COMPARISON OF TWO SINGLE CURTAIN AND TWO DOUBLE CURTAIN TRELLIS SYSTEMS WITH MARQUETTE AND PETITE PEARL WINE GRAPES

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

A field study was conducted to evaluate the influence of a trellis system, Genova double curtain (GDC), Scott Henry (SH), mid-wire that was vertical shoot positioned (VSP), and high wire cordon (HW), on fruit ripening and indirectly its influence on cold hardiness for cold-hardy, red wine grape cultivars, Marquette and Petite Pearl. In 2017, ‘Petite Pearl’ reached higher yields than ‘Marquette’, while VSP and SH trellis systems resulted in higher yields. However, in 2018, ‘Marquette’ had a greater yield than ‘Petite Pearl’. In 2019, 77.34% of ‘Marquette’ and 52.34% of ‘Petite Pearl’ had severe winter injury regardless of the trellis system. Unpredictable climate patterns in terms of growing degree-days, minimum winter air temperature, and rainfall manipulated both cultivars’ phenology during early establishment. Results suggest that under North Dakota climatic conditions, proper cultivar selection is more important than trellis system selection for sustainable grape production.

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DEDICATION

To my family,

To Turkiye,

To people who make it possible,

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INTRODUCTION

Grape production is a huge economic opportunity; however, it is also a risky investment in cold regions (Dami and Beam, 2004). In contrast to the common idea that grapes are only grown in warm climates where they are able to reach a high yield, achieve excellent berry quality, and produce terrific wine; cold-climate growers are able to produce grapes with characteristics for commercial winemaking with the help of breeding programs and novel trellis systems during the growing process (Guerrini et al., 2018). However, the natural climate remains the largest restraint on wine grape cultivation in cold regions (Pedneault et al., 2013). Thus, the significant challenge for colder regions, like North Dakota, is the unpredictable, abrupt temperature fluctuations and the extremely cold climate. This unpredictability includes early fall and late spring frost threats, short growing seasons, and lack of heat accumulation during the grape ripening phase that have a detrimental effect on the consistency of fruit quality and yield for cold climate vineyards.

The combination of cold-hardy interspecific hybrid grape cultivars and trellis systems has the potential to aid grape producers in cold regions letting them produce high-quality grapes for the wine industry. Because of diverse genetic backgrounds, cold-hardy cultivars demonstrate different growth habits (upward or downward growing) and speed (creating more leaves or wood) (Scharfetter et al. 2019). Thus, for each cultivar, a particular trellis system is needed, which can help to balance the vegetative and productive phases of the vine by responding to the genotypic and climate needs. Once taking into consideration the interaction of climate and cultivar, producers need to consider, if a two fruit zone trellis system or a one fruit zone trellis systems would boost yield, berry quality, and sustainability of the vineyard. The most common two fruit zone trellis systems are Genova double curtain and Scott Henry. The most common one fruit zone trellis systems are mid-wire vertical shoot positioning and high wire, which are more prevalent in cold regions. Trellis systems are adapted to promote fruitfulness by increasing sun penetration. Wimmer et al. (2018) reported by selecting proper cultivars with particular trellis systems in cold regions, producers could increase yield and develop fruit composition. Therefore, in order to decrease potential risk factors like uncontrolled climate patterns, one should regard both cultivars and the different trellis systems that are relevant to the climate patterns of the region.

Recently, in North Dakota, grape production has reached a remarkable position as an alternative product for North Dakota's farmers due to the development of cold-hardy interspecific hybrid grape cultivars with fruit characteristics similar to *Vitis vinifera* cultivars. Unfortunately, 'Marquette', a red wine grape cultivar that has received high accolades in wine competitions, performed inconsistently in an NDSU variety trial (Hatterman-Valenti et al., 2014). However, if a proper trellis system for a specific cultivar is selected before establishing a vineyard, growers may reach a more consistent production process by reducing the risk factors associated with cold climates (Wimmer et. al. 2018). While the testing of new grape cultivars, such as 'Petite Pearl', at NDSU has utilized the high wire trellis system, other trellis systems should be examined for their influence on fruit production and composition. Therefore, the goal of this research was to determine which trellis system, mid-wire versus high-wire and single curtain versus double curtain, has the greatest influence on yield and fruit composition for 'Marquette' and 'Petite Pearl' during early production years, and to evaluate trellis system influence on the phenology of each cultivar under North Dakota environmental conditions.

LITERATURE REVIEW

Grape

Grape taxonomy

Grapes belong to the *Vitaceae* family and are one of the oldest cultivated plants in the world. Currently, the most significant cultivated grapes were derived from two major subspecies: the *Vitis vinifera* subsp. *vinifera*, a historically cultivated grape, and *Vitis vinifera* subsp. *silvestris*, a cultivated grape originating from a wild grape ancestor (Adam-Blondo et al., 2004). Grapes have a short genome size of 475-500 Mb and are comprised of 19 chromosomes. It has a highly heterozygous genotype due to mutations, natural and human selection, and propagation by both sexual and asexual methods (Duan et al., 2015). This complex genetic structure has made it difficult to map the grape's genetic code and may make the application of novel methods for grape genetic studies difficult and/or uncertain.

Grape origin

There are ambiguous hypotheses about where grapes originated and how they evolved from a wild to cultivated species. There is plenty of researches about grape evaluation and origin, which of them depend on archeological and historical studies with the traditional methods such as morphometric methods, and the others generally base on genetic studies by using special methods with different computer programs. Interestingly, Manen et al., (2003) claimed that traditionally, the morphometric method has been used to identify cultivars. It cannot distinguish differences between cultivated and wild grapes. However, this method does not permit the identification of the origin of cultivar to a regional group. In contrast, Terral et al., (2010) argued that the morphometric method was much better than genetic methods because an ancient seed might not be adequate for genetic analysis. Therefore, lately, a combination study with conventional and state of the art methods has been recommended than just one method or one way in order to discovery grape origin and grape evolution.

Indeed, remains of grape seed or ancient tools have provided significant evidence for most scientists to clarify grape history. Looking to archeological and historical data, the domestication of the grapes has existed since the Neolithic period when storage was used for grape juice and wine. In Iran, some equipment used to make wine was found, while in Turkey, grape seeds were discovered that dated from 8000 BC. These remains provide an opportunity to obtain evidence about both the origin of grape and grape evolution (This et al., 2006). In addition, Ucchesu et al., (2016) used linear discriminant analysis (LDA) with computer vision techniques to evaluate the grape size and shape for remains of cultivated grape. When comparing both grape variety with the methods, they explained that the grape remains that came from Sardinia have correlated 75% percent with wild grapes.

What is more, McGovern et al., (2017) evaluated not just botanical and archeological criteria, but also the chemical residues such as tartaric acid, malic acid, succinic acid, and citric acid on the ancient pottery found in the around Georgia. This evidence demonstrated that the early Neolithic period (5000-6000 BC) wine was one of the essential beverages around Georgia before reaching Europe. Additionally, Karasik et al., (2018) showed that both the morphometric method with 3D technology or simple sequence repeat (SSR) supported each other and that either could be used for the discrimination of the grape species between wild and cultivated grapes. Thus, there are several methods to obtain consistent information from grape remains, which indicates the origin of these grapes.

Recently, novel genetic methods and analyzing techniques have been used to determine geographic origins between cultivated and wild grapes. Aradhya et al., (2002) applied microsatellite markers to the deoxyribonucleic acid (DNA) of 222 cultivated and 22 wild grapes collected from various areas to compare their relationships. They showed that French cultivars had close geographical origins to the wild grapes from southwestern France and Tunisia. In addition, Arroyo-Garcia et al. (2006) used chloroplast DNA polymorphisms of 1201 grapes to clarify the affinity between *V. vinifera* subsp. *vinifera* and *V. vinifera* subsp. *silvestri* for regions Near East, Middle East, Eastern Europe, Balkan Peninsula, Italian Peninsula, Northern Africa, Central Europe, and the Iberian Peninsula. They show that the Near East and western Mediterranean region had germplasm of the cultivated grapes. In contrast, a large amount of germplasm for the wild grape was found to originate from the Iberian Peninsula. Similarly, Myles et al. (2010) claimed that the origin of *V. vinifera* subsp. *vinifera* was in the Near East. In addition, they reported that although grapes have huge genetic diversity, there was no relationship between wine and table grapes.

Riaz et al., (2018) focused on the gene distribution and the potential domestication for wild and cultivated grapevine through the Mediterranean and inner Asia regions. They tested 1378 wild and cultivated grapes gathered from the described areas and applied the methods of cluster analysis, principal coordinate analysis, and structure with simple sequence repeat (SSR) markers. According to their findings, three significant groups represented imported gene flow across the areas. The results show that although there was extensive gene flow among the areas, there was a narrow variation between both grapes. In summary, hypotheses concerning the grape origin, evolution, and domestication remain uncertain. However, as new techniques and methods are developed, the unknown aspects of grape origin will become clear.

Grape Production and Health Benefits

Grape production

The grape is a very unique fruit, and it has various purposes. Grapes leaves are commonly used in prepared dishes while the fruit is consumed as wine, fresh as table grapes, juice, raisins, and jam, as well as used for dietary supplements, grape seed oil, and vinegar to promote human health (Pezzuto, 2008). In order to meet the market needs for these products, grapes are cultivated in many countries. According to the Food and Agriculture Organization (FAO), China is surprisingly the largest producer of grapes in the world (1,690.035 kg/ha) followed by America with 1,649.931 kg/ha and then third-ranking Australia with 1,332.36 kg/ha (FAO, 2017). The next two highest grape-producing countries, Italy and Turkey, have similar production rates at 1,069.98 kg/ha and 1,007.42 kg/ha, respectively. Contrary to conventional expectations, France ranks last with 795, 23 kg/ha. Additionally, within the USA, California is the largest producer of grapes (6,750,000 kg), followed by New York (175,000 kg), Pennsylvania (95,000 kg), Washington (78,000 kg), and Michigan (70,000 kg) (USDA, 2018). Worldwide, countries are responding to the growing market demands for grapes in both culinary and health markets.

Health benefits

Increasing awareness of common, but serious, diseases around the world, people are in search of natural ways to promote health. Therefore, scientists tend to search natural foods that have a significant beneficial component for humans such as the grape. Recently, grapes have been utilized as a dietary supplement because of their high antioxidant, abundant resveratrol, and rich mineral content (Pezzuto, 2008) For instance, Wightman and Heubergerb (2015) analyzed the effect of low-density lipoprotein (LDL) oxidation, oxidative stress, and endothelial function with the help of the several clinical studies conducted over more than two decades. This research focused on how a modified diet comprised of blueberries, strawberries, cranberries, and grapes affected human health. Their clinical studies showed that the diet with grapes was more effective than diets with strawberries, cranberries, or blueberries in terms of reducing the risk of heart disease, preventing some cancers, protecting against aging and Alzheimer disease. In particular, the researchers pointed out that the diet including grapes was more effective in reducing LDL and oxidative stress levels, as well as providing numerous phenolic compounds that are known to prevent serious disease. Furthermore, Schneider et al. (2000) explained that the resveratrol in grape and wine might prevent the growth of colon cancer cells in humans because the resveratrol creates a low toxicity condition in cells. This study demonstrated that when 25 μM resveratrol interacts with the polyamine metabolism of the CaCo-2 human colon cancer cell, resveratrol restrains 70% of the growth of the cancer cells as well as decreases the activity of ornithine decarboxylase (ODC), which causes growth of the colon cancer cells. This means that using grape dietary supplements or consuming adequate fresh grapes or products that include grape could help prevent some severe diseases and promote human health.

An equally important product of grape production is grape seed oil, and the increasing demand in Australia, Korea, Japan, and the United States due to its benefit on human health. Winemaking countries, especially France, Italy, and Spain, have significant grape seed oil production that is marketed all around the world (Yamakoshi et al., 2002; Ma and Zhang, 2017). This product is high in antioxidants and polyphenolic compounds and contains 40% fiber, 16% oil, 11% proteins, and 7% complex phenols such as catechins, epicatechin, and epicatechin-3-O-gallate. Naturally, this abundant source of beneficial micro-elements provides a rich opportunity for pharmacological studies (Ma and Zhang, 2017).

According to Maier et al. (2008), during the extraction process of the grapeseed oil, the important point is to protect the polyphenolic and the antioxidant activities. Their results showed that applying methanol/0.1 % HCl, water (75°C), and a mixture of ethanol-water to residue grape seed produced the best outcome of approximately 2.9 mg/kg, with minor amounts of catechin, epicatechin (1.3 mg/kg each), and trans-resveratrol (0.3 mg/kg). In addition, Rombaut et al., (2014) compared three different methods for extracting grape seed oil: screw pressing with cold pressing methods, supercritical CO2 extraction, and gas-assisted mechanical expression. This study determined that the best way to increase the polyphenol level was with screw pressing. These studies showed that the technique used was also important to obtain quality grape seed oil.

Moreover, grape juice is preferred by many people because of its nice aromatic features. Krikorian et al. (2012) pointed out that ‘Concord’ grape juice promotes neurocognitive function and memory in older adults as well as postponing aging. They selected people who were around 68 years of age and used ‘Concord’ grape juice or a placebo beverage for the research. Participants given the grape juice illustrated decreased semantic inference for memory tasks, and when the right hemisphere of the brain was monitored, participants had a significant magnetic resonance activation compared to people consuming the placebo beverage. In addition, Silva et al. (2015) compared two grape juices from different cultivar: ‘BRS-Cora’ and ‘Isabella’ in terms of the polyphenol content and antioxidant activities. They reported that ‘BRS-Cora’ had greater total polyphenols and anthocyanin, and antioxidant potential when compared to Isabella’s components and that these important components can prevent prevalent and serious diseases by reducing oxidative stress. Moreover, they put forward the idea that ‘BRS-Cora’ grape juice was a functional food due to the high concentration of gallic acid and epigallocatechin gallate. On the other hand, Beltrame et al. (2017) compared grape and orange juices in terms of pH, titratable acidity, calcium, and phosphate fluoride percentages in order to assess the effect of dental erosion in humans. The study used five different grape and orange juices that were pure, powdered, or concentrated along with the control beverages of de-ionized water and a carbonated cola beverage. Results showed that grape juice has a greater effect on enamel structure loss than orange juice due to the high pH: titratable acid ratio. In addition, both powdered grape and orange juices demonstrated less impact on dental erosion than concentrated juices.

Raisins and vinegar are other prevalent ways to consume grapes and to provide benefits to human health. According to the report of the National Health and Nutrition Examination Survey (NHANES), they compared three different groups of children that either consumed dried raisins, ate foods containing raisins, or did not consume raisins (Fulgoni et al., 2018). The children were ages 8-12, and the study was conducted from 2001 to 2012. They showed that there was a significant difference among the groups. Children consuming raisins had higher fiber (23%), potassium (16%), and magnesium (12%) than children not consuming raisin. Likewise, children consuming foods containing raisins such as bread or bagels with raisin had higher fiber (15%), potassium (5%), and magnesium (11%) than children not consuming raisins. Sinanoglu et al., (2018) tested well-known balsamic vinegar from different grape cultivars using spectrophotometric, chromatographic, colorimetric, and spectroscopic methods in order to characterize the vinegar antioxidant and metabolic profiles. They reported that red grape balsamic vinegar showed stronger metabolic character than vinegar from apples or white grapes. Further research by Nile et al., (2013) evaluated the total phenolic contents and antioxidant levels from grape pulp and skin for fifteen grape cultivar, which they include three different species; *V. vinifera*, *V. labrusca*, and *V. hybrid*. They reported higher phenolic and antioxidant components in the grape pulp than grape skin and demonstrated different phenolic components percentages and antioxidant levels for each species. In summary, the grape is undeniably an irreplaceable fruit in terms of its contribution to a nation's economy and health benefits for children through senior citizens. However, due to fruit high pH: titratable acid ratio, there is a concern for dental erosion from tooth enamel structure loss, and especially from concentrated fruit juice.

Evaluation of Cold-hardy Wine Grapes

Cold-hardy cultivars

All grape cultivars are generally grouped according to the intended purpose and climate conditions. Among all grape cultivars, table grape cultivars and wine grape cultivars have the highest market value around the world. However, until the development of cold-hardy interspecific hybrids, the production of table and wine grape cultivars was limited to regions with winter temperatures that did not exceed -20 °C (Perry et al., 2012).

