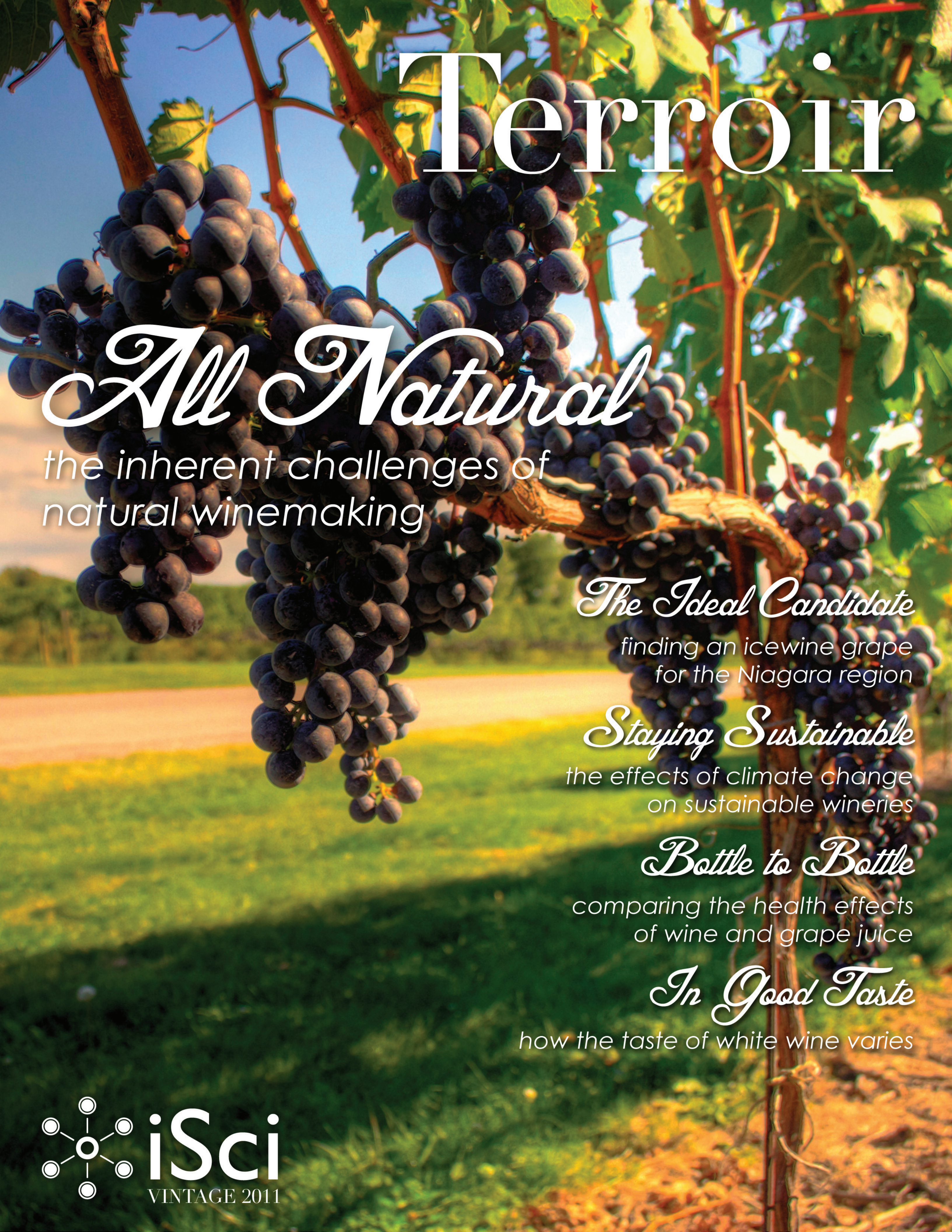

Terroir

All Natural
the inherent challenges of natural winemaking

The Ideal Candidate
finding an icewine grape for the Niagara region

Staying Sustainable
the effects of climate change on sustainable wineries

Bottle to Bottle
comparing the health effects of wine and grape juice

In Good Taste
how the taste of white wine varies

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Terroir

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WINE SCIENCE

HOW CAN SOMETHING THAT TASTES SO GOOD BE SO INTERESTING SCIENTIFICALLY?

This Publication is written by members of the ISCI 3A12 class of 2011

Working in small groups, students in ISCI 3A12 examined the science behind wine making, from the art of viticulture to its eventual consumption by the public. Students performed literature-based reviews and original research in order to understand the wine industry and its complexity; including the environmental requirements and consequences of winemaking, the short- and long-term health effects of drinking wine, and what factors contribute to the quality, aroma, and taste of wine. This research was formatted to resemble a publicly accessible scientific article, and compiled to create each Vintage of *Terroir*.

We hope you enjoy reading this publication.

