the entire evaluation period.

'Valiant' and ES 12-6-18 had the highest number of clusters per vine averaging more than 100 clusters even though vines were pruned to only 40 buds per vine (Fig. 4). This was expected as both cultivars have fruitful non-count buds. ES 5-4-71 had the fewest clusters per vine. This cultivar has also shown considerable vine dieback most years, which would have contributed to the low number of clusters per vine. 'Frontenac' 'Frontenac Gris', 'LaCrescent', and MN1131 had the greatest number of berries per cluster. In contrast, 'Bluebell had the fewest berries per cluster, but because the berries are very large in comparison to others, individual cluster weight was the greatest.

Fruit composition

Soluble solid concentration, pH, and TA varied for each cultivar by year. Greater AGDD during 2012 and 2013 led to higher averaged SSC values for most cultivars whereas in 2009, when only 1184 AGDD occurred, only 'Baltica' reached an averaged SSC value above 20 % (data not shown). The average SSC for all cultivars over the seven year testing period was greater than 19% with the exception of ES 5-4-71 (Fig. 5). Results suggest that as long as more than 1200 AGDD occur, the cultivars evaluated will reach targeted SSC levels of ≈20% for white-skinned grapes and ≈22 to 24% for red-skinned grapes. Juice pH levels increased to 3.0 for most cultivars even during the cool growing season of 2009 (data not shown). An exception was 'LaCrescent', which had the highest average pH in 2009 at 3.7 followed by the lowest average pH in 2010 at 2.7. This was unexpected because 'LaCrescent' had the lowest SSC in 2009 and 2010 at 13% and 16%, respectively. 'LaCrescent' may have been over-cropped in 2008 contributing to the unique pH and SSC values in 2009. The RI for 'LaCrescent' went from 18.5 in 2008 to 0.3 in 2009 (Table 2). The highest average TA value over seven years was 20.1 g L^{-1} for 'King of the North'. 'Alpenglow' and 'Bluebell' had the lowest average TA values over years at 8.5 and 8.6 g L^{-1}, respectively. *V. riparia*-based grape cultivars tended to have TA values above 10 g L^{-1}, regardless of the growing season and AGDD, suggesting that a longer growing season and more heat units may not reduce the TA levels for these cultivars. However, Aipperspach, (2013) reported that 'Marquette' TA level could be reduced by leaf-pulling. Unfortunately, this study showed that 'Frontenac Gris' TA levels were not affected by leaf-pulling, suggesting that this response is not consistent in all *V. riparia*-based grape cultivars.

The greatest difficulty facing new and existing wineries in North Dakota is a reliable supply of domestically produced grapes that are suitable for quality wines. The results from the seven-year cultivar trial indicate that grape cultivars must be able to ripen their fruit with 1184 AGDDs and a growing season of only 132 days as observed in 2010. Grape results indicated that three cultivars: 'King of the North' ES 12-6-18, and 'Valiant', were adapted to North Dakota conditions. 'Marquette', MN1200, and ES 5-4-71 did not have reliable hardiness as each yielded less than an average 350 kg ha^{-1} over the seven-year testing period. The highest yielding white winegrape, when averaged over seven years, was 'Alpenglow' with a yield less than half from the top three yielding cultivars. Therefore, research at NDSU has been initiated that focuses on the development of hardier *V. riparia*-based cold-hardy winegrape cultivars that will survive and consistently produce fruit and high quality wine when grown in North Dakota. Recent successes by public and private programs in other states using *V. riparia* native to North Dakota, suggest that progress could be made fairly quickly. Collections of extremely hardy and early ripening *V. riparia* biotypes from around North Dakota and northwestern Montana are being characterized for fruit quality, including flavor, acidity, and polyphenol profile. These superior biotypes are being crossed with extremely early ripening "quality" *Vitis vinifera* parents, such as 'Perle Csaba' and 'Siegerrebe', and interspecific hybrids such as 'Solaris' and 'Burmunk' to create well-adapted, early-ripening, fully hardy, grape cultivars for North Dakota that produce quality wines.