When selecting cultivars, one must consider climate, potential spring frost, growing degree days (GDD), topography, soil conditions, disease resistance, and aromatic character of the berries and wine (Perry et al., 2012). In addition, when growing grapes for wine, certain considerations must be taken into account: the choice of region, winemaking methods, and timing for harvest (Guerrini et al., 2018). All of these considerations influence the ratio of the chemical components of grapes. These listed considerations are inseparable, and any change in any one condition or a poor condition at any growth phase could trigger the quality of the final product. Thus, most research elaborates on all probabilities and interactions among them.

Moreover, common cultivars in cold climates are divided into four basic groups: northern or interspecific hybrid, French-America, American, and *Vitis* cultivars. In the beginning, the northern hybrid cultivars were crossed for disease resistance after the outbreak of phylloxera in Europe. Even now, they remain popular rootstock in most countries and have a significant market capacity in cold territories (Domoto et al., 2016). Marquette is a northern hybrid cultivar that originated from MN1094 and French hybrid Ravat 264. This northern hybrid is a popular red wine cultivar for cold climates. Its bud break is very early. Another northern hybrid cultivar is Petite Pearl, a cross of MN1094 and ES4-7-26. It is a new cultivar that is extremely cold-hardy with a late harvest. Both of these northern hybrids resist the most common grape diseases.

Overall, the development of cold-hardy cultivars such as Marquette, Frontenac, Petite Pearl and King of the North has enabled grape production in regions considered too cold for winegrape production. However, even with cold-hardy cultivars, growers need to consider zones is to help reach more healthy berries and more yield as well as considerable wine quality as long as all conditions that mean above are taken into account.

Cold-hardy wines

There has been an increase in winemaking in the last decade using northern hybrid grapes. However, reaching the best wine quality has not been achievable with the interspecific hybrids, especially when these grapes are exposed to freezing temperatures before the fruit has ripened completely. Therefore, researchers have been focusing on improving wine quality using different methods with cold-hardy grapes as well as determining wine quality with grapes subjected to different climatic conditions.

As a consequence of the interaction between cultivar and climate, fruit composition affects a wine’s chemical profile. The most well-known wine chemical components are total soluble solids, titratable acid, malic and lactic acid, a range of polyphenol- related parameters, volatile compounds, color, and bitterness (Guerrini et al., 2018). Wine is affected by the ratio of each chemical component. Other equally important criteria for wine are tannin and wine color. Although interspecific hybrids have abundant color pigments, they have low tannin concentrations, which is needed for a desirable mouthfeel in wine (Gawel et al., 2001; Boulton, 2001). Both basic wine components are generally evaluated for consumer satisfaction.

Pedneault et al., (2013) explained how environmental conditions affected berry maturity, aroma, and phenolic compounds for the cold-hardy grape cultivars, Marquette and Frontenac. The results showed different ripening patterns for both 'Marquette' and 'Frontenac'in southwest Quebec, Canada compared to the northern areas of the province. They concluded that the difference in accumulated growing degree days between both zones was sufficient to alter wine quality even if made from the same cultivars. Tannin concentration and wine color among northern hybrid cultivars have great importance in winemaking because they differ remarkably when compared to *V. vinifera* cultivars. For example, Burtch et. al. (2017) observed that through wine fermentation a color transition within *V. vinifera* cultivars ranged from purple to red with the help from anthocyanin monoglucoside, and increasing tannin concentration, while hybrid cultivars wine fermentation does not follow the same procedure due to anthocyanin diglucoside, and low tannin concertation. Moreover, Manns et al., (2013) evaluated cold soak and hot press winemaking methods for the cold-hardy grape cultivars Marquette, Corot Noir, and Marechal Foch by adding enzymes and tannin. They reported that during the winemaking process, especially in the hot press method, there was a rise in the ratio of tannin, anthocyanin, and other phenolics, but this uptrend was not stable. They concluded that the unstable uptrend was because of the high-level of diglucosides in hybrid grapes. In addition, Rice et al., (2017) measured tannin and pigment content extracted from the skins and seeds of cultivars Marquette, Frontenac, and St. Croix by contrasting two different locations and harvest times. They determined that the total tannin was between 0.29 and 0.66 mg/berry and that the berry of the Marquette berries had a high-level of bitter seed tannin (0.54 mg/berry) while, 'St. Croix' berries had a high-level of softer skin tannin (0.24mg/berry). Overall, the results suggest the difficulty winemakers will have when trying to make wine from cold-hardy cultivars resemble wine from *V. vinifera* cultivars.

Climate

Winter injury

Climate plays a critical role in grapevine production due to its ability to limit fruit yield and composition. However, grapes naturally have a unique defense mechanism to help them survive severe climate conditions (Rubio et al., 2015). Grapevines demonstrate a substantial response to changing climatic conditions such as diverse seasonal temperature, light intensity, and photoperiod. In response to a shorter photoperiod and cooler temperatures, vines trigger dormancy, their defense mechanism controlled primarily by plant hormones and genetics. Additionally, vine buds and other plant organs, are responsible for the dormancy response and yield for the next year. Grape shoots arise from compound (primary, secondary, and tertiary) buds. These special features provide an opportunity to save the plant from freeze effects and a warranty for future yield (Mills et al., 2006). If the primary buds were damaged from unexpected temperature changes, like a late spring freeze, the secondary buds would break. Thus, most studies in temperate areas focus on how unpredictable temperatures across the dormancy period influence bud injury as well as emphasizing the advantage of the structure of secondary bud fruitfulness during grape production in cold-climate regions.

In addition, Frioni et al. (2017) evaluated berry composition, vine performance, and yield of ‘Marquette’ grapes after a spring freeze. The late spring freeze destroyed almost 80% of primary buds in 2012. However, it was not as extreme in 2013, so the primary buds were more productive than the secondary buds in 2013. Results indicated that when comparing the productivity of the primary and secondary buds, there were no significant differences for fruit composition between years, but there was a higher yield in the second year due to the contribution of the primary buds. Similarly, Mills et al. (2006) evaluated cultivars for the lowest winter temperature that was lethal for bud and cane tissue during winter. The study was conducted using the method of differential thermal analysis (DTA) and showed that the grape cultivars could be separated from the hardiest cultivar to the least hardy cultivar for their region. These were 'Cabernet Sauvignon', 'Riesling', and 'Merlot', 'Pinot Gris', respectively. Moreover, they explained that buds and canes with surface moisture were more susceptible than dry buds and cane tissue when exposed to cold weather. Thus, cultivar cold hardiness is controlled genetically as well as climatic conditions that influence the progression of dormancy and the drying of buds and cane tissue.

Londo et al. (2018) showed the role of the plant hormone abscisic acid (ABA), which was released when cold weather began, and how this hormone has an important influence on plant physiology. They explained how the *V. vinifera* leaves responded to gene expression when exposed to a low temperature (4 Cº) or freeze shock (-3 Cº). Even though there was no visible leaf damage, the pathways for gene expression and regulation mechanisms such as plant hormones ABA and ethylene differed, significantly. In addition, Karimi et al. (2015) clarified that *V. vinifera* and *V. riparia-based hybrid* grape cultivars had distinct gene transcription responses when subjected to cold temperatures. There was a remarkable rise in gene transcription for *V.riparia-based hybrids* in contrast to the expression for *V. vinifera* when exposed to the low freezing temperatures. Additionally, Rubio et al., (2019) explained the relationship between ABA, low temperatures, and gene expression for cold-hardy *V.riparia-based hybrid* cultivars. They demonstrated that there was considerable interaction between the release of ABA and gene expression under low temperatures and the bud adaptation variability between cultivars to cold climate.

These winter injury trials demonstrated an important interaction between the unpredictable climate conditions and plant defense mechanisms. Although grapes have a plant defense mechanism to adapt to climate conditions of the regions, erratic weather conditions do not allow enough time for adaptation. Thus, under severe and erratic climate conditions, growers could lose a significant amount of vine and vine yield.

Impact of climate changing

Unquestionably, climate-change could be one of the biggest problems in the near future for all humans and nature. When Londo and Martinson (2016) evaluated the impact of climate change on grape production, they predicted a temperature rise of 2 or 3° C in the north part of the USA, which concerned the authors about buds breaking dormancy processes during an unexpected time causing unstable vine physiology and yield. Additionally, Schultze et al., (2016) reported that due to increasing temperatures, growers in Michigan have converted their grape species from *V. labrusca* to *V. vinifera* cultivars and would expect this conversion to increase in the future. Furthermore, Barnuud et.al., (2013) evaluated berry anthocyanin and titratable acid (for ‘Shiraz’, ‘Cabernet Sauvignon’, and ‘Chardonnay’, three economically important wine grape cultivars in the Western Australian) according to the Intergovernmental Panel on climate change special report emissions scenario (IPCC SRES A2) and with the help of climate outputs claimed that the impact of climate change would adversely affect berry composition and wine quality in the future.

On the other hand, Leuveen and Destrac-irvine (2017) explained that though rising temperatures would cause drought and vine exposure to more ultraviolet B-rays (UV- B) radiation, growers would be able to harvest more crop and growers in cold areas would have new opportunities. They concluded that growers will need new cultivars; thus, breeding programs should improve and build on new ideas. Likewise, Duchene (2016) suggested that new environmental conditions would bring novel advantages for grape growers around the world. People in a breeding program should work on new cultivars and develop new grafted cultivars with new rootstock options. Overall, positive and negative aspects of climate change are anticipated and should be investigated in order to guide growers for the inevitable situation in the future regardless of where the grapes are grown.

Trellis Systems

Grape growers utilize trellis systems that fit their region and cultivar in order to manage their vineyard and business successfully. Trellis systems are literally the most important part of the grape production because grapes, unlike fruit trees, do not have the main trunk as a support system in nature. Therefore, any trellis system supports the vine to help decrease winter and disease damages and labor costs, increase yield ratio, produce more high-quality berries, provide effective sunshine, and improve air movement during the growing period (Reynolds and Heuvel, 2009). However, selecting a proper trellis system for each cultivar is not easy, as they should complete each other to obtain high-quality grape production. Therefore, studies using trellis systems have continued from region to region to determine how a trellis system affects yield, disease, the atmosphere around the trellis system, and fruit composition such as fruit soluble solids concentration (SSC), titratable acid (TA), and pH as well as phenolic compounds.

Controlling the atmosphere created around a trellis system is an important point because a trellis system is designed to increase photosynthetic activity that is needed by the vines while decreasing diseases around a vine. Therefore, researches have evaluated and focused on how sunlight reaches buds to increase yield and quality or how to prevent disease by reducing humidity around leaves. From Germany, Kraus et al., (2018) reported that a semi-minimal pruned hedge (SMPH) was the commonly used training system because it was environmentally friendly, and resulted in a high yield ratio, as well as fewer labor costs. However, SMPH has a high leaf area and poor air movement, which caused undesirable microclimate and disease problems. Therefore, they compared the SMPH and vertical shoot position (VSP) trellis systems in order to examine differences between temperature and humidity leading to diseases and poor berry quality. Their results showed that SMPH had 3% higher humidity and a 0.9 ℃ higher average temperature than VSP through the canopy area, which promoted prevalent grape diseases such as Downy Mildew, Powdery Mildew, and Botrytis. Similarly, a study from Italy examined the impact of climate efficacy and trellis systems on sugar accumulation of ‘Sangiovese’ grape (Valentini et al., 2019). These authors compared the Guyot system to the V-shaped open canopy trellis through the 2017 season by measuring the leaf area, light interception, photosynthetic activity, and stem potential according to a gravimetric approach. The study showed that the trellis systems did not influence fruit yield or leaf area differences. However, the Guyot trellis enabled better performance than V-shaped open canopy for all other measured criteria. Another study from Nebraska reported on how sunlight penetration, yield, and fruit composition for an interspecific hybrid were affected by the trellis system (Bovougian et al., 2012). Of the four-trellis systems, Genova double curtain (GDC), HC, Smart-Dyson, and VSP, the GDC resulted in a higher yield, pH, and Brix compared to the other trellis systems. Likewise, Wang et. al. (2019) compared T- shaped and V-shaped trellis systems for three different grape cultivars, ‘Ruiducuixia’, ‘Ruiduwuheyi’, and ‘Ruiduhongyu’. They suggested a T-shaped trellis system for Northern China because that T- trellis system generated more photosynthetic activity that the vines need, and was able to decrease disease frequency, increase fruit quality and require less labor.

Furthermore, undeniably, excellent wine comes from a fruit that has ideal quality criteria. Those common fruit compositions are SSC, TA, and pH as well as grapes phenolic components. Recently, studies that evaluated wine quality in response to a trellis system have had varying results. For instance, Ying Liu et al., (2015) evaluated three trellis systems (Single Guyot (SG), VSP, and Four-Arm Kniffin (4AK)) and found those trellis systems had no influence on yield or disease in the wet area of China for ‘Cabernet Sauvignon’ grapes. However, they showed that the highest level of anthocyanin was in VSP, followed by SG. In addition, Falcao et al., (2008) used two trellis systems (Y training system and VSP) for two areas in Brazil from 2004 to 2006 to compare the berry maturation of ‘Cabernet Sauvignon’. They reported that grapes on the VSP showed better performance than grapes on the Y system for average TA and pH, but the variation of the climate and precipitation in the two areas may have affected the results. Similarly, an approach from Wimmer et al. (2018) examined three different trellis systems (high cordon (HC), Scott Henry (SH), vertical shoot position (VSP)) with four interspecific hybrid cultivars (Marquette, Frontenac, Brianna, and La Crescent) and found no effect of training system on the vine size and the cane pruning weight. Regardless of the cultivar, the highest yields occurred with SH and HC trellis systems. Further, these authors reported only minor differences in fruit SSC, TA, and pH among the trellis systems. Consequently, though there are many factors that affect grape production, proper trellis system selection has a significant role in maintaining berry quality and indirectly creating more conceivable production for growers.

Canopy management

Canopy management is as important as a trellis system because it is needed in order to produce quality wine and to reach adequate yield. Balancing the vegetative part of the vine and the reproductive part of the vine is not easy, especially in cold regions because of the short growing season and lack of light and heat accumulation across the growing process. Thus, there are some techniques used to manage canopy all around the world such as different pruning methods, shoot thinning, and leaf removal, which is used individually or combined depending on the growing region, climate, and cultivar. For example, Scafidi et al. (2017) examined the effect on canopy management with leaf removal in order to increase wine quality on 'Cabernet Sauvignon'. They tested a two-wire vertical trellis system during fruit set and veraison and claimed that when the leaves were removed at fruit set, the effect on skin anthocyanin composition was greater than when defoliation occurred at veraison.

Similarly, Wang et. al. (2019) showed that 'Shiraz' and 'Semillon' shoot thinning and cluster thinning influenced berry ripening because the number of clusters was decreased. Further, leaf removal provided more light capture and air movement during to growing season. In addition, Sabbatini et al. (2015) demonstrated how canopy management using pruning level impacted yield, berry quality, and the vigor of the vine. They tested four different pruning levels (20,40,80, and 120 nodes/vine) with three trellis systems (Hudson River Umbrella (HRU), Umbrella Kniffen (UK), and Hybrid (HYB)) on 'Niagara' grapes for four years and showed that retaining 20 to 40 and 120 nodes/vine for 'Niagara' grapes caused undesired results, even though there was no effect on yield, berry quality, and vine productivity. When vines were pruned to retain 80 nodes/vine, they obtained a high yield ratio, fine berry feature, and more sustainable vines. Furthermore, Kyraleou et al., (2014) used a divided canopy (Lyre) and VSP with two different pruning systems (Royat and Guyot) for ‘Xinomavro’ in order to determine the interaction between trellis systems and pruning systems on the phenolic compositions extracted from grape seeds and skins. The results showed that grapes on the Lyre system increased berry and wine quality because of the higher anthocyanin content. The last study from Michigan, Frioni et. al. (2017) reported that especially in the cool area doing cluster thinning and leaf removal provided early fruit ripening. This means that under the short growing season, canopy management can hasten fruit ripening. The study demonstrated that although noticeably different weather patterns occurred across the research, the cluster thinning, and leaf removal shortened the veraison dates approximately 15 to 20 days in both years. Consequently, proper canopy management is crucial for the sustainability of grapevine production. By balancing vegetative and reproductive aspects of the vine to produce quality wine and to reach adequate yield, especially in cold regions with a short growing session.