For more information about the project or to obtain additional copies of *Terroir* please contact Sarah Robinson at isci@mcmaster.ca

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E BOTTLE

Determining an Ideal Icewine Cultivar for the Niagara Region

S. Barkley,[1] K. Costa,[1] E. Kramer,[1] A. Pantaleo,[1] D. Rosati[1]

The Niagara Peninsula of Ontario, Canada is a uniquely situated cool climate viticultural region that could benefit from focusing production efforts on a single cultivar to increase visibility of its wines in the global market. Determining if such an ideal cultivar exists requires an analysis of the region's growing conditions, particularly its soils and climate. Niagara is an excellent region for the production of icewine, which has the highest potential for increased global sales as a signature Canadian wine. In particular, Riesling is very well suited to Niagara's cool climate and has considerable international appeal. This makes it a promising target for future viticultural efforts in the Niagara Peninsula.

The ancient practices of grape growing and winemaking – viticulture and enology – comprise a delicate balance between well-established traditions and individual preferences that differ between viticultural areas. Of the winemaking regions around the world, the Niagara Peninsula is unique for its cool climate, fertile soils, and diverse productivity. Every year, the Niagara region produces more than 18 million litres of wine, resulting from the production of close to 40 different varietals, including Chardonnay, Pinot Noir, Riesling, Cabernet Franc, Merlot, Cabernet Sauvignon, Vidal, and Gewürztraminer (*1*). Many factors affect these cultivars' ability to grow in a given region, including climate, soil conditions, and disease susceptibility (*2*). Information about these factors, along with market demand statistics, can be used to predict which cultivars will grow best in the Niagara region and whether there is a single cultivar that is most likely to thrive in Niagara in terms of both viticulture and marketability. This analysis then raises the question of whether focusing production on a single cultivar best suited to the region could optimize Niagara's wine production and make Niagara's wines more competitive in a global market. Our review will explore this question through an analysis of Niagara's growing conditions, the growing requirements of cultivars, and the current market status of Ontario wines.

GEOLOGIC AND CLIMATIC CONDITIONS IN NIAGARA

The Vintner's Quality Alliance (VQA), Ontario's regulating body for wine production, has divided the Niagara Peninsula into ten sub-appellations (Fig. 1), which are regions that possess a distinct terroir or "character" of wine as influenced by the climate, soil, and geology of the region (*3, 4*). Half of Niagara's sub-appellations consist mainly of clay loam till with less silts and sands, while the remaining sub-appellations have greater variability and contain more gravels and sands interspersed with clay loam.

The VQA soil data can be combined with information from the Canadian Ministry of Agriculture's 1989 soil survey of the Niagara region (*5*) and with an earlier study by Haynes (*6*) to provide a more detailed overview of soil types. The data generally agree with each other, supporting the VQA's soil descriptions while emphasizing the small-scale variations present. Since sub-appellations are also designated based on climatic and geologic factors, they only provide an approximation of soil properties in Niagara.

Soils can influence the productivity of cultivars as well as the characteristics of wines produced from those cultivars. In particular, yield and grape quality are directly affected by the amount of water available to the roots. Vines grown on thick, fine-grained soils where the water table is close to the surface are generally more vigorous than vines grown in thin, coarse-grained soils with lower porosity (*7, 8, 9*). However, more vigorous vines often produce lower quality grapes that contain reduced concentrations of compounds that positively contribute to the flavour and aroma of a wine, including sugars and anthocyanins (*7*). Although the Niagara region is dominated by clay soils (*3, 5, 6*), small-scale variations within sub-appellations may significantly affect grapevine productivity. This reduces the effectiveness of assessing cultivar

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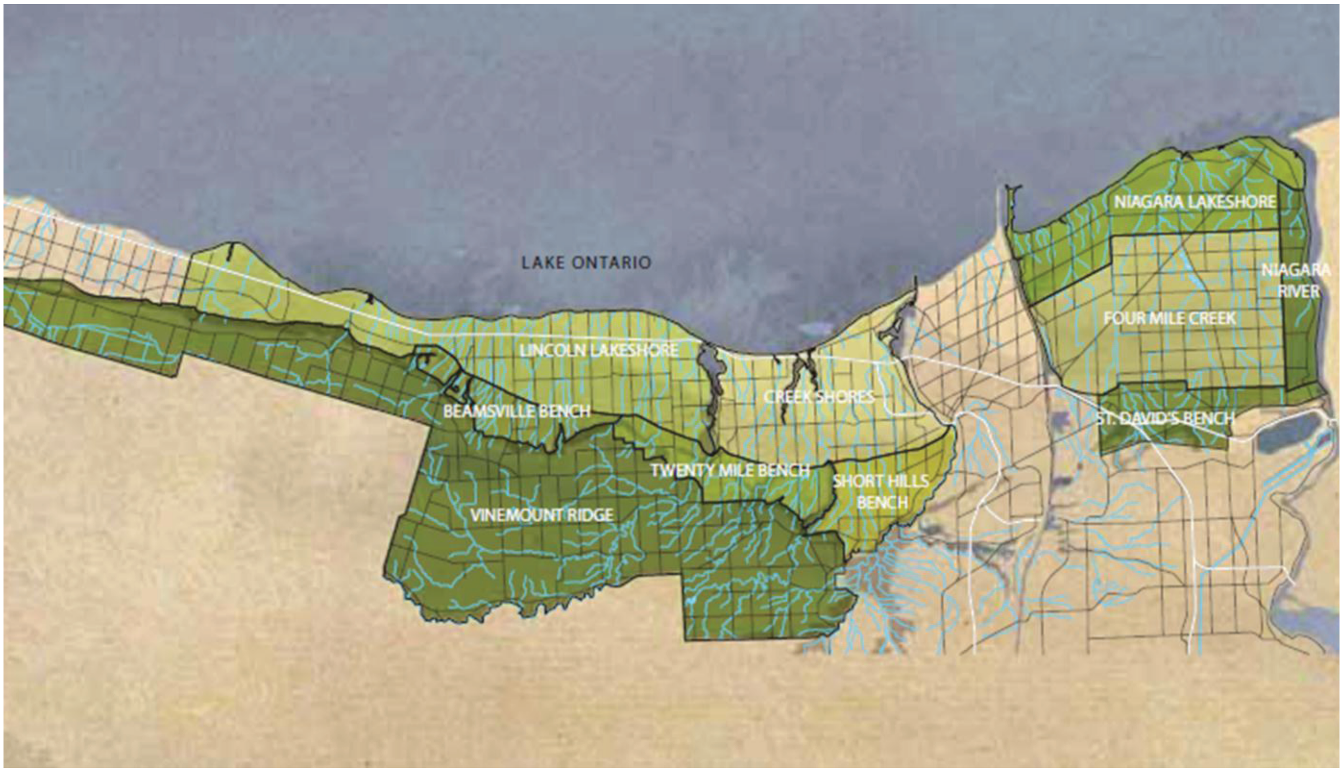