ACKNOWLEDGEMENTS

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Tables

Table 1. Weather data from the Prosper, ND weather station (NDAWN, 2014).

			≤ 0 °C day of yr		
	Lowest	Ave. low	Preceding	Following	AGDD[2]
Winter	(day of yr)	(month)	Fall	Spring	
2007-08	-36 (51)	-21 (Jan.)	254	134	1305

2008-09	-35 (13)	-25 (Jan.)	276	137	1261
2009-10	-37 (2)	-20 (Feb.)	272	129	1184
2010-11	-35 (20)	-23 (Jan.)	261	123	1316
2011-12	-27 (19)	-14 (Jan.)	257	116	1287
2012-13	-28 (365)	-19 (Jan.)	260	132	1447
2013-14	-34 (2)	-24 (Jan.)	286	136	1497
30-year ave.	-20	-19 (Jan.)	291	108	1413

[1] Largest diurnal temperature range where one temperature is < 0 °C.

[2] Abbreviation AGDD = accumulated growing degree day and calculated from daily temperatures 1 April to 30 Sept. using a base of 10 °C and upper temperature limit of 30 °C.

Table 2. Average values for yield and crop load of hybrid grapes grown in eastern North Dakota over seven growing seasons. Ravaz index is the ratio of yield to dormant pruning weight per vine and indicates vine crop load.

	2007		2008		2009		2010		2011		2012		2013	
Cultivar[1]	Yield ($kg\ ha^{-1}$)	Ravaz index	Yield ($kg\ ha^{-1}$)	Ravaz index	Yield ($kg\ ha^{-1}$)	Ravaz index	Yield ($kg\ ha^{-1}$)	Ravaz index	Yield ($kg\ ha^{-1}$)	Ravaz index	Yield ($kg\ ha^{-1}$)	Ravaz index	Yield ($kg\ ha^{-1}$)	Ravaz index
Alp	675 abc[2]	4 ab	990 c	4 c	1287 de	4 bcd	9 e	0 c	1126 bcd	2 bc	572 d	2 e	2209 bc	10 cd
Balt	73 cd	1 c	1137 c	3 c	3093 b	5 bcd	158 de	1 c	297 e	1 c	1045 cd	4 cde	1516 cd	9 cd
Bbell	152 cd	1 c	1124 c	14 b	3408 b	10 b	532 cd	1 c	2576 a	6 a	1390 abc	5.3 bcd	1212 cd	7 cd
ES 12	1003 a	6 a	1085 c	6 bc	2922 bc	6 bcd	1340 a	3 b	1544 b	2 bc	1588 abc	2 e	3648 a	8 cd
ES 5-	561 abc	3 b	394 de	8 b	112 f	1 d	0 e	0 c	1155 bcd	2 bc	482 d	3 de	2103 bcd	34 a
Front	645 abc	4 ab	1984 b	10 b	2739 bc	8 bc	13 e	1 c	1531 b	5 a	2138 ab	10 a	2057 bcd	12 cd
FGris	185 cd	2 bc	1058 c	10 b	1179 def	4 bcd	15 e	1 c	1261 bc	4 ab	1049 cd	8 abc	1155 cd	23 b
King	948 a	4 ab	2618 a	13 b	3419 b	16 a	1098 ab	4 a	2660 a	5 a	2235 a	7 abcd	1828 cd	10 cd
LaCr	306 bcd	1 c	869 cd	19 b	114 f	1 d	2 e	0 c	471 de	1 c	1311 bcd	3 cde	3311 ab	9 cd
M 11	279 bcd	1 c	594 cde	2 c	1384 de	2 cd	86 e	1 c	737 cde	1 c	1045 cd	3 de	1366 cd	4 d
M 12	233 cd	1 c	407 de	7 b	506 ef	3 cd	26 e	1 c	603 cde	1 c	794 cd	3 cde	1230 cd	10 cd
Marq	13 d	0 c	99 e	5 c	433 ef	2 cd	0 e	0 c	876 bcd	2 bc	1076 cd	3 cde	970 d	9 cd
Sabr	118 bcd	2 bc	634 cde	4 c	1960 cd	5 bcd	66 e	1 c	946 bcd	1 c	497 d	2 e	1575 cd	5 d
Sseed	40 cd	1	821 cd	29 a	994 def	6 bcd	0 e	0 c	1060 bcd	4 ab	1067 cd	8 abcd	3003 ab	24 b
StCr	106 bcd	2 bc	869 cd	10 b	937 def	4 bcd	9 e	0 c	660 cde	1 c	1164 cd	4 bcde	2143 bcd	11 cd