MATERIALS AND METHODS

General Description

The experimental vineyard was located at the NDSU Absaraka Horticulture Research Station (46°59' N 97°21'W) near Absaraka, ND. The study was initiated in 2015, with fruit harvest beginning in 2017 and ending in 2019. The experiment site has a Warsing sandy loam, mixed, super active, and frigid Oxyaquic Hapludolls soil type. During the study, the relevant meteorological data were collected from the nearby North Dakota Agricultural Weather Network station in Prosper, which is 18.9 miles away from the Absaraka research center (NDAWN, 2019).

In the experiment, ‘Marquette’ and ‘Petite Pearl’ were selected as two non-grafted, cold-hardy red wine grapes. ‘Marquette’, a cross between MN 1094 and French hybrid Ravat 262, was released in 2006 by the University of Minnesota. ‘Petite Pearl’, a cross between MN 1094 and E.S.4-7-26, was introduced in 2009 by Tom Plocher. Additionally, these cultivars are considered adapted for cold regions and called cold climate interspecific hybrids grapes (CCIHG) or super hardy cultivars (Domoto et al., 2016). Each vine was trained to one of four different trellis systems in 2016, Geneva Double curtain (GDC), Scott Henry (SH), high wire cordon (HWC), and mid-wire vertical shoot positioning (VSP), respectively, using 14-gauge wire. The trellis systems are generally categorized as single- or double-curtain according to their fruit zone. The HWC has a single fruit zone while the GDC has two fruit zones, but both have cordons trained 1.8 meters above the ground. Similarly, the VSP has a single fruit zone with cordons trained 0.91 meters above the ground. The SH has two fruit zones with cordons for the first fruit zone trained at 0.91 meters, while cordons for the second fruit zone were trained 1.21 meters above the ground.

The experimental location does not utilize supplemental irrigation. Throughout the growing season, fertilizer, insecticide, and fungicide were not used. Herbicide was applied during the dormant season (April) by applying (0.17 l/ha) flumioxazin (Chateau® WDG, Valent USA LLC, Walnut Creek CA) and (0.65 l/ha) glyphosate (Roundup®WeatherMax,Bayer Crop Science, St. Louis MO). During the growing season (early July), (1.65 l/ha) glufosinate (Rely® 280, BASF Corp., Research Triangle Park NC) was applied to control emerged weeds and for sucker control. No pest (insect or fungi) damage was observed in the experimental area except for bird damage, even though netting was used. Additional fundamental viticulture practices were performed: growing grass between vine rows that was routinely mowed, hand weeded for weed escapes and routine pruning of sucker growth for those that escaped herbicide burn down. The first-year canes were frequently either trained upward with catch wires or combed downward depending on cordon position in order to maintain proper shape for the trellis system. Bud pruning was done one time after the general threat of the frost events using the balanced pruning approach of two or three buds per spur with a base of 30 buds per vine with the addition of 10 buds for every 454 g of dormant one-year-old wood removed (Dami et al., 2005). When berry verasion started, the vines were covered with netting to prevent bird damage. All cultural practices were done properly and at appropriate times since all play a crucial role in the economical sustainability of the vineyard.

Experimental Design and Data Collection

The experiment was arranged as a split-plot based on a randomized complete block design (RCBD) with eight replications composed of four plant sub-samples. The whole plot factor for this experiment was the trellis systems with the two grape cultivars as sub-plots. The experimental site was established in a north to south positioning with 2.4 meters (8 feet) spacing between plants, 3.1 meters (10 feet) between rows, and 120 m long rows with 256 vines row^{-1}. There were used 128 numbers of ‘Marquette’ and 128 numbers of ‘Petite Pearl’ as a plant material. All data collected from the study were categorized as either vegetative characteristics or fruit characteristics.

Data were recorded every other day to monitor the phenological stages from bud break until veraison was complete. When a vine reached 50 percent of bud break, bloom, versaison, and final harvest time, the dates were recorded. Cumulative precipitation (mm), growing degree-days (GDD), maximum and minimum air temperatures (°C), first and last frost days, and the number of frost-free days (above 0°C) was considered for each growing season from the beginning of May to the end of September. Daily GDDs were calculated (Eq. 1) from the daily maximum and minimum air temperature, which was based on the 10°C lower threshold, and 30°C upper limit from May to September.

$$\text{GDD} = [(\text{maximum temperature} + \text{minimum temperature})/2] - \text{base temperature } (10^{\circ}\text{C}) \quad (\text{Eq.1})$$

Vegetative characteristic data collected included pruning weight, retained nodes, and specific phenology dates. Dormant pruning initially left approximately three buds per spur. Pruned one-year-old wood were weighed using a digital scale (Yamato-DP-6200, Yamato Scale, Hanns-Martin-Schleyer-Straße 13 D-47877 Willich, Germany) to determine bud counts per vine. After completed this step, the buds left per vine were recorded for each year.

Vine performance and fruit quality were evaluated by collecting data on yield, the number of clusters per vine, 60 berry weights using a digital scale (Ohaus- NVT16000/1, Ohaus Corp., Parsippany NJ), and fruit composition measurements after harvest. Hand harvest consisted of recording the fruit weight per vine using the Yamato-DP-6200 digital scale and the number of clusters removed from each vine. Three clusters were then randomly selected and placed in a plastic bag for further data collection. In the laboratory, each cluster was weighed and the number of berries per cluster recorded. A random sample of 60 berries was selected and weighed. From this sample fruit composition data on pH, total soluble solids, and titratable acidity (TA) was determined. Total soluble solids (Brix) were measured with a digital refractometer (PAL-1, Atago Co. LTD, Minato-ku, Tokyo, Japan), while juice pH was measured with the pH meter (Orion star A-III-Thermo Electron Corp., Beverly MA). Lastly, TA was determined (Eq. 2) using the pH meter after juice dilution with 100 ml of deionized water and the addition of 0.1N sodium hydroxide (NaOH) (ISO 17034 Sigma-Aldrich) until the endpoint of 8.2 pH (Iland et al. 2004).

$$\text{TA (g/L as tartaric acid)} = 75*0.1\text{(Normality of NaOH)} *\text{Titre value (ml)} / \text{(volume of juice used)} \qquad \text{(Eq.2)}$$

Statistical Analysis

The experiment was analyzed as a split-plot based on a RCBD arrangement. SAS 9.4 statistical software was used for the analysis of variance (SAS Institute Inc., Cary, NC). Tukey's honest significant difference test at $\alpha = 0.05$ was used for mean comparisons where appropriate. Severe winter dieback was recorded in 2019, with the majority of vine trunks removed and replaced with suckers that came from roots. Therefore, not all data from 2019 could be statistically analyzed. However, trunk damage data were collected to determine cultivar and trellis differences.

RESULTS AND DISCUSSION

Vegetative Characteristic

Evaluation of climate variability from the weather analysis helped to understand the growth pattern of grapes in North Dakota. In 2017, the accumulated GDDs (1st of May to 30th of September) was 1230 days. This was 207 days higher than the accumulated GDDs for 2019, 129 days less than the accumulated GDDs for 2018, and 42 days less than the historical average (Table 1). There were also remarkable differences among months in comparison to the historical data for GDDs.The noticeable numerical difference observed for May of 2019 with 139 GDDs less than May of 2018, 49 GDDs less than the historical average, and 48 GDDs less than May of 2017. According to Amerine and Winkler's (1944) GDD index that use for grapes, North Dakota is classified as a region I-b, which has 1111 to 1389 GDD, which indicated that in the study, both grape cultivars in the study fit within this GDD range. Conferring the Winkler index, a vine that obtained more heat accumulation during the growing season should have higher quality grapes and wine. Likewise, Frioni et al. (2019) reported that once the accumulated GDD was over the historical average, they had more bud fruitfulness the following season compared to any other season. Lastly, several researchers stated that high heat accumulation allows for a more productive season (Falco et al., 2008; Wimmer et al., 2018; Bradshaw et al., 2018). In this study, more accumulated GDD during the 2018 growing season suggest that it should be more productive and profitable than the other seasons.

The total precipitation of 2019 demonstrated different conditions compared to 2018, 2017 and the historical data, with 588.1 mm, 347.9 mm, 359 mm, and 397.8 mm, rainfall respectively (Table 1). Rainfall in 2019 was 190.3 mm more than the historical average rainfall, 240.2 mm more than the rainfall of 2018, and 229.1 mm more than 2017's rainfall. Undeniably, without an irrigation system for supplemental watering, inadequate precipitation can affect vegetative and reproductive phases of the vine, negatively. There is a contradictory idea for grape water needs. Appropriate water can raise grape yield and develop berry quality (Santos et al., 2003; Santos et al., 2005; Hirzel et al., 2017). In contrast, excessive water can reduce sugar content and anthocyanin level of grapes (Esteban et al., 2001), and environmental conditions and cultivar's genotype are important to reach high yields and great berries (Chaves et al., 2007; Zhang et al., 2020).

Table 1. Cumulative growing degree-day (base 10°C) and precipitation (mm) accumulation along with the historical averages for Prosper, ND, in 2017, 2018 and 2019.

	GDD				Precipitation			
	2017	2018	2019	Historic [a]	2017	2018	2019	Historic [a]
Month	-- Growing degree days--				--mm--			
May	165	256	117	166	16.8	53.9	60	77.5
June	275	313	272	264	87.9	79.3	122	100.3
July	341	319	365	352	50.0	65.3	156.1	87.9
August	257	295	265	324	52.6	78.5	102.4	66.5
September	192	176	184	166	151.7	70.9	147.7	65.5
Total	1230	1359	1023	1272	359	347.9	588.1	397.8

[a] Historic represents the 30-year average from 1981 to 2010 for Prosper, ND.
Weather data obtained from: (https://ndawn.ndsu.nodak.edu/weather-data-yearly.html).

The last spring frost events (0°C) occurred within 9 days of each other on 19 May 2017, 11 May 2018, and 20 May 2019 (Table 2). The first fall frost event (0°C) in 2019 occurred 12 days later than the 2018 fall frost event and 2 days later than the 2017 fall frost event. Although GDDs in 2019 was lower than the other years, the last spring and first fall frost events did not cause an unexpected situation. In addition, the 2019 frost-free days were just three more days than 2018. Moreover, the number of frost-free days were equal for 2017 and 2019 growing seasons and the difference to the historical frost-free days (144 days) was less than 4 days for all growing seasons.

Table 2. Dates of last spring and first fall freeze events and frost-free days in 2017, 2018, and 2019 for Prosper, ND.

Frost Event	2017	2018	2019	Historic [b]
Last Spring (0°C)	19 May	11 May	20 May	9 May
First Fall (0°C)	8 October	28 September	10 October	1 October
Frost Free Days [a]	143	140	143	144

[a] The number of days between last spring and first fall frost.

[b] Historic represents the 30-year average from 1981 to 2010 for Prosper, ND.

Weather data obtained from: (https://ndawn.ndsu.nodak.edu/weather-data-yearly.html).

Bradshaw et al. (2018) reported the frost-free days for south Burlington, ranged from 147 days to 198 days. Several authors have stated how climate change has influenced the production pattern, either positively or negatively (Londo and Martinson, 2016; Schultze et al., 2016; Leuveen and Destrac-irvine, 2017). In contrast to these articles, climate change may not affect or cause changes to North Dakota's climate trend because large climatic fluctuations were already present so that there was no substantial alteration to the growing season length when compared to historical weather data. The weather data demonstrated that cultivars could still be productive under short growing seasons in the North Dakota climate. Furthermore, frost events are important since the late last spring frost may lead to damage of primary buds on the vine and the early first fall frost can reduce berry quality (Pedneault et al., 2013; Manns et al., 2013; Frioni et al., 2017).In the current study, the freeze events in bud break time and harvest time did not affect both cultivars in 2018 and 2019; however, in 2017, the last spring freeze event coincided with bud break time of 'Marquette' and the first fall freeze event overlapped with the harvest time of 'Petite Pearl' (Table 3).

Table 3. Phenological development of 'Marquette' and 'Petite Pearl' cultivars grown at the North Dakota State University Horticulture Research Farm near Absaraka, ND in 2017, 2018 and 2019.

	2017		2018		2019	
	Marquette	Petite Pearl	Marquette	Petite Pearl	Marquette	Petite Pearl
Phenological stages	-------------------------------------Date-------------------------------------					
Bud break [a]	19 May	25 May	20 May	26 May	7 Jun	18 Jun
Bloom [b]	9 Jun	15 Jun	9 Jun	12 Jun	30 Jun	10 Jul
Veraison [c]	9 Aug	15 Aug	27 Jul	12 Aug	16 Aug	24 Aug
Harvest [d]	2 Oct	9 Oct	26 Sep	26 Sep	30 Sep	30 Sep

[a] once 50% of buds on a plant have a break
[b] once 50% of flowering is opened on a vine
[c] once 50% of the berries on a vine has changed color
[d] harvest time

Phenological development of 'Marquette' and 'Petite Pearl' varied for each growing season (Table 3). In 2017 and 2018, the bud break of 'Petite Pearl' was six days later than 'Marquette, while, in 2019, there was a delay in bud break for both cultivars with the bud break of 'Petite Pearl' 11 days later than 'Marquette'. Delayed bud break in 2019 was attributed to the minimum daily temperatures in May, which resulted in the latest last spring freeze event (20 May) and lower GDDs during May than the previous two years (Tables 1 and 2). However, the bud break delay in 2019 did not create large numerical differences for the number of days between bud break and other phenological events among the three years evaluated (Table 4).

The bloom time and the veraison time occurred on various dates across to growing seasons for both cultivars (Table 3). 'Marquette' and 'Petite pearl' completed their phenological phases later in 2019 than the 2018 and 2017 growing seasons due to fewer GGDs (°C), lower maximum and minimum daily air temperature (°C), and higher rainfall (mm), in the 2019 growing season (Table 1, Figures 1, 2, and 3). The number of days from bud break to harvest for 'Marquette' and 'Petite Pearl' was 136 and 137 days respectively in 2017, 129 and 123 days in 2018, and 114 and 104 days in 2019 for, (Table 4). When linked with the frost-free days and the number of days needed to mature fruit, although growing season is too short, there was still enough time to reach fruit ripening for both cultivars in 2019 (Tables 2 and 4). Interestingly, Scharfetter et al. (2019) reported that their harvest time was 25 September 2017 with 1412 GDDs for 'Marquette' and 27 September 2017 with 1436 GGDs for 'Petite Pearl' in Madison. Although they reached higher GDDs, cultivars maturation followed identical phenological patterns for days from bud break to harvest.

In 2017, the harvest time varied because a late fall allowed more fruit ripening until the first fall frost event, while, in 2018 and 2019' the harvest time was managed by the predicted first fall freeze time. Both cultivars were harvested on the same date 26 September of 2018 and 30 September of 2019, which turned out to be 2 and 10 days before the first fall freeze event, respectively.

Table 4. The number of days between phenological events of bud break to harvest for 'Marquette' and 'Petite Pearl' cultivars grown at the North Dakota State University Horticulture Research Farm near Absaraka, ND in 2017, 2018 and 2019.

	2017		2018		2019	
	Marquette	Petite Pearl	Marquette	Petite Pearl	Marquette	Petite Pearl
	-----------------------------------Number of days--------------------------------					
Bud break-Bloom	21	21	20	17	23	22
Bloom-Verasion	61	61	48	61	46	45
Veraison-Harvest	54	55	61	45	45	37
Bud break-Harvest	136	137	129	123	114	104

From the climatic data (GDDs, frost-free days, and the number of days from bud-break to harvest), we can confirm that the selected cultivars, Marquette and Petite Pearl, will ripen fruit in North Dakota's short growing season. There are few published studies that have included the 'Petite Pearl' cultivar. However, when evaluated in the current study, 'Petite Pearl' was classified in the northern hybrid grapes group. Additionally, previous research concludes that the northern hybrid grapes group cultivars can adapt to areas that have a short growing season (Pedneault et al., 2013; Domato et al., 2016; Frioni et al., 2017). Moreover, the researchers stated the amount of grape production and berry and wine quality cannot be considered in the absence of collected phenological dates and weather data, since there is a strong relationship between the grape maturation stages and climate (Meier et al. 2007; Sun et al. 2018; Carlo et al. 2019).