Figure 1: Boundaries of the ten sub-appellations identified by the VQA within the Niagara region *(3)*.

suitability through analysis of sub-appellations alone.

The Niagara region also experiences highly variable daily weather conditions. Summer weather is dominated by tropical air masses, resulting in hot and humid conditions (*10*). Most precipitation during these months is due to convective systems over warm land masses, but occasional cold fronts bring precipitation to the entire region and decrease humidity (*10*). In autumn, the stable conditions of the summer can deteriorate quickly as polar air masses start moving into the Great Lakes region. Storms originating in the Midwest can travel up the Ohio Valley to Niagara, resulting in cold and wet conditions (*10*). Winter weather is typically cold, but is punctuated by sudden increases in regional temperature and widespread thawing when subtropical air masses are carried into the Great Lakes region and replace the customary polar air masses. Cold Arctic air masses often move south immediately after these warm spells, leading to severe drops in temperature (*10*). Winter precipitation consists mainly of snow.

Most regions at Niagara's latitude experience very hot summers and frigid winters, and thus are not suitable for growing grapes (*11*). However, Niagara Peninsula temperatures are regulated throughout the year by Lake Ontario and the Niagara Escarpment. Lake Ontario's small surface area and appreciable depth, is particularly effective at storing heat (*10*). During autumn, heat stored in the lake extends the growing season by maintaining air temperatures above the 10 °C minimum required for grape metabolism (*10, 12*). Since only 24% of Lake Ontario's surface freezes in an average winter, the exposed water moderates temperatures throughout the season (*10*). Normally, these effects prevent the temperature from dropping below -20 °C, the critical temperature below which most grapevines sustain damage (*2*). However, in the event of an especially cold winter when more than 95% of the lake's surface is frozen, Lake Ontario allows much colder winds to blow in from the north (*10*). In spring, Lake Ontario warms slowly and reduces temperature fluctuations, which delays the opening of buds on grape vines until after the last spring frost. Finally, high summer temperatures that could lead to water stress are moderated by cool air from Lake Ontario. Lake Erie has similar effects on Niagara Peninsula temperatures, although they are not as pronounced (*10*).

Varietal	Icewine Production (Litres)	Table Wine Production (Litres)	Potential Production If Used Only for Table Wines $Litres\ of\ Table\ Wine + \frac{Litres\ of\ Icewine}{0.15}$
Vidal	1 486 919	2 260 649	12 173 442
Riesling	335 275	6 580 241	8 815 408
Cabernet Franc	258 775	5 419 474	7 144 641

Table 1: VQA icewine and table wine production of selected varietals for April 2009-September 2011.

Lake Ontario is surrounded by the 30-50 metre high Niagara Escarpment. The Niagara wine growing region lies principally between the escarpment and the lake, with north-facing slopes of roughly 3% gradient (*10*). This sloping ground effectively "drains" low density cold air away from the escarpment in the winter. The escarpment also reduces local wind speeds through creation of an air cushion 0.3-2.5 kilometre from its base that acts as a buffer for incoming wind. Finally, the escarpment creates a convection current that sends cool air back towards the lake and allows warm air to replace it, further increasing the average winter temperature (*10*).

The effect of Lake Ontario and the Niagara Escarpment, along with the region's soil properties, influence which cultivars are able to grow in Niagara successfully. Although several cultivars can survive these conditions, Niagara's cool climate is best suited to cold-hardy cultivars with a short growing season.