Val	2 8 4 ab	4 ab	1969 b	16 b	4580 a	20 a	849 bc	2 b	2596 a	4 ab	1648 abc	9 ab	1716 cd	1 7 bc

[1] Abreviations: Alp=Alpenglow, Balt=Baltica, Bbell=Bluebell, ES12=ES 12-6-18, ES5-=ES 5-4-71, Front=Frontenac, FGris=Frontenac Gris, King=King of the North, LaCr=LaCrescent, M11=MN1131, M12=MN1200, Marq=Marquette, Sabr=Sabrevois, Sseed=Somerset seedless, StCr=St. Croix, Val=Valiant.

[2] Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference test at $P \leq 0.05$.

Figures

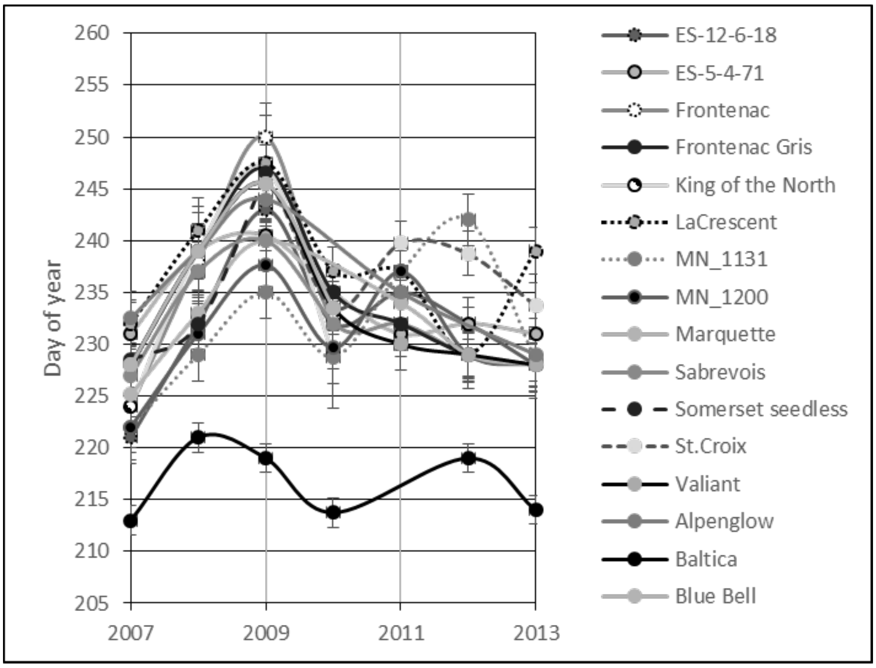

Fig. 1. Effect of cultivar and year on 50% veraison at eastern North Dakota. Error bars represent ± standard error.