In the current study, the influence of the winter minimum air temperature on the vine's life cycle was strongly observed. After harvest, vines began to pass through the acclimation process quickly, which traditionally concludes by the middle of February. After the middle of February, the vines defense mechanism reverses and the vines become more sensitive to temperature swings, this is called the deacclimation process (Londo and Martinson, 2016). In 2017, once acclimation of the vines began, the minimum temperature decreased to -17°C early on 8 November and the last term of acclimation was on 29 December at - 32°C. During the deacclimation time, no extreme winter weather events occured in 2017, even when the minimum temperature was around -18°C (Figure 1). In 2018, at the beginning of the acclimation stage, the temperature dropped to -20°C on 18 November, and during the acclimation stage, the temperature reached - 32°C and - 30°C in January (Figure 2). Similar to the 2017 deacclimation period, the temperature was not too low by 13 March (-19°C) (Figure 1) and no extreme weather events occurred. In contrast to the 2017 and 2018 winter conditions, the 2019 winter conditions exposed the vines to more frequent extreme low temperatures during both the acclimation and deacclimation periods. In 2019, the first extremely low temperature came too early on 10 November (-22°C) and 11 November (-22°C). By the end of January, the average low temperature was almost - 25°C then the temperature dropped dramatically. The lowest point was a cascade, (-33°C), (-36°C), and (-35°C) on 29, 30, and 31 January. Unfortunately, once the deacclimation period began, the vines were exposed to severe cold temperature events repeatedly during February (9 February (-29°C), 25 February (-30°C), and 27 February (-30°C)) (Figure 3).

When comparing the low winter temperatures for the three years, in 2019, the winter had an extended number of days below freezing, especially in early winter when the dramatic temperature drop may have affected the vine acclimation process negatively. Additionally, in the study, the vines were exposed to freezing temperatures over and over during the deacclimation process in 2019. In the current study, it was thought that the frequent extreme temperatures caused severe damage to the vines from trunk splitting, including the xylem and phloem, of the vines. Therefore, in 2019, the low winter temperatures created serious winter damage to both 'Marquette' and 'Petite Pearl', although both cultivars have cold hardiness features. These cultivars are hybrid cultivars and their backgrounds include mainly *Vitis riparia* and marginally *Vitis vinifera* (Luby and Hemstad, 2003; Zabadal et al., 2007). Due to the variety of genes, these hybrid cultivars tend to pass rapidly through the deacclimation period, so they are more vulnerable to changing temperatures during deacclimation (Zabadal et al., 2007; Ferguson et al., 2013; Bradshaw et. al., 2018). *V.riparia* can resist temperatures down to - 30°C, but *V. vinifera* is sensitive to a cold climate (Zabadal et al., 2007; Dami et al., 2012). When testing buds LT_{50} levels or the temperature that 50 percent of the buds on the vine can be killed, using differential thermal analysis (DTA); *V. riparia* buds are slightly damaged at between -25°C and -28°C (Londo and Martison, 2016), while 93% of the *V. vinifera* buds are killed when low temperatures hit -26°C (Zabadal et al., 2007; Dami et al., 2012). Wolf and Cook (1994) observed that with 'Cabernet Sauvignon' buds, the (LT_{10}) or temperature that was lethal to 10% of a bud sample was -20°C, while -23°C was lethal to 50% of a bud sample (LT_{50}), and -24°C was lethal to 90% of the bud samples (LT_{90}). Karimi (2015) tested 20 *Vitis vinifera* cultivars during the acclimation and deacclimation periods, and reported 50% of a bud samples (LT_{50}) were killed at -15°C to -26°C. Furthermore, DTA indicates that winter injury occurs first on phloem tissue and then xylem tissue (Ferguson et al., 2014; Goa et al., 2014; Londo and Martison, 2016). Therefore, in the current study, the cultivar's genetic background and the severity of the winter low-temperatures may address the winter damage that caused the xylem and phloem to die.

Grapes are perennial plants. Consequently, to consider only the weather conditions during the growing season would be inadequate for grape production. Air temperatures beyond the growing season are likely crucial. Therefore, apart from the genetic reality of cultivar, GDDs, rainfall, the number of frost-free days, and the climate trend of an area must be considered for sustainable grapevine production (Kalberer et al., 2006; Alikadic et al., 2019; Kovoleskia and Londo, 2019). Recording all the specific dates with weather data, along with the phenology has great importance to observe understand the growth and dormancy patterns of different grape cultivars in North Dakota.

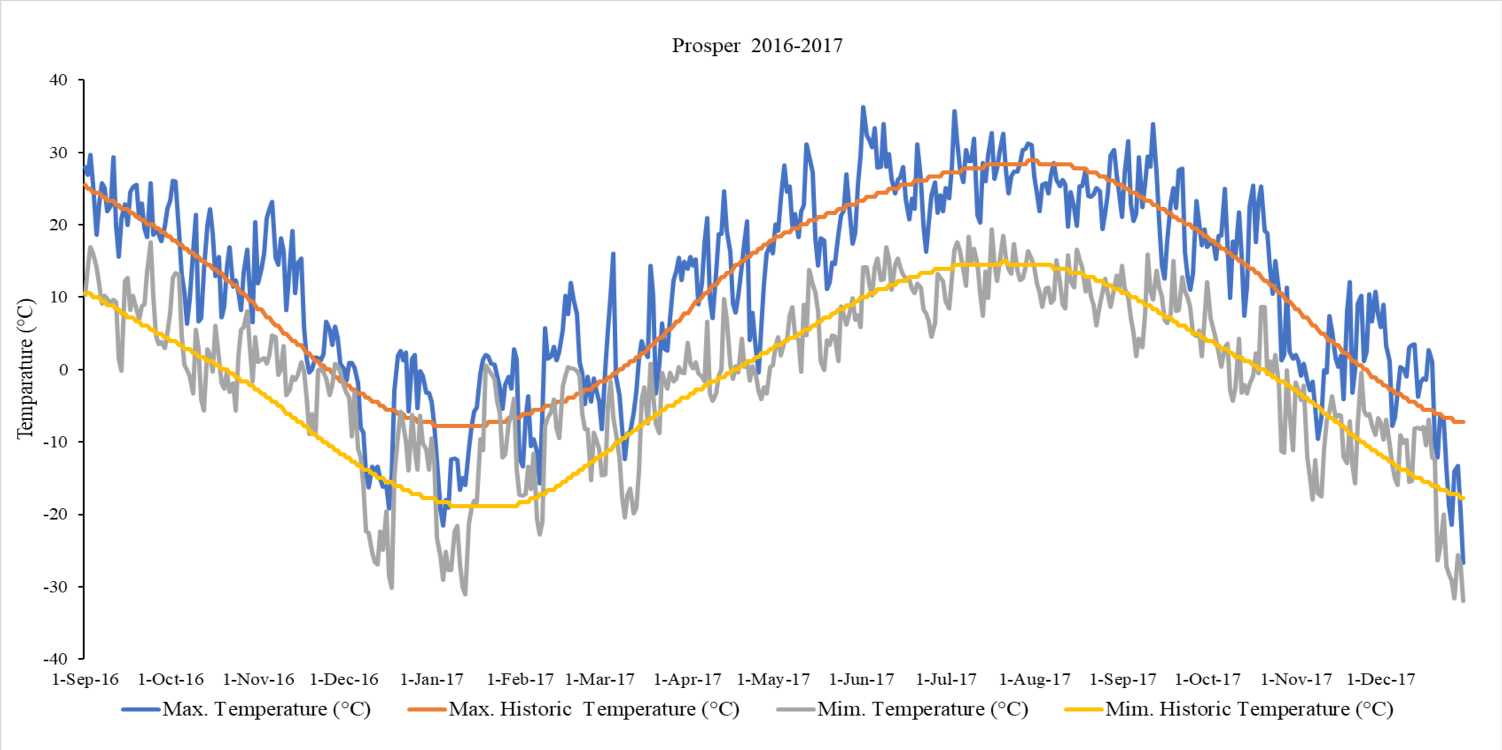

Figure 1. Daily maximum and minimum temperature (°C) and historical maximum and minimum temperature (°C) along with growing season for Prosper, ND, in 2016 and 2017.
Historic represents the 30-year average from 1981 to 2010 for Prosper, ND.
Weather data obtained from: (https://ndawn.ndsu.nodak.edu/weather-data-yearly.html).

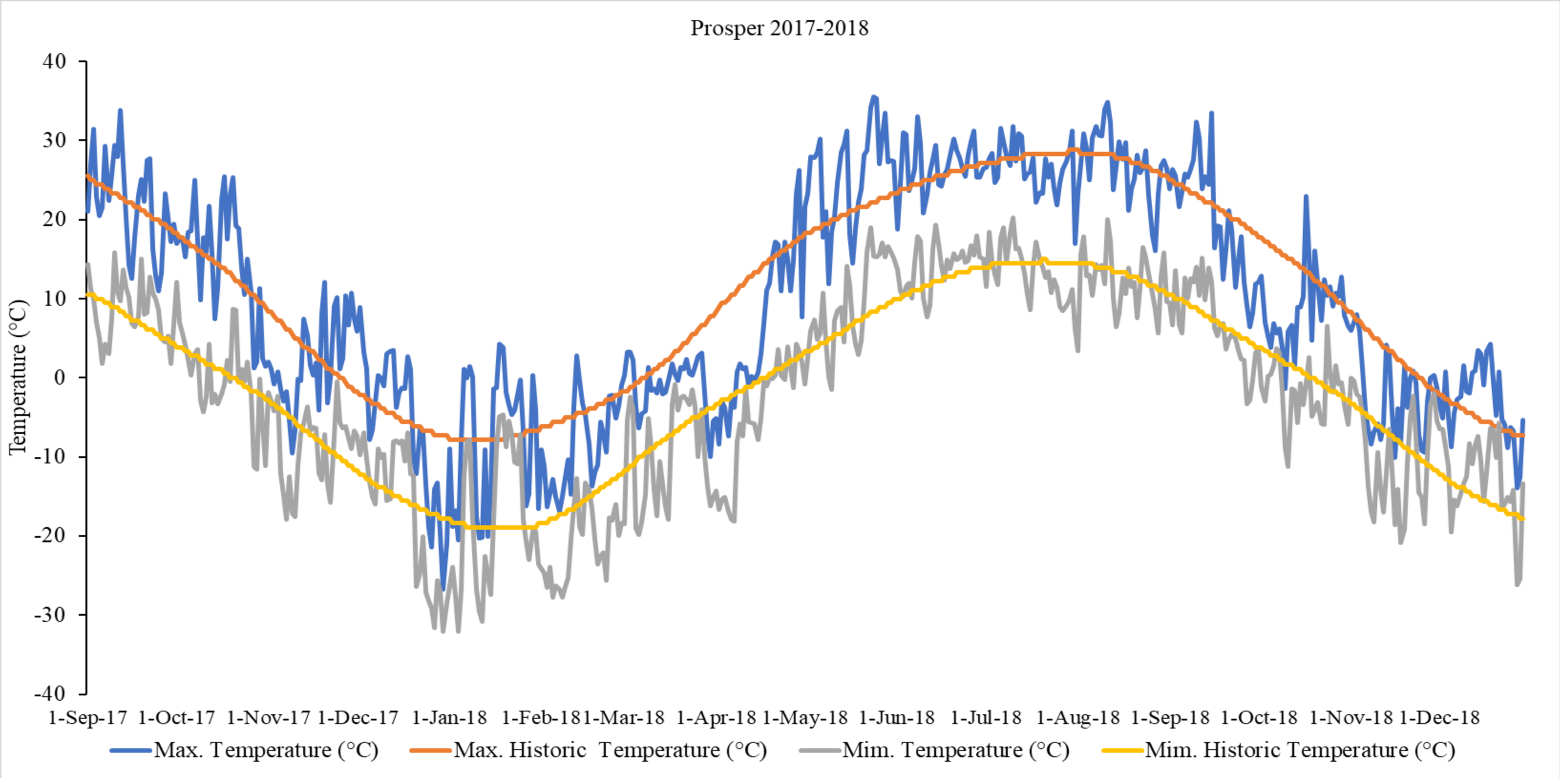

Figure 2. Daily maximum and minimum temperature (°C) and historical maximum and minimum temperature (°C) along with growing season for Prosper, ND, in 2017 and 2018.
Historic represents the 30-year average from 1981 to 2010 for Prosper, ND.
Weather data obtained from: (https://ndawn.ndsu.nodak.edu/weather-data-yearly.html).

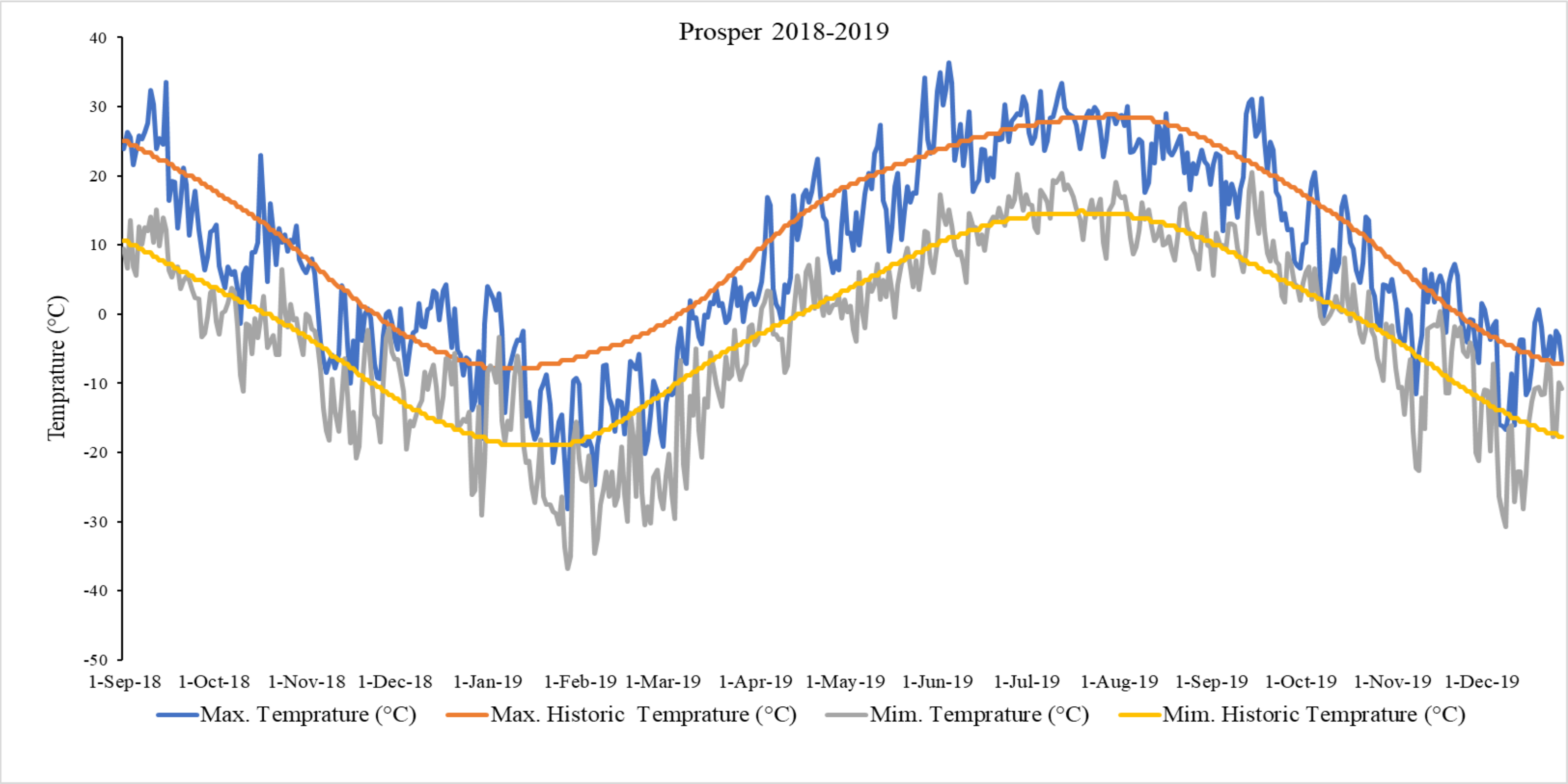

Figure 3. Daily maximum and minimum temperature (°C) and historical maximum and minimum temperature (°C) along with growing season for Prosper, ND, in 2018 and 2019.
Historic represents the 30-year average from 1981 to 2010 for Prosper, ND.
Weather data obtained from: (https://ndawn.ndsu.nodak.edu/weather-data-yearly.html).