ICEWINE: CULTIVARS AND GROWING CONDITIONS

Cultivars that can survive in cooler regions are well suited to the production of icewine, a specialty product that is enjoyed by consumers around the world. Icewine is a unique type of wine produced from grapes that are left on the vine to overripen until they are frozen (*13*). Although icewine (or "eiswein") originated in Germany, the climate of the Niagara region is better suited to its production as German and Austrian winters are sometimes too mild for icewine production (*6, 13*). Niagara's summer temperatures are high enough for grapes to fully ripen, and its winter temperatures are cold enough for grapes to freeze completely, but Lake Ontario and the Niagara Escarpment mitigate the occurrence of extremely cold conditions that damage vines (*10*).

In Ontario, VQA regulations require that a very specific process be followed for icewine production. Grapes are left to overripen on the vine after the growing season has finished, allowing excess sugar and acid to accumulate (*6, 13*). According to VQA standards, the grapes must be kept at or below -8 °C for a sustained period of time, with the ideal freezing temperature between -12 °C and -10 °C (*13, 14*). This temperature must be naturally maintained while the grapes are pressed, so grapes are often harvested and pressed in the middle of the night. Most of the water in the grapes is left behind as ice crystals, and the small quantity of juice extracted is extremely concentrated. Fermentation results in a sweet, aromatic wine with high acidity and high alcohol content (*6, 13*).

Varietals are selected for icewine based primarily on their taste and on consumer demand. Since icewine grapes remain on the vine for a long period of time and endure low temperatures, they must have certain characteristics. It is important that the grapes are cold tolerant, that they have relatively thick skin, that the skin cannot be punctured easily, and that the berries cannot be easily detached from the pedicel (the stem that attaches a grape to the bunch) (*15*).

The Niagara region produces more Vidal icewine by volume than it does any other varietal, followed by Riesling and Cabernet Franc (Table 1). More Riesling table wine is produced in the Niagara region than Vidal or Cabernet Franc. The total volume of all Riesling wine produced is greater than that of Vidal or Cabernet Franc, but this comparison does not account for the fact that grapes used for icewine only produce 15% of the yield that they would produce if used for table wine (*13, 1*). When this factor is accounted for, it seems more Vidal grapes are used in the Niagara region than Riesling or Cabernet Franc grapes (Table 1).

Due to the popularity of icewine in the global market, only the three varietals discussed above will be considered when analyzing whether a single varietal should be mass produced in Niagara. Factors that influence a cultivar's suitability include adaptations to Niagara's cool climate, resistance to fungal diseases, and marketability on a global scale. Only through consideration of these factors can it be decided which cultivars best represents an ideal grape for the Niagara region.

CULTIVAR SUITABILITY TO NIAGARA

To evaluate the cold hardiness of different cultivars, it is necessary to understand how grapevines are damaged by cold and the means by which they are able to protect themselves. Cold damage occurs when water within plant cells freezes and expands, bursting and killing the cells. Although growing grapevine tissue can be killed when temperatures fall below -2 °C, dormant tissue can survive much lower temperatures (*16*). The most susceptible organs of dormant plants are the buds that will form the following year's leaves and flowers. A vine that experiences bud loss can partially compensate through increased growth of surviving buds, but these buds will grow with undesirable geometries. Winter pruning is conducted to optimize plant growth and fruit production based on anticipated shoot development, so a change in geometry can significantly compromise vine productivity (*2*). A vine that loses nearly all of its buds will have greatly reduced productivity and yield, but can survive and be restored to good health if the following winter is not as severe.

Grapevines have a number of defences that allow them to minimize cold damage. These mechanisms, which involve decreasing the water content of tissues, allow European *Vitis vinifera* grapes to withstand temperatures of -20 °C, while a North American *V. riparia* can survive temperatures as low as -40 °C (*10, 16*). The most important defence is the bulk accumulation of cryoprotectants inside plant cells. These compounds, which include raffinose (a complex sugar), proteins, and other molecules, decrease cytoplasm freezing temperature by increasing the solute concentration within the cell. Grapevines also interrupt circulation from the roots to the rest of the plant by sealing transport vessels with the polymer suberin, which prevents water from travelling into the plant during a winter warm spell (*2*). Different species of grapes, and different cultivars within the species *V. vinifera*, demonstrate these cold-tolerance adaptations to varying degrees and thus differ in their cold hardiness.

Vines sustaining cold damage rarely do so during the coldest parts of the year because they are already well acclimated during these periods. Acclimation is driven by changing day length and is characterised by a decreasing growth rate, onset of dormancy, and reduction of tissue water concentration. Accumulation of cryoprotectants requires weeks, and so a sudden cold snap in early winter can be lethal to grapes (*2*). Even more important is deacclimation time, the time required for a grapevine to initiate growth and become more susceptible to cold damage after the onset of warm temperatures (*16*). Deacclimation time is usually on the order of days and can sometimes occur during a warm spell in January or February, with devastating results when cold weather returns (*2*). Acclimation and deacclimation times are particularly relevant for viticulture in Niagara because of the region's considerable fluctuations in winter and spring temperatures. Grapes grown in Niagara should have a long deacclimation time to prevent premature revival from dormancy. Additionally, they should have a fairly brief growing season, as grapes have very little metabolic activity below 10 °C and will not ripen at temperatures below this threshold (*12*).