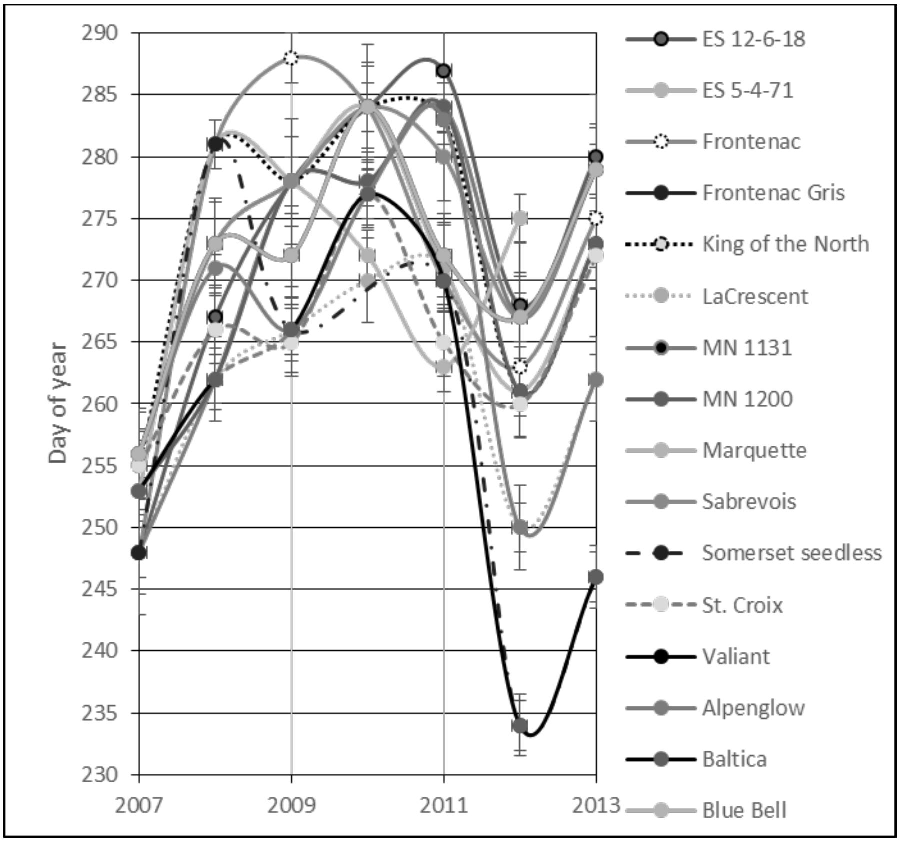

Fig. 2. Effect of cultivar and year on the harvest time at eastern North Dakota. Error bars represent ± standard error.

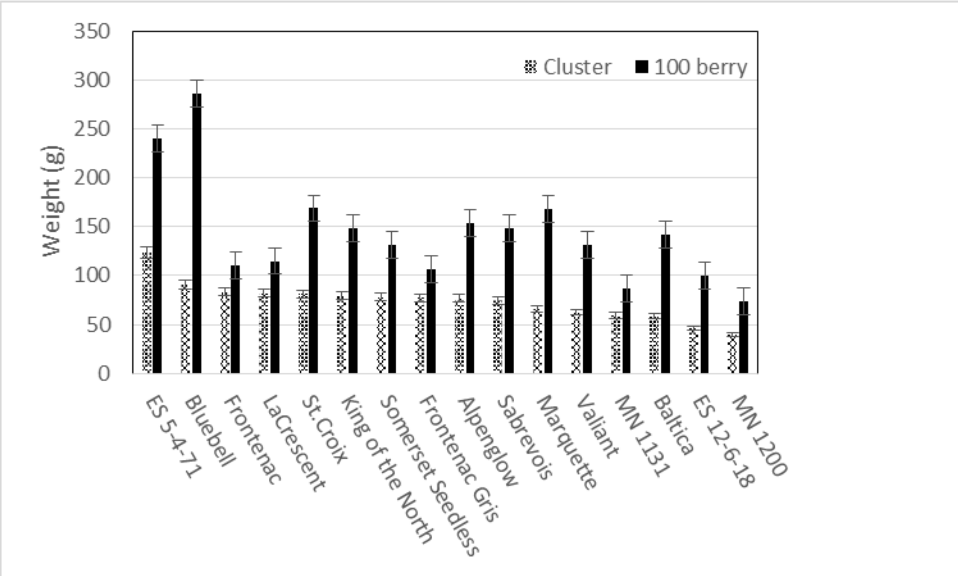

Fig. 3. Effect of cultivar averaged over seven years on cluster weight and the weight of 100-berries at eastern North Dakota. Error bars represent ± standard error.