Yield components

Components of yield can include pruning weight, which defines 1-year-old canes weight per vine, retained nodes per vine, and cluster number per node for each vine. Those results give an idea about the crop load for each vine each year.

In 2017, there were no significant pruning weight differences between cultivars, among trellis systems, and the interaction of cultivar by trellis system (Table 5). However, at $P < 0.1$, the pruning weight for ‘Marquette’ was greater than the pruning weight for ‘Petite Pearl’. In 2018, only the cultivars influenced differences for pruning weight, with ‘Marquette’ having a greater average pruning weight (233.23 g/per vine) compared to ‘Petite Pearl’ (172.65 g/per vine). The second-year pruning weights were approximately three times larger than the first-year pruning weights and suggests that the older vines can produce more fruit. The pruning weight in 2019’s was approximately four times larger the average pruning weights in 2018 (Table 5). However, the 2019 data was not statistically analyzed due to the number of vines that died to the ground (Table 6).

There is a common idea that if the trellis system led to downward shoot positioning like HW and GDC, the downward bending of the shoots would reduce vigor compared to shoot positioning with upward growth (Vanden Heuvel et al., 2004; Bavougian et al., 2012; Wimmer et al., 2018). This may be true for mature vines, but for vines just becoming established as in the current study, there were no significant trellis differences with vines trained to downward shoot positions producing as much one-year-old wood as vines trained to upward shoot positions.

Both cultivars and trellis systems influenced the number of retained nodes per vine in 2017 and 2018 (Table 5). In 2017 and 2018, the number of the retained nodes for ‘Marquette’ (20 and 20 nodes/per vine) was greater than retained nodes for ‘Petite Pearl’ (14 and 10 nodes/per vine), respectively. Additionally, in 2017, vines trained to the SH trellis systems, with two fruit zones had more nodes retained (21 nodes /per vine) compared to node retention for vines trained to VSP (17 nodes /per vine), GDC (15 nodes /per vine), and HW (14 nodes /per vine). However, in 2018, vines trained to the SH trellis system only had more retained nodes than vines trained to HW. In both years, the trellis by cultivar interaction on retained node number was not significant. In 2019, both cultivars were finally coming close to the balanced pruning method formula of 30+10 for most hybrid grape cultivars (Dami et al. 2005) (Table 6).

Bud fruitfulness was evaluated from the cluster number per vine and can be used to estimate the quantity of crop at harvest and the degree of sunlight received by the buds. Cultivars influenced bud fruitfulness in 2017, while trellis system influenced bud fruitfulness in 2018 (Table 5). In 2017, ‘Petite pearl’ had more clusters per retained node compared to ‘Marquette’. In 2018, vines trained to the GDC trellis system had more clusters per retained node than vines trained to the VSP trellis system. Bud fruitfulness decreased in 2018 regardless of cultivar or trellis system. Since a younger vine might have fewer retained buds and more sunlight penetration onto these buds, greater fruitfulness was expected in 2017. In 2019, bud fruitfulness was very low for vines that did not have trunks removed (Table 6). This was also expected as vines that did not have severe trunk injury most like had primary bud injury and perhaps even secondary bud injury. Similar to our results, Winner et al. (2018) reported that ‘Marquette’ did not show any numerical differences among trellis systems (divided - undivided) in terms of pruning weight and cluster numbers, but ‘La Crescent’ reached a greater pruning weight with the Scott Henry trellis system. In contrast to our results, Reynolds and Heuvel (2009) reported that pruning weights were 0.62 kg/ per vine for ‘Seyval’ and 1.35 kg/vine for ‘Chancellor’ when trained on the GDC trellis.

Table 5. Yield components by pruning weight, retained node, and fruitfulness for cultivars ‘Marquette’ and ‘Petite Pearl’, and trellis systems Geneva Double Curtain, Scott Henry, vertical shoot positioned, and high wire, at Absaraka, ND in 2017 and 2018.

Treatment	Pruning weight [1]		Retained node		Fruitfulness [2]	
	2017	2018	2017	2018	2017	2018
	--g/per vine--		--number/per vine--		--cluster number/retained node--	
Cultivars						
Marquette	98.74	233.23 a	19.92 a	19.66 a	2.07 b	1.44
Petite Pearl	80.50	172.65 b	13.78 b	10.23 b	3.20 a	1.29
P- value	0.0534	0.0048	0.0003	<.0001	0.0049	0.1389
Trellis						
GDC [3]	86.40	216.17	15.04 b	15.11 ab	2.21	1.57 a
SH	72.74	191.62	21.06 a	16.35 a	2.93	1.30 ab
VSP	99.88	218.68	17.02 b	15.93 ab	3.16	1.12 b
HW	99.46	185.29	14.24 b	12.39 b	2.24	1.47 ab
P- value	0.1326	0.5390	0.0132	0.0298	0.1856	0.0184
Cultivar*Trellis						
M * GDC	96.31	243.21	17.72	19.34	1.93	1.62
M * SH	76.73	208.27	23.74	20.14	2.12	1.36
M * VSP	101.51	248.60	21.58	22.98	2.49	1.19
M * HW	120.41	232.82	16.65	16.18	1.73	1.59
P.P * GDC	76.48	189.13	12.48	10.88	2.48	1.52
P.P * SH	68.75	174.97	18.38	12.56	3.74	1.23
P.P * VSP	98.26	188.75	12.45	8.88	3.83	1.05
P.P * HW	78.52	137.75	11.82	8.60	2.74	1.35
P- value	0.4488	0.7387	0.7087	0.0658	0.7642	0.9670

[1] Weight of one-year-old pruning per vine.

[2] Fruitfulness = cluster number/nodes retained.

[3] Abbreviations GDC=Geneva Double Curtain, SH=Scott Henry, VSP=Vertical Shoot Positioned, HW=High Wire, M=Marquette, P. P= Petite Pearl.

[a,b] Means in a column (year) followed by the different letters are significantly different and means were separated at $P \leq 0.05$ by Tukey’s test.

Table 6. Average yield components of pruning weight, retained nodes, and fruitfulness for 'Marquette' and 'Petite Pearl' that survived at Absaraka, ND in 2019.

Treatment	Pruning weight [1] --gr/per vine--	Retained node --nodes/per vine--	Fruitfulness [2] --cluster/retained node--
Marquette	1070.56*	40.92	0.38
Petite Pearl	630.34	34.27	0.48

[1] Weight of one-year-old pruning per vine.

[2] Fruitfulness = cluster number/nodes retained.

*Numbers not calculated statistically due to extensive trunk damage and grapevine loss; the numbers represent the average mean.

They showed there was a significant interaction between cultivar and different trellis systems for pruning weights. Scharfetter et al. (2019) reported pruning weights much greater than our pruning weights for 'Marquette' and 'Petite Pearl' at 2.5 kg/vine and 1.16 kg/vine, respectively. Bradshaw et al. (2018) reported that 'Marquette' had significant pruning weight per vine differences between years. However, their pruning weights in both years for 'Marquette' were higher than our results, which was attributed to the age of their vines compared to newly fruiting vines in the current study.

Some of the differences in pruning weight were also attributed to the cultivars' genetic backgrounds. For instance, Athucha et al. (2018) evaluated red and white wine cultivar's performance (2011 to 2014) and reported that white cultivars had greater pruning weights than red cultivars. Howell (2001) expressed that there was an important impact of retained nodes for yield from 20 nodes to 160 nodes; however, more than 55 retained nodes did not create a great variation on yield per vine. Sabbattini et al. (2015) demonstrated that leaving a high number of retained nodes did not affect harvest components. In the current study, cultivar and vine trellis system differences for retained node number varied between years, making it difficult to refer to its effect on yield.

Yield

Berry weight was influenced by cultivar differences both years and the interaction of cultivar by trellis system in 2018 (Table 7). Graphing the interaction of cultivar by trellis system indicated that instead of a true interaction, the interaction was due to an order of magnitude (Figure A1). In 2017, ‘Marquette’s average individual berry weight (1.10 g) was greater than the average individual berry weight for ‘Petite Pearl’ (0.88 g). In 2018, like the previous season, ‘Marquette’ average individual berry weight was greater than the average individual berry weight for ‘Petite Pearl’. The interaction result indicated that the average individual berry weights for ‘Marquette’ vines on GDC, SH, and VSP trellises were greater than the average individual berry weight for ‘Petite Pearl’ vines on the VSP trellis. In 2019, the average individual berry weight for ‘Petite Pearl’ was numerically heavier than the average individual berry weight for ‘Marquette’ even though berry weights only differed by 0.06 g (Table 7). The current study results suggest that genetically, ‘Marquette’ produces a larger (heavier) berry compared to ‘Petite Pearl’. The inconsistent cultivar by trellis system result suggests that young fruit bearing vines can have variable responses.

Cluster mass was influenced by cultivar differences both years, trellis system in 2017, and the interaction of cultivar by trellis system in 2018 (Table 7). Graphing the interaction of cultivar by trellis system indicated that this was a true interaction due to the difference in cultivar cluster mass responses for the VSP trellis (Figure A2). In 2017, ‘Marquette’ clusters were heavier (102. 76 g) compared to the cluster weights from ‘Petite Pearl’ (74.38 g) while, just the opposite occurred in 2018. In 2019, ‘Marquette’ clusters on average weighed more than twice the weight of ‘Petite Pearl’ clusters even though these averages came from one vine per replicate instead of four vines per replicate (Table 8). The heavier cluster weight with ‘Marquette’ was expected as this cultivar has longer, and wider clusters and their berries were found to be slightly larger than ‘Petite Pearl’. ‘Petite Pearl’ clusters are more compact, and their berries are slightly smaller than ‘Marquette’ (Domoto et al., 2016).

The trellis effect in 2017 indicated that vines on the HW trellis system had heavier clusters than vines on the SH trellis system; while in 2018, there were no differences among the trellis systems in terms of cluster mass (Table 7).

Interestingly, cluster number was higher in 2017, but there were no differences between cultivars, while in 2018, ‘Marquette’ produced more clusters per vine than ‘Petite Pearl’. Vines on the SH and VSP trellises produced more clusters per vine than vines on HW and GDC trellises in 2017. In both years, the cultivar by trellis interaction was not significant. Cluster numbers for vines on the VSP and SH, trellis in 2017 were almost two times more than 2018’s cluster numbers. This outcome reflects the ability to develop a cordon on the mid-wire earlier than the high-wire trellis systems. Cordons on both VSP and SH trellises were initiated earlier than cordons for HW and GDC trellises because of the cordon distance from the ground. Winner et al. (2018) also reported that the first years of a study do not show trellis performance. However, results may suggest that high wire trellis systems could be more productive the first year of fruiting by transitioning from a mid-wire trellis the first year of fruiting to a high wire trellis the second year of fruiting. Cultivars for both years and trellis system influenced yield differences (Table 7). The first year of the study, cultivars were more productive than the second year of the study. In 2017, ‘Petite Pearl yield (2.58 kg/ per vine) was greater than the yield for ‘Marquette’ (2.02 kg/ per vine).

Table 7. Yield responses of berry weight, cluster mass, cluster number, and yield for cultivars ‘Marquette’ and ‘Petite Pearl’, trellis systems Geneva Double Curtain, Scott Henry, vertical shoot positioned, and high wire, at Absaraka, ND in 2017 and 2018.

Treatment	Berry weight		Cluster mass		Cluster number		Yield	
	2017	2018	2017	2018	2017	2018	2017	2018
	--g--		--g--		--number --		--kg/per vine--	
Cultivars								
Marquette	1.10 a	1.36 a	102.76 a	86.99 b	40.68	27.64 a	2.02 b	1.63 a
Petite Pearl	0.88 b	1.26 b	74.38 b	106.98 a	34.82	13.08 b	2.58 a	1.19 b
P- value	<.0001	<.0001	<.0001	<.0001	0.0763	<.0001	0.0151	0.0100
Trellis								
GDC [1]	1.01	1.33	92.06 ab	103.90	28.62 b	23.44	1.77 b	1.75
SH	0.96	1.32	74.60 b	91.24	49.01 a	20.25	2.56 a	1.32
VSP	0.99	1.28	92.70 ab	91.79	44.69 a	18.58	2.88 a	1.18
HW	1.00	1.31	94.91 a	101.00	28.58 b	19.17	1.99 b	1.37
P- value	0.4954	0.3937	0.0314	0.0653	<.0001	0.3619	0.0040	0.0942
Cultivar*Trellis								
M * GDC	1.14	1.37 a	78.04	94.60 bcd	32.37	30.35	1.61	1.82
M * SH	1.06	1.38 a	60.74	77.76 d	49.74	25.97	1.91	1.47
M * VSP	1.14	1.39 a	76.38	93.96 bcd	51.32	27.80	2.79	1.65
M * HW	1.06	1.32 ab	82.36	81.63 cd	29.29	26.45	1.77	1.57
P.P * GDC	0.89	1.30 ab	106.09	113.21 ab	24.87	16.53	1.92	1.68
P.P * SH	0.85	1.26 ab	88.46	104.73 abc	48.46	14.53	3.21	1.18
P.P * VSP	0.85	1.18 b	109.02	89.62 bcd	38.06	9.37	2.97	0.71
P.P * HW	0.94	1.31 ab	107.45	120.36 a	27.87	11.88	2.22	1.17
P- value	0.1111	0.0164	0.9623	0.0046	0.5006	0.6876	0.2837	0.3179

[1] Abbreviations GDC=Geneva Double Curtain, SH=Scott Henry, VSP=Vertical Shoot Positioned, HW=High Wire, M= Marquette, P. P= Petite Pearl.

[a,b] Means in a column (year) followed by the different letters are significantly different and means were separated at $P \leq 0.05$ by Tukey’s test.

However, in 2018, it was just the opposite with ‘Petite Pearl’ yield (1.19 kg/per vine) lower than the yield for ‘Marquette’ (1.63 kg/per vine). In 2019, the average yield was reduced for both cultivars (Table 8). However, the decrease was most severe for ‘Marquette’ suggesting that ‘Petite Pearl’ had only a slightly better tolerance to the devastating winter kill event.

The trellis effect in 2017 indicated that vines on SH and VSP trellises had greater yields compared to vines on GDC and HW trellises (Table 7). Vines on the GDC and HW trellises showed a similar effect for cluster number, an important variable in the determination of yield. In both years, the cultivar by trellis interaction was not significant for yield. Although some authors reported similar results with the current study, others reported contrasting results from our study. For instance, Sabbattini et al. (2015) tested ‘Niagara’ with three different trellis systems, umbrella kniffen (UK), Hudson River umbrella (HRU), and bybrid (HYB), from 1999 to 2003, and reported that there was no effect of the trellis systems on yield (kg/vine), cluster no, fruitfulness (kg/node), and cluster weight (g). Bavougian et al. (2012) compared GDC, VSP, HW and SH using ‘Frontenac’ and reported that there were no significant results among trellis systems in terms of yield and berry weight for the first fruiting year. However, for the second year, they reported that vines on GDC (4.21 kg/plant) had a higher yield than vines on HW (2.52 kg/plant), VSP (3.01 kg/plant), and SH (3.73 kg/plant). Wimmer et al. (2018) tested ‘Marquette’ with three different trellis systems, HW, SH, and VSP. They did not find significant yield differences the first year of the study. Nevertheless, vines reached their highest yield with SH (8.5 kg/row), HW (5.6 kg/row), and VSP (4.8 kg/row) on the second year. The authors’ second-year result, especially for SH, was interesting since SH in our study did not have acceptable performance in the second year of our study. Liu et al. (2015) demonstrated the interaction of ‘Cabernet Sauvignon’ (*Vitis vinifera*) with Single Guyot (SG), Spur-pruned VSP, and four-arm kniffin (4AK) trellis systems. They reported the yield (kg) and cluster weight (g), respectively, were 2.2 kg and 123.2g for SH, 2.3 kg and 115.1g for VSP, and 3.6 kg and 141.3 g for 4AK. Wolf et al. (2013) implemented five training systems with 'Shiraz'. The study results showed a variation during the five years. Berry weight was the highest at VSP (1.17g) and crop yield was highest on a minimally pruned training system (4.9 kg/row).