The three varietals used to produce the majority of icewine in Niagara are all relatively cold hardy. Because Vidal is a hybrid between *V. vinifera* and a North American grape, it exhibits some characteristics of its North American parentage. These include high productivity and an increased rate of sugar and acid production in the fruit, which makes this cultivar suitable for regions with a short growing season (*17, 18*). Cabernet Franc is closely related to Cabernet Sauvignon, but has a slightly different flavour and is consistently more cold hardy. In fact, Cabernet Franc was the most cold hardy red *V. vinifera* cultivar tested in one study, with cold hardiness comparable to the white grapes Vidal and Riesling (*18*). Cabernet Franc ripens earlier than most grapes used for red wine, but also buds earlier, which increases the risk of frost damage (*17*). Riesling is a white *V. vinifera* grape of German origin that is exceptionally cold hardy, but is also grown in warmer climates such as California because of its popularity (*17*). Numerous studies have found that Riesling is more cold tolerant than Cabernet Franc or other *V. vinifera* varieties and also deacclimates more slowly in the spring, which is a very desirable trait for growth in Niagara (*12, 17, 19*).

Low temperatures are not the only stresses faced by grapevines growing in Ontario. Fungal infections, the most threatening being botrytis and powdery mildew, are notoriously difficult to control in Niagara (*12*). High levels of precipitation and humidity result in conditions that promote fungal infection (*10*). Different cultivars have varying susceptibilities to fungal diseases, although there is little scientific consensus regarding the details of these differences (*17, 18*). Generally, Riesling is least resistant to fungal infection and Cabernet Franc is most resistant, with Vidal somewhere in between (*18*). The exception to this general rule is the important fungal pathogen botrytis, for which Vidal is least susceptible as a hybrid cultivar (*18*).

Soil types are not of primary importance when selecting a cultivar as all *V. vinifera* grapes are planted on genetically distinct rootstocks that interact directly with the soil and mediate the interaction with the grafted vine. Soil properties are very relevant when selecting a rootstock, but do not impact the grafted vine significantly. Nevertheless, some evidence suggests that Riesling performs better in well drained soils, while Cabernet Franc can withstand wetter conditions (*17*).

CULTIVAR MARKETABILITY

In addition to their compatibility with the Niagara environment, these cultivars must also be evaluated for their desirability and popularity among consumers. All three cultivars produce successful, in-demand varietal wines and account for the greatest volume of icewine produced in Niagara (Table 1) (*1*). In terms of Niagara table wine production, Riesling constitutes the second largest volume of wine, Cabernet Franc the third largest, and Vidal the sixth. These data provide evidence that all three cultivars are hardy enough to be grown in Niagara and also indicate sufficient demand to make their production profitable.

Due to Ontario's low wine exports (*20*), Ontario customers currently account for the majority of Niagara wine sales. In the most recent annual report from the LCBO (2009-2010), VQA table wine sales increased by 19% and are predicted to continue increasing (*21*). In a report on improving Canadian wine exports, officials proposed that icewines have the greatest marketing and sales potential and that varietals currently used for both icewines and table wines should be a focus for Canadian growth. The report specifically suggested that Riesling and Cabernet Franc would be best suited to this focus (*22*).

Of the three cultivars best suited for icewine production, all are exceptionally cold hardy, although Riesling deacclimates most slowly in spring and thus has a lower risk of cold damage. Generally, Cabernet Franc is most resistant to fungal infection and Riesling is the most susceptible. All three are used to produce significant quantities of both icewine and table wine in Niagara, although Riesling and Cabernet Franc are much more popular globally as *V. vinifera* varietals (*17*).

RIESLING: THE VARIETAL OF CHOICE

When all of these factors are considered, Riesling emerges as the cultivar best suited for mass-production in the Niagara Peninsula. It has one of the highest cold tolerances and a long deacclimation time, both of which are ideal for the cool climate of Niagara (*19*). Reports from the VQA also show consistently high production of Riesling wines in Ontario, indicating a continued demand for both icewine and table wine products (*23*). Because icewine is an important export for the Canadian wine industry (*20, 24*), selecting a cold hardy varietal that produces quality icewine is of great importance. Cabernet Franc has a similar duality of use, being successfully produced as both a table wine and an icewine. However, it is not nearly as popular as Riesling in the global market. Vidal, while a successful icewine grape, is a hybrid grape and has little consumer demand as a table wine in Ontario and remains largely unheard of outside of North America (*17*). Riesling's versatility, cold tolerance, and popularity combine to make it a cultivar that is very well suited to the Niagara region. It has the potential to promote Canadian icewines and table wines worldwide, providing further stimulus for major production (*22*). This has not yet occurred because individual vineyards select cultivars to be grown based on current demand, which is restricted to the Ontario market and favours production of multiple varietals. If the Niagara wine industry as a whole wishes to increase its presence on a global scale, it should consider focusing efforts on varietals and products that are more desirable internationally. Such a plan is under development by the Ontario Government in cooperation with the VQA, for release in the near future (*25*).