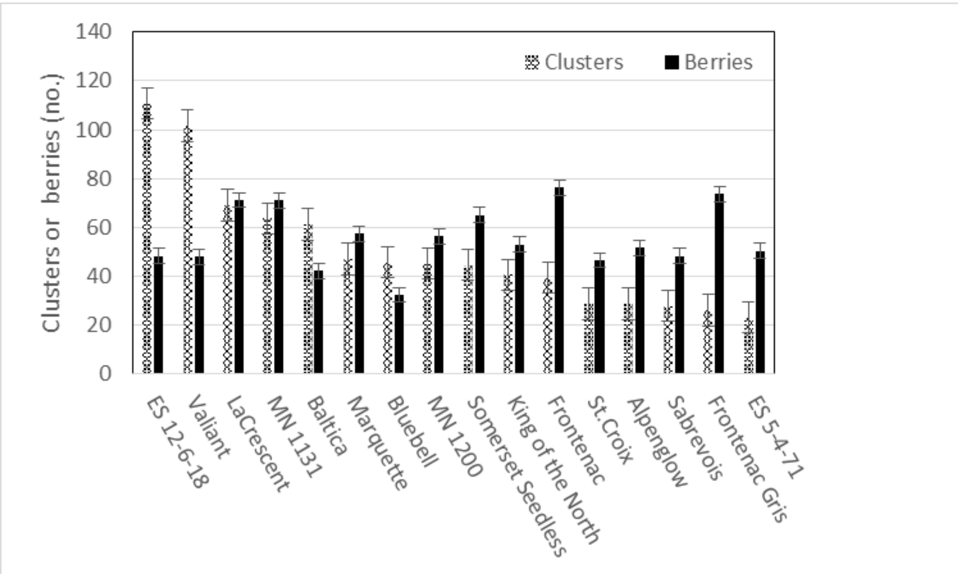

Fig. 4. Effect of cultivar averaged over seven years on the number of clusters/vine and number berries/cluster at eastern North Dakota. Error bars represent ± standard error.

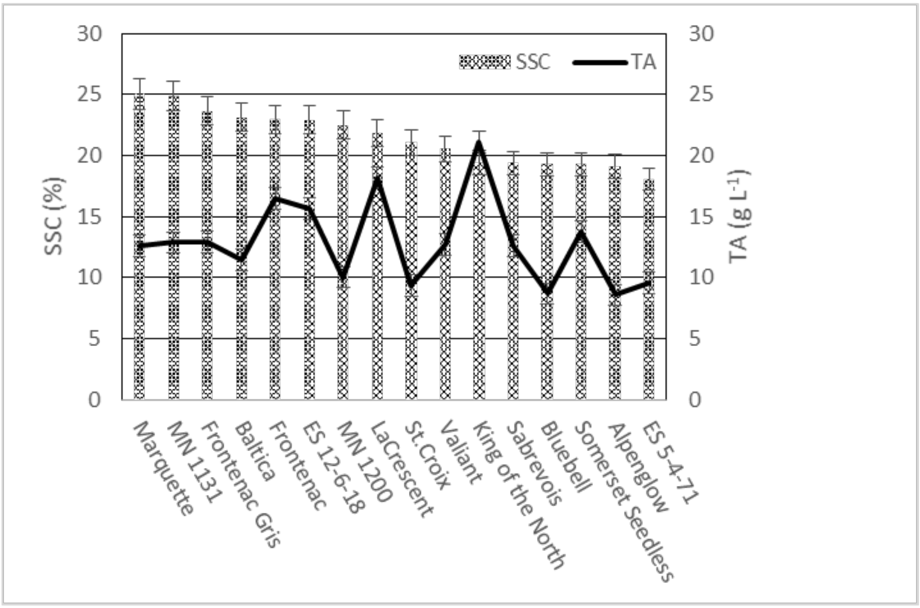

Fig. 5. Effect of cultivar averaged over seven years on soluble solids concentration (SSC) as a percentage and titratable acidity (TA) levels as g L^{-1} at eastern North Dakota. Error bars represent ± standard error.