The relationship between yield components and yield outcomes were obvious in this study. For example, decreased bud fruitfulness in 2018 was directly related to cluster number and yield. When examining cluster number and yield associated with vines on a trellis system; vines on VSP and SH in 2017 had 44.64 clusters per vine and 49.01 clusters per vine, respectively, while the same trellis systems had 18.58 clusters per vine and 20.55 cluster per vine in 2018. This dramatic decrease directly affected the yield outcome. The dramatic decrease may have resulted from shoot differentiation within the buds. Because each bud includes a primary, secondary, and tertiary bud and all may be able to show different productivity even if they were not exposed to climate severity during the growing season (Pool et al., 1978; Sanchez and Dokoozlian, 2015; Wimmer et al., 2018). From the climatic data, it is difficult to accept the yield decrease in 2018 because vines in 2018 had the highest level of GDD and last spring freeze (11 May) did not conflict with the bud break time (20 May for Marquette and 26 May for Petite Pearl) (Tables 1, 2, and 3). On the other hand, shoot position on the cane may have influenced fruitfulness, cluster number, and yield (Khanduja and Balasubrahmanyan, 1972; May 2004). There are studies about how low placed buds on cane decrease yield for American grape cultivars, but this has not been reported for cold-hardy cultivars (Wimmer et al., 2018). However, there are several studies that show how a high placed cordon like the HW and GDC trellis can provide more sunlight penetration, capture higher temperatures for bud improvement and increased yield (Wolf et al., 2003; Sabbattini et al., 2015; Athucha et al., 2018; Bradshaw et al., 2018; Wimmer et al., 2018). When examining the difference in pruning weights between 2017 and 2018, vines on the VSP and SH trellises had higher pruning weights in 2018 comparedto 2017. Furthermore, the current study could not assess yield output statistically for 2019, when vines would have been considered established (Table 8). Unfortunately, this would only demonstrate how tragic winter damage can be for grape production in cold regions. In 2019, the vine damage for 'Marquette' was 77.34% or 99 out of 128 trunks removed, while the vine damage for 'Petite Pearl' was 52.34% or 67 out of 128 trunks removed. Vines trained to a SH trellis had the most damage, while vines trained to GDC were the least damaged (Figure 4).

Table 8. Average yield responses of berry weight, cluster mass, cluster number, and yield for 'Marquette', 'Petite Pearl' in Absaraka, ND in 2019.

Treatment	Berry weight -- gr --	Cluster mass -- gr --	Cluster number --no --	Yield --kg/per vine--
Marquette	1.05*	182.69	12.69	0.31
Petite Pearl	1.11	73.63	15.07	0.96

* Numbers not calculated statistically due to extensive trunk damage and grapevine loss; the numbers represent the average mean.

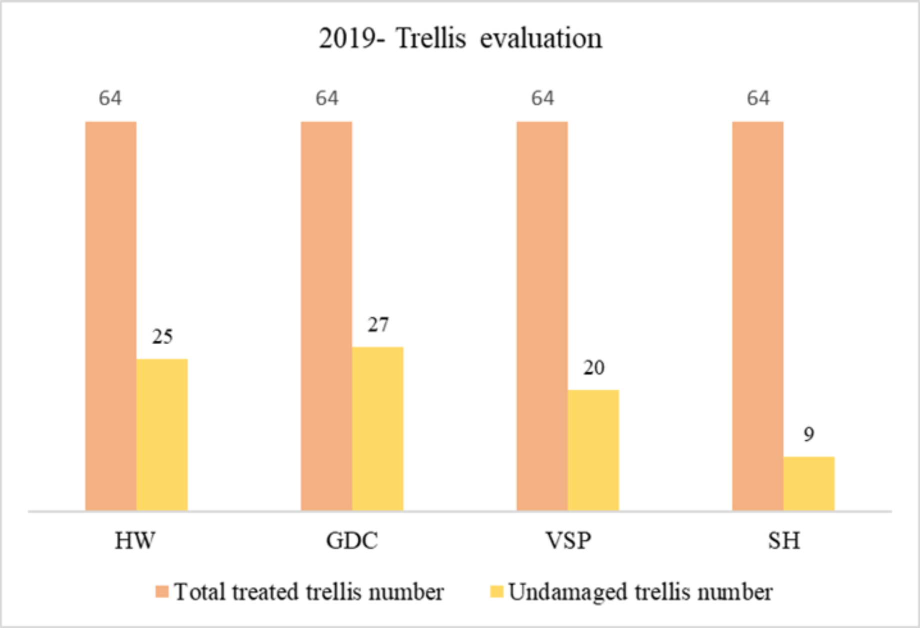

Figure 4. Total treated trellis number and undamaged trellis number for HW=High Wire GDC=Geneva Double Curtain, VSP=Vertical Shoot Positioned, and SH=Scott Henry in Absaraka, ND in 2019.

Fruit Characteristic

Fruit composition included pH, soluble solids, and TA, critical parameters influencing wine quality. Trellis system and the interaction of cultivar by trellis system did not affect fruit characteristics of pH, soluble solids, and TA (Table 9). However, there were significant differences between ‘Marquette’ and ‘Petite Pearl’ for pH, soluble solids, and titratable acidity. For both years, ‘Marquette’ had a lower pH level and higher soluble solids level compared to ‘Petite Pearl’. Naturally, soluble solids demonstrated opposite results to pH level due to an inverse correlation between them. In 2019, ‘Marquette’ fruit again had lower pH and higher soluble solids compared to ‘Petite Pearl’ fruit (Table 10). Results indicate that soluble solids:pH ratio vary for the two cultivars and that ‘Petite Pearl’ fruit pH level may become dangerously high by the time the soluble solids level is at the desirable winemaking level. On the other hand, ‘Marquette’ soluble solids level may become too high by the time the pH level is within the desirable range for winemaking. Dami (2014) reported that the generally recognized range of numbers for the pH, TA and soluble solids at harvest that are known to make a nice wine are pH 3.3–3.5, TA 0.6–0.8 %, and 18–24% soluble solids.

When focusing on 2017, ‘Marquette’ fruit TA (1.3%) was higher than ‘Petite Pearl’ fruit TA (0.81%) titratable acidity (Table 9). In 2018, the TA did not differ among cultivars. Furthermore, in 2019, with the severe winter temperatures, the lowest number of days from bud break to harvest, and the lack of GDDs, the TA levels were almost opposite of 2017 with higher ‘Petite Pearl’ fruit (1.28%) TA level compared to ‘Marquette’ fruit TA (0.85%) (Tables 9 and 10).

During the maturation period from versaison to harvest, the air temperature and rainfall or water status are essential, since they stimulate berry ripening and the expected wine quality is correlated to the maturation phase of fruit (Falcao et al., 2008). Thus, in cold regions like North Dakota, that have a short growing season, fewer GDDs, and dry soil, it may be challenging to accumulate temperature for berry maturation.

The current study did not detect an effect on fruit characteristics, pH, soluble solids, and TA when vines were trained to a divided or undivided trellis system. Additionally, previous studies reported that different trellis systems were not effective for berry quality improvement. For instance, Rice et al. (2017) indicated that there were no significant differences in pH, TA, and Brix for cold-hardy grape, ‘Marquette’, ‘Frontenac’, and ‘St. Croix’ with regard to trellis system. Wolf et al. (2003) stated that different trellis systems in the study did not influence Shiraz cultivar’s pH and Brix values. Additionally, Wimmer et al. (2018) tested GDC, HW, and SH with four different cultivars and reported that there was no difference in results for pH, soluble solids, and titratable acidity when comparing trellis system interaction with different cultivars. Scafidi et al. (2017) applied leaf removal for upper and lower cordons with a control group. The results showed that there were no differences in the control group with upper and lower cordons for fruit composition, but leaf removal affected fruit compositions. Ying Liu et al. (2015) looked at the three different trellis systems and reported that there was significant difference for soluble solids and acidy, but no differences for pH value in the first year of the study. In the second year of study, they did not notice any significant differences in fruit composition for all three-trellis systems.

Table 9. Fruit characteristics evaluation by pH, soluble solids, and titratable acidity for cultivars ‘Marquette’ and ‘Petite Pearl’, trellis systems Geneva Double Curtain, Scott Henry, vertical shoot positioned, and high wire, and the interaction of cultivar by trellis system at Absaraka, ND in 2017 and 2018.

Treatment	pH [1]		Soluble solids		Titratable acidity	
	2017	2018	2017	2018	2017	2018
	-- -log[H+] --		-- °Brix --		--% --	
Cultivars						
Marquette	3.03 b	3.07 b	25.96 a	28.65 a	1.30 b	1.14
Petite Pearl	3.22 a	3.35 a	22.53 b	24.22 b	0.81 a	1.08
P- value	<.0001	<.0001	<.0001	<.0001	<.0001	0.1639
Trellis						
GDC [2]	3.13	3.22	24.88	26.25	1.09	1.01
SH	3.13	3.22	23.68	26.23	1.08	1.11
VSP	3.15	3.19	24.06	26.44	1.04	1.18
HW	3.09	3.22	24.36	26.83	1.00	1.14
P- value	0.1462	0.1526	0.2172	0.5427	0.1824	0.0660
Cultivar*Trellis						
M * GDC	3.02	3.07	26.68	28.52	1.35	1.08
M * SH	3.04	3.09	25.68	28.42	1.25	1.15
M * VSP	3.03	3.05	25.41	28.73	1.27	1.16
M * HW	3.02	3.08	26.07	28.95	1.33	1.17
P.P * GDC	3.23	3.36	23.08	23.98	0.80	0.94
P.P * SH	3.22	3.34	21.68	24.05	0.83	1.07
P.P * VSP	3.28	3.34	22.71	24.15	0.74	1.20
P.P * HW	3.16	3.36	22.65	24.71	0.86	1.12
P- value	0.1742	0.9229	0.7169	0.6168	0.4745	0.5668

[1] Fruit characteristics: pH, Soluble solids and titratable acidity were averages of a 60-berry sample per vine.

[2] Abbreviations GDC=Geneva Double Curtain, SH=Scott Henry, VSP=Vertical Shoot Positioned, HW=High Wire, M=Marquette, P. P= Petite Pearl.

[a,b] Means in a column (year) followed by the different letters are significantly different and means were separated at $P \leq 0.05$ by Tukey’s test.

Table 10. Fruit composition of pH, soluble solids, and titratable acidity for ‘Marquette’, ‘Petite Pearl’ in Absaraka, ND in 2019.

Treatment	pH [1] -- -log[H+] --	Soluble solids -- °Brix --	Titratable acidity --% --
Marquette	2.93*	25.01	0.85
Petite Pearl	3.80	18.64	1.28

[1] Fruit characteristics: pH, Soluble solids and titratable acidity were averages of a 60-berry sample per vine.

*Numbers not calculated statistically due to extensive trunk damage and grapevine loss; the numbers represent the average mean.

CONCLUSION

Under North Dakota's climate condition, a grape producer should consider the influence of extreme and unpredictable cold weather during the growing season to accomplish fruit maturity and maintainable vine longevity, yield and fruit composition. Abrupt temperature swings impact grape production in North Dakota and regions that have similar climatic conditions via minimum temperature severity in the dormant phase of the vine, late spring freeze damage, inadequate length of the growing season, and early fall frost. North Dakota's climate can be categorized by a short growing season (140-143 frost-free days) with growing degree-days (1023-1359 GDD with base temperature of 10°C). Grape yield and fruit composition are frequently restricted by extremely lower winter temperatures, spring freeze, early fall frost with dry and infrequent rainfall during the growing season.

The current study evaluated two cold-hardy grape cultivars, 'Marquette and Petite Pearl', with trellis systems that have two fruit zones, GDC and SH, and trellis systems that have one fruit zone, mid-wire VSP and HW, during production years, in 2017, 2018, and 2019. The results of the study varied for yield components, yield, and fruit composition.

The performance comparison between 'Petite Pearl and Marquette' is important since there is limited information about 'Petite Pearl'. In general, 'Marquette' was slightly better than 'Petite Pearl' for each variable evaluated as a cold-hardy red wine cultivar under North Dakota climate.

The results for comparing vines trained to two fruit zone trellis systems or to one fruit zone trellis systems were significant for yield components and yield the first year of the study. However, in the second year of the study, there were no significant trellis effects apart from fruitfulness and retained nodes. First year results did suggest that high wire trellis systems could be more productive the first year of fruiting by transitioning from a mid-wire trellis the first year of fruiting to a high wire trellis the second year of fruiting. The interaction of cultivars by trellis was not significant for yield components, yield, or fruit composition with the exceptions of berry weight and cluster mass in 2018. Berry weight and cluster mass differences for the interaction of cultivar by trellis systems had no consistent pattern or trend.

As a conclusion, for the experiment conducted under the North Dakota conditions, neither cultivar should be recommended regardless of the trellis system. Selection of a cultivar that can survive is more crucial than selecting a trellis system for grape growers. Recommendation of a trellis system for a particular cultivar requires numerous years in order to take into account vine needs to reach a sustainable yield and ensure continuity of earnings.

REFERENCE

Adam-Blondon, A.F., C. Roux, D. Claux, G. Butterlin, D. Merdinoglu, and P. This. 2004. Mapping 245 SSR markers on the *Vitis vinifera* genome: a tool for grape genetic. Theor Appl Genet.109: 1017–102.

Alikadica A., I. Pertot, E. Eccel, C. Dolcia, C. Zarboa, A. Caffarra, R. D. Filippia, and C. Furlanelloa. 2019. The impact of climate change on grapevine phenology and the influence of altitude: A regional study. Agricultural and Forest Meteorology. Science Direct.271: 73-82.

Amerine, M.A., and Winkler, A.J., 1944. Composition and quality of musts and wines of California grapes. Hilgardia 15: 493-675.

Aradhya M. K., G.S. Dangl, B.H. Prins, J.M. Boursiquot, M.A. Walker, C.P. Meredith, and C.J. Simon. 2002. Genetic structure and differentiation in cultivated grape, *Vitis vinifera* L. Genet. Res., Camb.81: 179–192.

Arroyo-García R., L. Ruiz-García, L. Bolling, R. Ocete, M.A. López, C. Arnold, A. Ergul, G. Söylemezoğlu, H. Uzun, F. Cabello, J. Ibáñez, M.K. Aradhya, A. Atanassov, I. Atanassov, S. Balint, J.L. Cenis, L. Costantini, S. Goris-Lavets, M.S. Grando, B.Y. Klein, P.E. McGovern, D. Merdinoglu, I. Pejic, F. Pelsy, N. Primikirios, V. Risovannaya, KA. Roubelakis-Angelakis, H. Snoussi, P. Sotiri, S. Tamhankar, P. This, L. Troshin, J.M. Malpica, F. Lefort, and J.M. Martinez-Zapater. 2006. Multiple origins of cultivated grapevine (*Vitis vinifera* L. ssp. *sativa*) based on chloroplast DNA polymorphisms. Mol Ecol. 12:3707-14.

Atucha, A., J. Hedtcke, and B. A. Workmaster. 2018. Evaluation of cold-climate interspecific hybrid wine grape cultivars for the upper midwest. Journal of the American Pomological Society. 72(2): 80-9.

Barnuud, N.N., A. Zerihun, F. Mpelasoka, M. Gibberd, and B. Bates. 2014. Responses of grape berry anthocyanin and titratable acidity to the projected climate change across the Western Australian wine regions. Int. J. Biometeorol. 58(6): 1279-1293.

Bavougıan, C. M., P.E. Read., and E. Walter-Shea. 2012. Training system effects on sunlight penetration, canopy structure, yield, and fruit characteristics of 'Frontenac'grapevine (*Vitis* spp.). International Journal of Fruit Science.12: 402–409.

Beltrame, A.P.C.A., R.A.T. Noschang, D.P. Lacerda, L.C. Souza, and I.C.S. Almeida. 2017. Are grape juices more erosive than orange juice? Eur Arch Paediatr Dent.18:263–27.

Boulton, R. 2001. The co pigmentation of anthocyanins and its role in the color of red wine: a critical review. American Journal of Enology and Viticulture.52: 67-87.