CONCLUSION

As the Niagara wine industry continues to evolve and gain international recognition, winemakers must strive to further promote Niagara wine as a distinct, unique product comparable to the wines produced in Europe. Grape growers in Niagara face unique challenges because of the region's short growing season, cold climate, and humidity. Through critical analysis of Niagara's soil and climate, the cold hardiness and disease tolerance of cultivars, and current production statistics, Riesling becomes the cultivar of choice for the Niagara region. Riesling is the best choice not only because it grows very well in Niagara, but also because it has the greatest potential for success: Riesling can thrive in the growing Ontario market through the production of table wines and succeed internationally through the production of high quality icewines. During this time of growth in the local wine industry, Riesling could be the cultivar that shapes Niagara's identity as a winemaking region.

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A Comprehensive Review of Climate Change and its Effects on the Sustainability of Wineries in the Niagara Region

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Climate change has the potential to greatly impact the sustainability of the global wine industry. Changing climatic patterns will threaten the viability of growing winegrapes. Increasing temperature means and variability will impact the winegrape varietals that can be grown in a region. Changing precipitation trends may affect water availability and by extension water usage and financial viability of growing winegrapes. The changing effects of temperature and precipitation may further affect both the quantity of crop yields and the quality of wine produced. An examination of the Niagara Region illustrates these potential impacts and the financial implications for local wineries. In order to minimize the impacts of the changing climate, adapting agricultural practices and financial safeguards is necessary for the continued sustainability of the industry.

Glossary

Varietal

Describes the grape variety used to make a certain wine. Examples: Chardonnay, Merlot, Pinot Nior.

Wine styles

Types and flavours of wine based on palate structure, flavour quality and flavour quantity. These components affect the overall balance of the wine.

Phenological Timing

The specific timing of different life cycles.

Véraison

"Pre-ripening" phase, the fruit loses chlorophyll (green berries) and some of the fruit develops colour (red grapes).

Degree-days

An indication of the number of growing days during the year. Computed by taking the integral over time of the daily temperature throughout the growing season.

Introduction

Climate change is a global phenomenon that not only has large-scale implications but small-scale local impacts as well. The agricultural industry is particularly sensitive to changes in climate because crops require specific conditions in order to grow successfully. The narrow climate zones for growing winegrapes are especially susceptible to these changes. Specifically, changes in temperature and precipitation patterns affect how well the winegrapes are able to grow and mature. Vineyards and wineries must modify their practices to account for the potential impacts of climate change. This adaptability is essential because certain economies rely heavily on wine production. In Ontario, the Niagara Region (Fig. 1) produces over 90% of wine by volume (*1*). Thus, vintners must consider the unique characteristics of the region in order to ensure economic and environmental viability.

Overview

The wine industry is a dynamic and ever-changing business that is influenced by many different factors, including climate, geology, consumer interest, and global competition. Climate is an especially important factor shaping the wine industry, because growing winegrapes is fundamentally controlled by the environment. Climate change is one of the most important issues that the industry, and the whole world, is currently facing.

What is climate change?

According to the Government of Canada, climate change is "a long-term shift in climate measured by changes in temperature, precipitation, winds, and other indicators" (*2*). Many aspects of our lives, including our economy and agriculture, can be impacted by climate change. The wine industry will be affected by climate change because the ability to grow winegrapes is heavily dependent on environmental factors, including temperature and precipitation. Grape-growing regions tend to be within small ecological niches. The growing conditions in these regions are very specific, so slight changes put these regions "at greater risk from both short-term climate variability and long-term climate change" (*3*). The degree to which climate change will influence the wine industry in the future is impossible to determine; however there are some models that predict changing temperature zones around the globe and how this will influence **varietals** grown in a given area (*3*). In the past 50 years, the global wine industry has mostly benefited from an increase in temperature due to a broadening ability to grow different varietals. Despite this, changing temperature patterns could also negatively impact winegrape growing by introducing new challenges (*3*).

What is sustainability?

Climate change is strongly linked to sustainability, especially in the agricultural and wine industries. There are

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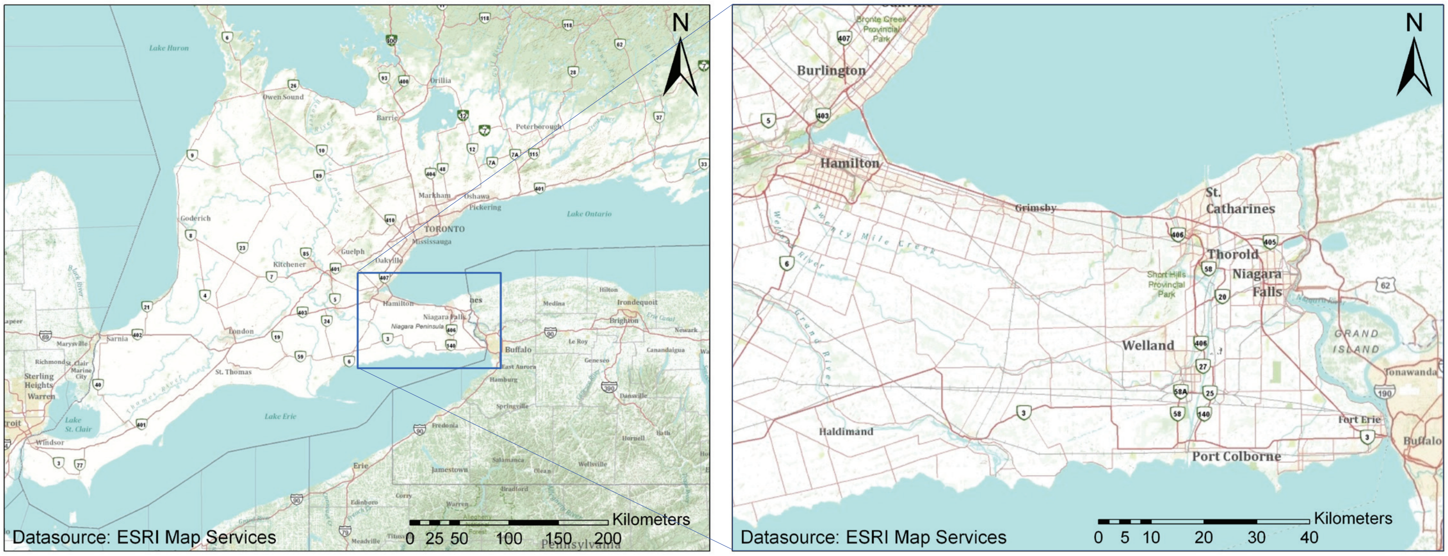

Fig. 1. The Niagara Peninsula in relation to southern Ontario. The peninsula is bounded by Lake Ontario to the north, the Niagara River to the east, and Lake Erie to the south, and contains the Niagara Escarpment that runs east from Hamilton across the peninsula past St. Catharines.

many sides to the term sustainable, but two are especially important to the wine industry. In areas such as California, sustainable is a description for environmentally friendly practices, and is used by vintners who look closely at their agricultural techniques and their impact on the environment (*4*). Conversely, the term sustainable is also used to describe environmental viability, in terms of how long a vineyard can continue to produce quality winegrapes. This concept is especially relevant to the wine industry in terms of the economic success of individual vineyards.

Climate change combined with an expanding global wine marketplace is putting certain regions and wine industries under pressure as to whether they will be able to grow grapes and continue to be prosperous in the future (*5*). Climate change will add to pressures on the wine industry because water usage, **phenological timing**, and composition of wines will all be affected. Ultimately, this will change the types of wines that are produced, because of shifting regional **wine styles** and shifting regions that are viable for growing each winegrape varietal (*3*). These pressures will ultimately determine whether certain wine making regions of the world can be both environmentally and economically sustainable in the long-term.

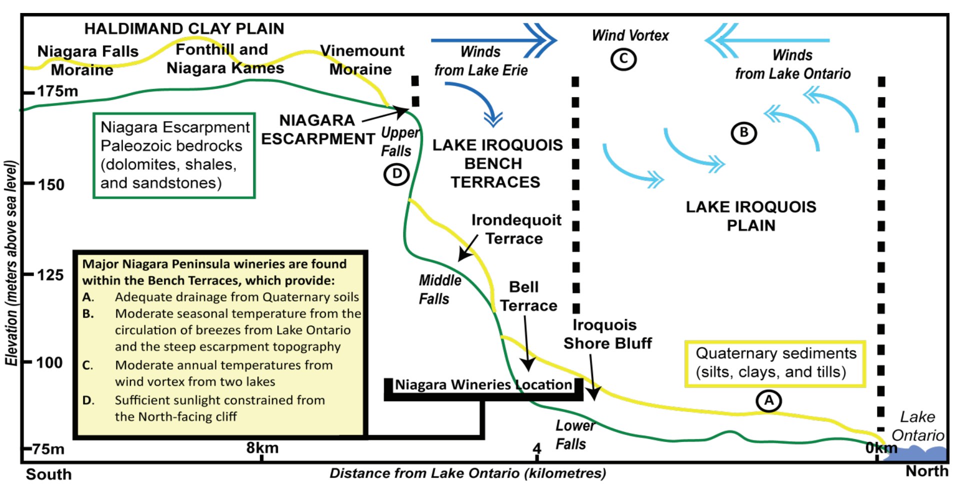

Fig. 2. The schematic shows a composite North-South cross-section of the geology and physiography across the Niagara Peninsula from Lake Ontario to the Niagara Escarpment. The two distinct geologic units are outlined in green and yellow, and major wind patterns are displayed with blue arrows. The Lake Iroquois Bench Terraces contain the majority of the Niagara Region's wineries. The circled letters indicate major wine-growing features of the region, explained in the box in the bottom left of the figure. Adapted and modified from (*6*), with data from (*8, 21, 22*)

Relation to Niagara Region

This paper focuses on how climate change relates to the Canadian wine industry, specifically in the Niagara Region of Ontario. The Canadian wine industry has a relatively young history; significant growth began in 1988 when the industry began utilizing *Vitis vinifera* hybrids (*6*). Since then, Canada has developed a reputation in both international and domestic markets (*7*). In Ontario, much of this growth is led by the prosperous industry in the Niagara Region. Located in a temperate climate that is moderated by Lake Erie and Lake Ontario, Niagara offers an especially suitable region for growing winegrapes with warm summers, cool winters, and moderate winds (Fig. 2). Because this climate is so unique, even slight variations in climate will affect the ability of the region to grow quality winegrapes (*3*).