Bradshaw, T.L., S.L. Kingsley- Richards, J.Foster, and L.P.Berkett. 2018. Horticultural performance and juice quality of cold-climate grapes in Vermont, USA. Eur. Hortic. Sci. 83:42-48.

Burtch, E. C., A. K. Mansfield, and D.C. Manns. 2017. Reaction kinetics of monomeric anthocyanin conversion to polymeric pigments and their significance to color in interspecific hybrid wines. J. Agric. Food Chem. 65:31.

Carlo, P.D., E. Aruffo, and W. H. Brune. 2019. Precipitation intensity under a warming climate is threatening some Italian premium wines. Science of Total Environment. Volume 685 pages 508-513.

Chaves, M.M., T.P. Santos, C.R. Souza, M.F. Orton, M.L. Rodrigues, C.M. Lopes, J.P. Maroco, and J.S. Pereira. 2007. Deficit irrigation in grapevine improves water-use efficiency while controlling vigor and production quality. Annals of Applied Biology ISSN 0003-4746.150: 237–252.

Dami I. E., S. Ennahli, and Y. Zhang. 2012. Assessment of winter injury in grape cultivars and pruning strategies following freezing stress even. Am. J. Enol. Vitic.63:1. doi: 10.5344/ajev.2011.11040. DOI: https://doi.org/10.20870/oeno-one.2017.51.2.1647

Dami IE and Beam BA. 2004. Response of grapevines to soybean oil application. Am J Enol Vitic 55:269–275.

Dami, I. E., M. A. Ellis, D. C. Ferree, B. Bordelon, M. V. Brown, R. N. Williams, and D. Doohan. 2005. *Midwest Grape Production Guide*. Bulletin 919. Ohio State University Extension.

Dami, I. E. 2014.Improved Grape and Wine Quality in a Challenging Environment: An Eastern US Model for Sustainability and Economic Vitality. USDA- Specialty Crop Research Initiative (SCRI). Annual Progress Repor. The Ohio State University, Department of Horticulture and Crop Science. 7 pp.

Domoto, P., C. Anderson, M. Clark, and I. Geary. 2016. Northern hybrids growing grapes in Minnesota. Minnesota Grape Growers Association. Printed in the United States of America.p.15-43.

Duan, D., D. Halter, R. Baltenweck, C. Tisch, V. Tröster, A. Kortekamp, P. Hugueney, and P. Nick. 2015. Genetic diversity of stilbene metabolism in *Vitis sylvestris.* Journal of Experimental Botany, Molecular Cell Biology, Botanical Institute, German.66:3243–3257.

Duchene, E. 2016. How can grapevine genetics contribute to the adaptation to climate change? International Viticulture Enology Society.50:3.

Esteban, M.A., M. J. Villanueva, and J.R. Lissarrague. 2001. Effect of irrigation on changes in the anthocyanin composition of the skin of cv Tempranillo (*Vitis vinifera L*) grape berries during ripening. Journal of the Science of Food and Agriculture.81:409-420.

Falcão, L.D., E.S. Chaves, V.M. Burin, A.P. Falcão, E.F. Gris, V. Bonin, and M.T. Bordignon-Luiz. 2008. Maturity of cabernet Sauvignon berries from grapevines grown with two different training systems in a new grape growing region in Brazil. Cien. Inv. Agr.35: 271-282.

FAO. 2017. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/QC (Accessed May 2019).

Ferguson, J. C., M. M. Moyer, L. J. Mills, G. Hoogenboom, and M. Keller. 2013. Modeling dormant bud cold hardiness and bud break in twenty-three *Vitis* genotypes reveals variation by region of origin. Am J Enol Vitic.65:59-71. DOI:10.5344/ajev.2013.13098.

Frioni, T., A. Greena, J. E. Emlinga, S.Zhuang, A. Palliottic, P. Sivilottid, R. Falchid, and P. Sabbatini. 2017. Impact of spring freeze on yield, vine performance and fruit quality of Vitis interspecific hybrid Marquette. Scientia Horticultura.219:302–309.

Frioni, T., D. Acimovic, J. V. Weide, S. Tombesi, A. Palliotti, M. Gatti, S. Poni, and Paolo Sabbatini. 2019. Whole-canopy source-sink balance at bloom dictates fruit set in cv. pinot noir subjected to early leaf removal. Am. J. Enol. Vitic. 70:4.

Fulgoni, V. L., J. Painter, and A. Carughi. 2017. Association of raisin and raisin-containing food consumption with nutrient intake and diet quality in US children: NHANES 2001-2012. Food Science and Science. 1:8.

Gao Z., J. Li., H. Zhu, L. Sun, Y. Du, and H. Zhai. 2014. Using differential thermal analysis to analyze cold hardiness in the roots of grape varieties. Scientia Horticulturae.174:155-163.

Gawel, R. P.G. Iland, and I.L. Francis. 2001. Characterizing the astringency of red wine: a case study. Food Quality and Preference.12:83-94.

Guerrini, L., P. Masella., G. Angeloni., L. Calamai., S. Spinelli., S.D. Blasi., and A. Parenti. 2018. Harvest of Sangiovese grapes: the influence of material other than a grape and unripe berry on wine quality. European Food Research and Technology.244:1487-1496.

Hatterman-Valenti, H.M., C.P. Auwarter, and J.E. Stenger. 2016. Evaluation of cold-hardy grape cultivars for North Dakota and the North Dakota State University germplasm enhancement project. Acta Hortic. 1115:13-22.

Hirzel, R.D., K. Steenwerth, S.J. Parikh, and A. Oberholster. 2017. Impact of winery wastewater irrigation on soil, grape and wine composition. Agriculture Water Management.180: 178-189. https://doi.org/10.1016/j.scitotenv.2019.05.449

Howell, G.S. 2001. Sustainable grape productivity and the growth-yield relationship: a review. Am. J. Enol. Vitic. 52:3.

Iland, P.G., N. Bruer, E.Wilkes, and G. Edward. 2004. Anthocyanins (color) and total phenolics of grape berries. Chemical Analysis of Grapes and Wine: Techniques and Concepts.

Kalberer S. R., M. Wisniewski, and R. Arora. 2006. Deacclimation and reacclimation of cold-hardy plants: Current understanding and emerging concepts. Science Direct.171: 3-16.

Karimi, M., A. Ebadi, S.A. Mousavib, S.A. Salamia, and A. Zareic. 2015. Comparison of CBF1, CBF2, CBF3 and CBF4 expression in some grapevine cultivars and species under cold stress. Scientia Horticulturae 197: 521–526.

Karisik, A., O. Rahimi, M. David, E. Weiss, and E. Drori. 2018. Development of a 3D seed morphological tool for grapevine variety identification, and its comparison with SSR analysis. Scientific Reports.8:6545.

Khanduja, S. D, and V.R.Balasubrahmanyam. 1972. The fruitfulness of grapevine buds. Econ. Bot. 26:280–294.

Kovaleskia, A. P., and J. P. Londo. 2019. The tempo of gene regulation in wild and cultivated *Vitis* species shows coordination between cold deacclimation and bud break. Science Direct. Volume: 287. https://doi.org/10.1016/j.plantsci.2019.110178.

Kraus, C., T.P. Ton, K. Herzog, A. Hecht, M. Fischer, R.T. Voegele, C. Hoffmann, R. Töpfer, and A. Kicherer. 2018. Effects of canopy architecture and microclimate on grapevine health in two training systems. Julius Kühn-Institute, Federal Research Centre of Cultivated Plants, Plant Protection in Fruit Crops and Viticulture.57: 53–6.

Krikorian, R., E.L. Boespflug, D.E. Fleck, A.L. Stein, J.D. Wightman, M.D. Shidler, and S. Sadat-Hossieny. 2012. Concord grape juice supplementation and neurocognitive function in human aging. J. Agric. Food Chem. 60: 5736−5742.

Kyraleou, M.S. Kallithraka, S. Koundouras, K. Chira, S. Haroutounian, H. Spinthiropoulou, and Y. Kotseridis. 2014. Vine training system on the phenolic composition of red grapes (*Vitis Vinifera*. Cv. Xinomavro). J. Int. Sci. Vigne Vin.49:71-84.

Leeuwen, C.V., and A. Destrac- Irvine. 2017. Modified grape composition under climate change conditions requires adaptations in the vineyard. OENO One. 51:2.

Londo J.P., A.P. Kovaleski, and J.A.Lillis. 2018. Divergence in the transcriptional landscape between low temperature and freeze shock in cultivated grapevine (*Vitis vinifera*). Horticulture Research. 5:10.

Londo, P. J., and T. Martinson. 2016. Grapevine winter survival and prospects in an age of changing climate. Cornell’s Viticulture and Enology Program.

Luby, J. and P. Hemstad. 2003. Grape plant named ‘Frontenac gris’. USPP16478.

Ma, Z.F. and Zhang H. 2017. Phytochemical constituents, health benefits, and industrial applications of grape seeds: a mini review. Antioxidants Basel. 15:3.

Maiera, T., A. Schiebera, D.R. Kammerera, and R. Carlea. 2008. Residues of grape (*Vitis vinifera L.*) seed oil production as a valuable source of phenolic antioxidants. Food Chemistry.112:551–559.

Manen, J.F., L. Bouby, O. Dalnoki, P. Marinval, M. Turgay, and A. Schlumbaum. 2003. Microsatellites from archaeological *Vitis vinifera* seeds allow a tentative assignment of the geographical origin of ancient cultivars. Journal of Archaeological Science.30:721–729.

Manns, D.C., C.T.M.C. Lenerz, and A.K. Mansfield. 2013. Impact of processing parameters on the phenolic profile of wines produced from hybrid red grapes Marechal Foch, Corot Noir, and Marquette. Dept. of food science, Cornell Univ., New York State Agricultural Experiment Station. 1750:3841.

May, P. 2004. Flowering and fruit set in grapevines. Lythrum Press, Adelaide, Australia.

McGoverna, P., M. Jalabadzeb, S. Batiukc, M. P. Callahand, K. E. Smithd, G. R. Halla, E. Kvavadzeb, D. Maghradzee, N. Rusishvilib, L. Boubyf, O. Faillag, G. Colag, L. Marianig, E. Boarettoi, R. Bacilierij, P. Thijs, N. Walesk, and D. Lordkipanidze. 2017. Early Neolithic wine of Georgia in the South Caucasus. PNAS. E10309–E10318.

Meier, N., T. Rutishauser, C. Pfister, H. Wanner, and J. Luterbacher. 2007. Grape harvest dates as a proxy for Swiss April to August temperature reconstructions back to AD 1480. American Geophysical Union. VOL. 34. L20705. DOI: 10.1029/2007GL031381.

Mills, L.J., J.C. Ferguson, and M. Kelle. 2006. Cold-Hardiness evaluation of grapevine buds and cane tissues. Am. J. Enol. Vitic. 57:2.

Myles, S., A.R. Boyko, C.L. Owens, P.J. Brown, F. Grassi, M.K. Aradhya, B. Prins, A. Reynolds, J.M. Chia, D. Ware, C.D. Bustamante, and E.S. Buckler. 2010. Genetic structure and domestication history of the grape. Proceedings of the National Academy of Sciences of the United States of America. 9:108.

NDAWN Station, North Dakota Agricultural Weather Network, Fargo, ND. (Accessed, March 2020). https://ndawn.ndsu.nodak.edu/station-info.html?station=23

Nile, S.H., S.H. Kim, E. Y. Ko, and S. W. Park. 2013. Effect of irrigation on changes in the anthocyanin composition of the skin of cv Tempranillo (*Vitis vinifera* L) grape berries during ripening. Bio-Med International Research. Article ID 718065. https://doi.org/10.1155/2013/718065.

Pedneault, K., M. Dorais, and P. Angers. 2013. The flavor of cold-hardy grapes: impact of berry maturity and environmental conditions. Agric. Food Chem. 10418:10438.

Perry, R., P. Sabbatini, and J. Burns. 2012. Growing wine grapes in Michigan. Department of Horticulture, Michigan State University. 48824:1325.

Pezzuto, J.M. 2008. Grapes and human health: a perspective. J. Agric. Food Chem. 56: 6777–6784.

Pool, R.M., C. Pratt, and H.D. Hubbard. 1978. Structure of base buds in relation to yield of grapes. Amer. J. Enol. Viticult.29:36–41.

Reynolds, A.G., and J.E.V. Heuvel. 2009. Influence of grapevine training systems on vine growth and fruit composition: a review. Am. J. Enol. Vitic.60:3.

Riaz, S., G. D. Lorenzis, D. Velasco, A. Koehmsted, D. Maghradze ,Z. Bobokashvili, M. Musayev, G. Zdunic, V. Laucou, M. A. Walker, O. Failla, J. E. Preece, M. Aradhya, and R. Arroyo-Garcia. 2018. Genetic diversity analysis of cultivated and wild grapevine (*Vitis vinifera* L.*)* accessions around the Mediterranean basin and Central Asia. BMC Plant Biology.18:137.

Rice, S., J.A. Koziel, M. Dharmadhikari, and A. Fennell. 2017. Evaluation of tannins and anthocyanins in Marquette, Frontenac, and st. Croix cold-hardy-grape cultivars. Interdepartmental Toxicology Graduate Program, Iowa State University.3:47.

Rombaut, N., R. Savoire, B. Thomasset, T. Bélliard, J. Castello, É. V. Hecke, and J. L. Lanoisellé. 2014. Grapeseed oil extraction: Interest of supercritical fluid extraction and gas-assisted mechanical extraction for enhancing polyphenol co-extraction in oil. Comptes Rendus Chimie.17(3): 284-292.

Rubio, S., X. Noriega, and F.J. Péreza. 2019. ABA promotes starch synthesis and storage metabolism in dormant grapevine buds. Journal of Plant Physiology Journal of Plant Physiology. 234–235.

Sabbatini, P., K. Wierba, L. Clearwater, and G.S. Howell. 2015. Impact of training system and pruning severity on yield, fruit composition, and vegetative growth of ‘Niagara’ grapevines in Michigan. International Journal of Fruit Science.15:237–250.

Santos, T., P.Lopes, C. Manuel, A. Rodrigues, M. LucíliaSouza, Cláudia R. S.,Jorge, R.Maroco, J. Pereira, J. S. Chaves, and M.Manuela. 2005. Effects of partial root-zone drying irrigation on cluster microclimate and fruit composition of field-grown Castelão grapevines. Bunde Sanstalt fur Zuechtungs Forschungan Kulturpflanzen.44 (3), 117-125.

Sánchez, L.A and Dokoozlian, N.K. 2005. Bud microclimate and fruitfulness in *Vitis vinifera* LAmer. J. Enol. Viticult. 56: 319-329.

Santos, T., P.Lopes, C. Manuel, A. Rodrigues, M. LucíliaSouza, Cláudia R. S.,Jorge, R.Maroco, J. Pereira, J. S. Chaves, and M.Manuela. 2003. CSIRO. Functional Plant Biology, 30, 663-671.

Scafidi, P., M.G. Barbagallo, A. Pisciotta, M. Mazza, and M.O. Downey. 2017. Defoliation of two-wire vertical trellis: effect on grape quality. New Zealand Journal of Crop and Horticultural Science. 0114-0671.

Scharfetter J., B. A. Workmaster, and A. Atucha. 2019. Preveraison leaf removal changes fruit zone microclimate and phenolics in cold climate interspecific hybrid grapes grown under cool climate conditions. Am. J. Enol. Vitic. 70:3.

Schneider, Y., F. Vincent, B. Durantona, L. Badoloa, F. Gosse, C. Bergmanna, N. Seilera, and F. Raula. 2000. Anti-Proliferative effect of resveratrol, a natural component of grapes and wine, on human colonic cancer cell. Laboratory of Metabolic and Nutritional Control in Digestive Oncolog, France. Cancer Letters.58:85-91.

Schultze, S. R., P. Sabbatini, and L. Luo. 2016. Effects of a warming trend on cool climate viticulture in Michigan, US. Springer Plus. 5:1119. doi 10.1186/s40064-016-2777-1.

Silva, D.F.D., P.T.M. Pintro, L. Bazinet, and C. Couillard. 2015. Effect of commercial grape extracts on the cheese-making properties of milk. J. Dairy Sci. 98: 1552-1562.

Sinanoglou, V. J., P. Zoumpoulakis, C. Fotakis, N. Kalogeropoulos, A. Sakellari, S.Karavoltsos, and I. F. Strati. 2018. On the characterization and correlation of compositional, antioxidant and color profile of common and balsamic vinegars. Antioxidants, MDPI.7 (10):139.

Sun, F., M. L. Roderick, and G. D. Farquhar. 2018. Rainfall statistics, stationarity, and climate change. Institute of Geographic Sciences and Natural Resources Research. PNAS.115:2305–2310.

Terral, J.F., E. Tabard, L. Bouby, S. Ivorra, T. Pastor, I. Figueiral, S. Picq, J.B. Chevance, C. Jung, L. Fabre, C. Tardy, M. Compan, R. Bacilieri, T. Lacombe, and P. This. 2010. Evolution and history of grapevine (*Vitis vinifera*) under domestication: new morphometric perspectives to understand seed domestication syndrome andreveal origins of ancient European cultivars. Annals of Botany.105: 443 – 455.

This, P., T. Lacombe, and M.R. Tomas. 2006. Historical origins and genetic diversity of wine grapes. Trends in Genetic. 22:9.

Ucchesu, M., M. Orrù , O. Grillo , G. Venora , G. Paglietti , A. Ardu, and G. Bacchetta. 2016. Predictive method for correct identification of archaeological charred grape seeds: support for advances in knowledge of grape domestication process. Plosone. 11:2.

USDA-NASS. 2018. Agricultural-State Data. USDA Nat. Agr. Stat. Serv. https://www.nass.usda.gov/ (Accessed May 2019).

Valentini, G., G. Allegro, C. Pastore, E. Colucci, E. Magnanini, and I. Filippetti. 2019. Climate change and vine training systems: the influence different spatial distribution of shoots may have on sugar accumulation in Sangiovese grapevines. BIO Web of Conferences. 13: 04006.

Vanden Heuvel, J.E., J.T.A. Proctor, J.A. Sullivan, and K.H. Fisher. 2004. Influence of training/trellising system and rootstock selection on productivity and fruit composition of Chardonnay and Cabernet franc grapevines in Ontario, Canada. Am. J. Enol. Vitic.55:253-264.

Wang, X., R. D. Bei, S. Fuentes, and C. Collins. 2019. Influence of canopy management practices on canopy architecture and reproductive performance of Semillon and Shiraz grapevines in a hot climate. American Journal of Enology and Viticulture. doi: 10.5344/ajev.2019.19007.

Wightmana, J.D., and R. A. Heuberger. 2014. Effect of grape and other berries on cardiovascular health. J. Sci. Food Agric. 95:1584–1597.

Wimmer, M., B.N. Workmaster, and A. Atucha. 2018. Training systems for cold climate interspecific hybrid grape cultivars in Northern climate regions. Hortechonology. 28:2.

Wolf, T. K., P. R. Dry, P. G.Iland, D. Botting, J. Dick, U. Kennedy, and R. Risti. 2003. Response of Shiraz grapevines to five different training systems in the Barossa Valley, Australia. Australian Journal of Grape and Wine Research.9:82–9.

Wolf, T.K., and M.K. Cook. 1994. Cold hardiness of dormant buds of grape cultivars: comparison of thermal analysis and field survival. HortScience.29 (12): 1453-1455.

Yamakoshi, J., A. Sano, S. Tokutake, M. Saito, M. Kikuchi, Y. Kubota, Y. Kawachi, and F. Otsuka. 2004. Oral intake of pro anthocyanidin-rich extract from grape seeds improves chloasma. Phytother Res. 18(11): 895-9.

Ying Liu, M., M. Chi, H.Y. Tang, C.Z. Song, Z.M. Xi, and Z.W. Zhang. 2015. Effect of three training systems on grapes in a wet region of china: yield, incidence of disease and anthocyanin compositions of *Vitis vinifera* cv. Cabernet Sauvignon. Molecules.20:18967-18987.

Zabadal, T. J. 2007. Winter injury to grapevines and methods of protection. Department of Horticulture Southwest Michigan Research and Extension Center Michigan State University. Extension bulletin E2930 p: 7-14.

Zhang, C., L. Guan, X. Fan, T. Zheng, T. Dong, and C. Liu. 2020. Anatomical characteristics associated with different degrees of berry cracking in grapes. Science Horticulture.261:108992.

APPENDIX

Table A1. ANOVA for pruning weight in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	3384.70061	2.59	0.0343
Trellis	3	2652.91201	2.03	0.1326
Rep*Trellis	21	1048.60784	0.80	0.6957
Cultivars	1	5320.24360	4.07	0.0534
Cultivars*Trellis	3	1189.45376	0.91	0.4488
Error	28	1307.43717	-	-

Table A2. ANOVA for retained number in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	130.7537980	3.80	0.0051
Trellis	3	147.3045516	4.28	0.0132*
Rep*Trellis	21	24.4451682	0.71	0.7890
Cultivars	1	603.3778141	17.52	0.0003*
Cultivars*Trellis	3	16.0309057	0.47	0.7087
Error	28	34.440222	-	-

* Significant at the 0.05 probability level.

Table A3. ANOVA for fruitfulness in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	5.29204621	2.43	0.0442
Trellis	3	3.74127656	1.72	0.1856
Rep*Trellis	21	1.21488728	0.56	0.9137
Cultivars	1	20.35137656	9.36	0.0049*
Cultivars*Trellis	3	0.83864740	0.39	0.7642
Error	28	2.1747690	-	-

* Significant at the 0.05 probability level.

Table A4. ANOVA for berry weight in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.02186696	1.98	0.0936
Trellis	3	0.00901042	0.82	0.4954
Rep*Trellis	21	0.01257351	1.14	0.3676
Cultivars	1	0.74822500	67.84	<.0001*
Cultivars*Trellis	3	0.02418750	2.19	0.1111
Error	28	0.01102902	-	-

* Significant at the 0.05 probability level.

Table A5. ANOVA for cluster mass in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	573.80559	1.38	0.2510
Trellis	3	1410.34877	3.40	0.0314*
Rep*Trellis	21	343.22259	0.83	0.6690
Cultivars	1	12881.96625	31.06	<.0001*
Cultivars*Trellis	3	39.28486	0.09	0.9623
Error	28	414.76209	-	-

* Significant at the 0.05 probability level.

Table A6. ANOVA for cluster number in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	84.315279	0.52	0.8122
Trellis	3	1836.892554	11.32	<.0001*
Rep*Trellis	21	195.221899	1.20	0.3197
Cultivars	1	549.785256	3.39	0.0763
Cultivars*Trellis	3	131.004169	0.81	0.5006
Error	28	162.33596	-	-

* Significant at the 0.05 probability level.

Table A7. ANOVA for yield in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.11860156	0.16	0.9914
Trellis	3	4.17578073	5.56	0.0040*
Rep*Trellis	21	0.59190573	0.79	0.7104
Cultivars	1	5.03441406	6.70	0.0151*
Cultivars*Trellis	3	1.00112656	1.33	0.2837
Error	28	0.75124844	-	-

* Significant at the 0.05 probability level.

Table A8. ANOVA for pH in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.00388571	0.72	0.6558
Trellis	3	0.01046250	1.94	0.1462
Rep*Trellis	21	0.00531964	0.99	0.5058
Cultivars	1	0.62015625	114.95	<.0001*
Cultivars*Trellis	3	0.00959375	1.78	0.1742
Error	28	0.00539509	-	-

* Significant at the 0.05 probability level.

Table A9. ANOVA for total soluble solid in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	1.2825000	0.49	0.8323
Trellis	3	4.1100000	1.58	0.2172
Rep*Trellis	21	2.4558333	0.94	0.5498
Cultivars	1	188.3756250	72.26	<.0001*
Cultivars*Trellis	3	1.1822917	0.45	0.7169
Error	28	2.6070536	-	-

* Significant at the 0.05 probability level.

Table A10. ANOVA for titratable acidity in Absaraka, ND, in 2017.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.03557411	2.20	0.0653
Trellis	3	0.02809688	1.74	0.1824
Rep*Trellis	21	0.02286027	1.41	0.1944
Cultivars	1	3.90556406	241.34	<.0001*
Cultivars*Trellis	3	0.01387969	0.86	0.4745
Error	28	0.01618292	-	-

* Significant at the 0.05 probability level.

Table A11. ANOVA for pruning weight in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	16154.3980	2.59	0.0344
Trellis	3	4599.9285	0.74	0.5390
Rep*Trellis	21	6495.4928	1.04	0.4541
Cultivars	1	58712.3188	9.40	0.0048*
Cultivars*Trellis	3	2635.2649	0.42	0.7387
Error	28	6244.3643	-	-

* Significant at the 0.05 probability level.

Table A12. ANOVA for retained node number in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	27.582276	1.88	0.1116
Trellis	3	50.717025	3.45	0.0298*
Rep*Trellis	21	12.719719	0.87	0.6289
Cultivars	1	1423.901924	96.90	<.0001*
Cultivars*Trellis	3	39.449029	2.68	0.0658
Error	28	14.694314	-	-

* Significant at the 0.05 probability level.

Table A13. ANOVA for fruitfulness in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.29463728	1.86	0.1148
Trellis	3	0.62325990	3.93	0.0184*
Rep*Trellis	21	0.17052299	1.08	0.4214
Cultivars	1	0.36753906	2.32	0.1389
Cultivars*Trellis	3	0.01366406	0.09	0.9670
Error	28	0.15842567	-	-

* Significant at the 0.05 probability level.

Table A14. ANOVA for berry weight in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.00595513	0.84	0.5661
Trellis	3	0.00733906	1.03	0.3937
Rep*Trellis	21	0.00766644	1.08	0.4202
Cultivars	1	0.16301406	22.92	<.0001*
Cultivars*Trellis	3	0.02885156	4.06	0.0164
Error	28	0.00711362	-	-

* Significant at the 0.05 probability level.

Table A15. ANOVA for cluster mass in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	288.11872	1.17	0.3489
Trellis	3	660.74049	2.69	0.0653
Rep*Trellis	21	502.56441	2.05	0.0385
Cultivars	1	6393.40170	26.05	<.0001*
Cultivars*Trellis	3	1325.04752	5.40	0.0046*
Error	28	245.46029	-	-

* Significant at the 0.05 probability level.

Table A16. ANOVA for cluster number in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	116.193037	1.72	0.1451
Trellis	3	74.974577	1.11	0.3619
Rep*Trellis	21	35.988585	0.53	0.9299
Cultivars	1	3395.247227	50.23	<.0001*
Cultivars*Trellis	3	33.572535	0.50	0.6876
Error	28	67.594494	-	-

* Significant at the 0.05 probability level.

Table A17. ANOVA for yield in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.64270625	1.58	0.1836
Trellis	3	0.95672292	2.35	0.0942
Rep*Trellis	21	0.25629673	0.63	0.8620
Cultivars	1	3.11522500	7.64	0.0100*
Cultivars*Trellis	3	0.50089167	1.23	0.3179
Error	28	0.40773929	-	-

* Significant at the 0.05 probability level.

Table A18. ANOVA for pH in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.6256920	0.98	0.4663
Trellis	3	1.2151562	1.90	0.1526
Rep*Trellis	21	0.8312277	1.30	0.2554
Cultivars	1	314.6189062	491.85	<.0001*
Cultivars*Trellis	3	0.1018229	0.16	0.9229
Error	28	0.6396652	-	-

* Significant at the 0.05 probability level.

Table A19. ANOVA for total soluble solid in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.02619442	8.79	<.0001*
Trellis	3	0.00217656	0.73	0.5427
Rep*Trellis	21	0.00577537	1.94	0.0512
Cultivars	1	1.21826406	408.67	<.0001*
Cultivars*Trellis	3	0.00180573	0.61	0.6168
Error	28	0.00298103	-	-

* Significant at the 0.05 probability level.

Table A20. ANOVA for titratable acidity in Absaraka, ND, in 2018.

Source of variation	Degrees of freedom	Mean square	F- value	P- value
Replication	7	0.04296224	1.47	0.22
Trellis	3	0.07893320	2.69	0.0660
Rep*Trellis	21	0.01574691	0.54	0.9261
Cultivars	1	0.06004844	2.05	0.1639
Cultivars*Trellis	3	0.02019557	0.69	0.5668
Error	28	0.02931903	-	-

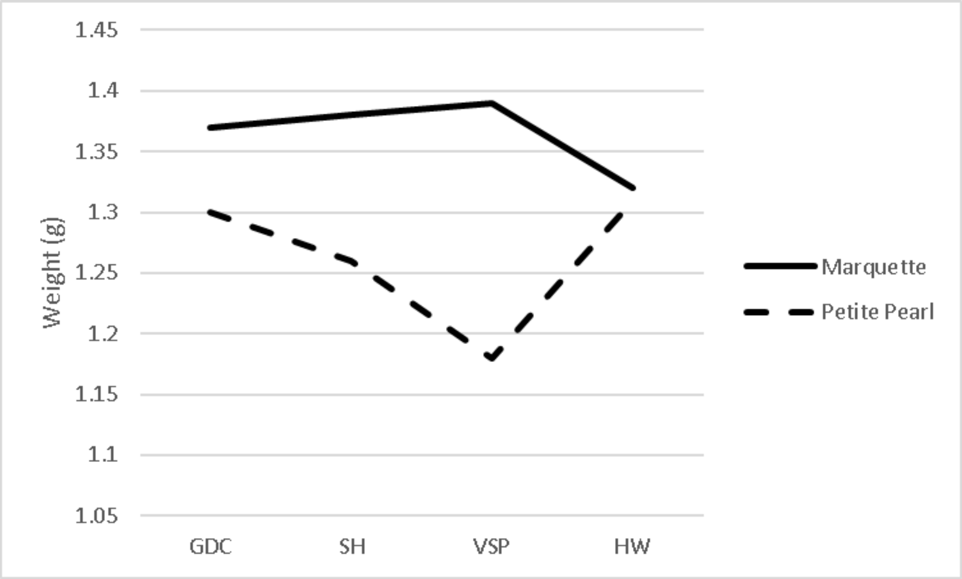

Figure A1. Illustration of the interaction of cultivar by trellis system for berry weight in 2018. Abbreviations GDC=Geneva double curtain, SH=Scott Henry, VSP=vertical shoot position, HW=high wire.

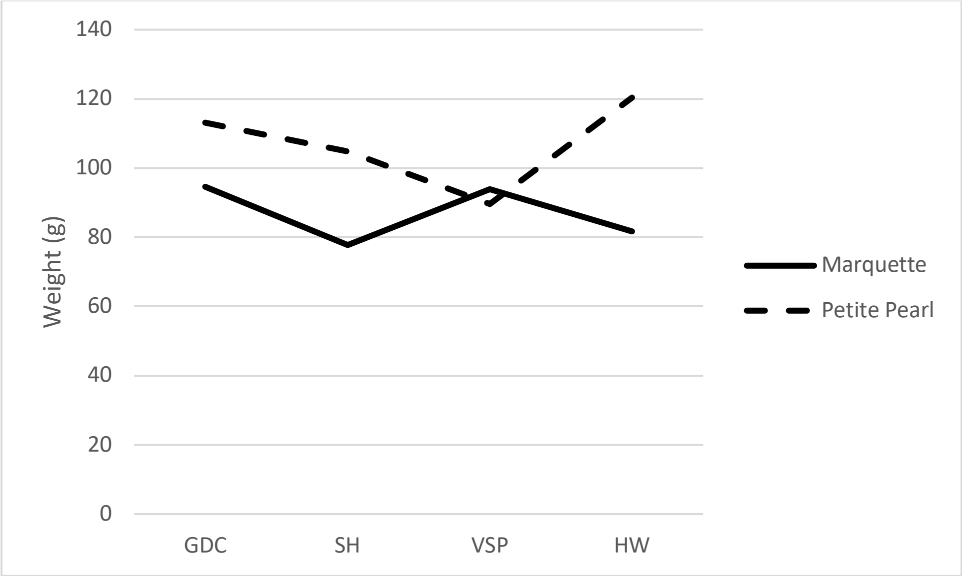

Figure A2. Illustration of the interaction of cultivar by trellis system for cluster mass in 2018. Abbreviations GDC=Geneva double curtain, SH=Scott Henry, VSP=vertical shoot position, HW=high wire.