Niagara Characteristics

The Niagara Region, located at the same latitude as famous wine-growing regions in Europe, provides the

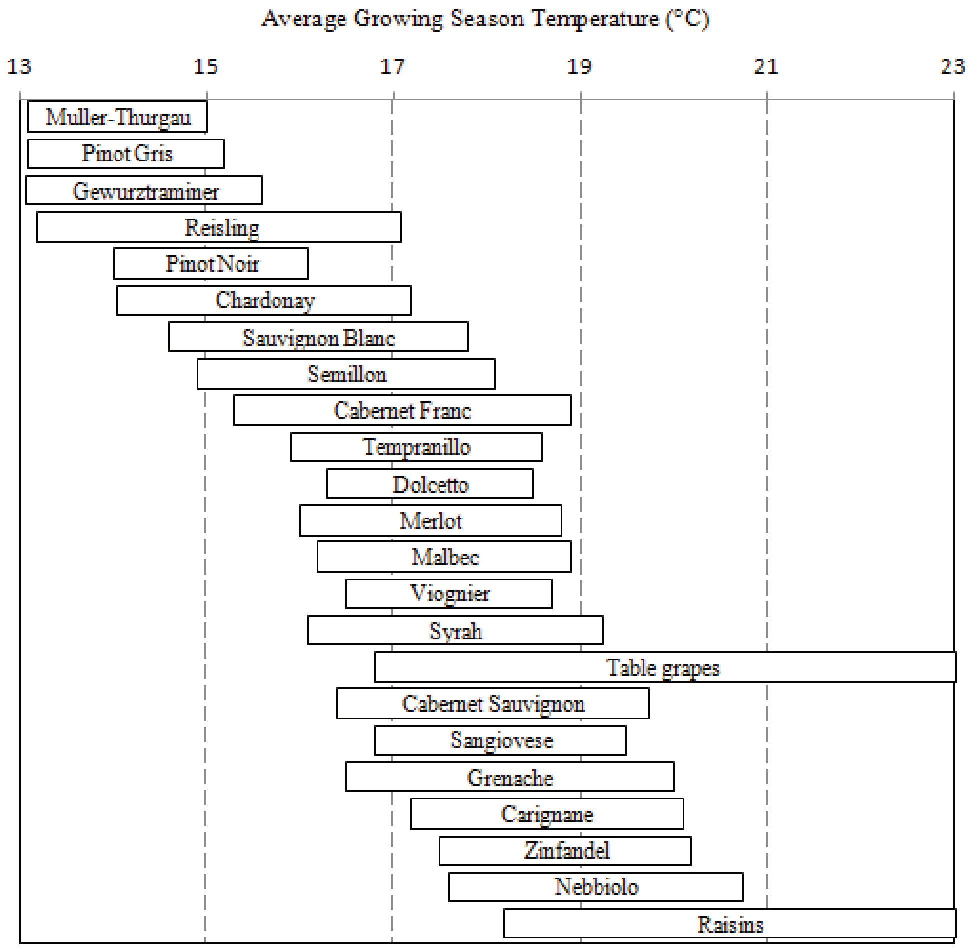

Fig 3. This chart shows the mean growing season temperature for various winegrape varietals. Each varietal requires a unique one-dimensional temperature niche for proper growth, based on its pheonological timing. The width of each bar indicates the range of mean temperature in which the varietal can be grown and produce a high quality wine. Data is accurate within an error of ±0.6°C. Modified from (*3*).

appropriate summer temperatures and daylight hours suited for growing winegrapes. However, the region is located at a colder isotherm than these famous European regions, making it a cool-climate viticultural region (*6*). Because of this, certain factors such as wind and frost are important considerations for winegrape growth in Niagara. The effects of the cool-climate factors are partially diminished by the topography of the region. For example, the high Niagara Escarpment provides shelter from the potentially damaging cold winds (*8*). To suit the cooler temperature, sturdier varietals such as Riesling or Chardonnay must be used (*3, 9*).

The Niagara Region was formed by subglacial and proglacial sediments deposited in the most recent glaciation events (*6*) (Fig. 2). Shallow clays and loams formed during periods of glaciation provide adequate drainage needed for growing winegrapes. *Vitus vinifera* cannot grow in situations where the roots are drowned with water, so appropriate drainage is essential. The steep Escarpment slope provides drainage, and the silty clays have enough porosity to allow further drainage (*6*).

Temperature and the Niagara Wine Region

Temperature

The types of winegrapes that can grow in a region are directly dependent on the seasonal average temperature of that region (Fig. 3). For example, Cabernet Sauvignon winegrapes must be grown in warmer regions such as Bordeaux and Napa, while Pinot Noir winegrapes require cooler regions such as Northern Oregon or Burgundy to grow (*3*). In addition, day-to-day variations in temperature impact the quality of wine produced. Climate change, which influences both the mean and the variability of temperature conditions, will therefore greatly affect wine production worldwide (*3*). Changing average temperatures have the potential to greatly impact the winegrape growing process, including growing season lengths, harvest dates, and frequency of frost occurrence. Changes to any of these factors would have significant effects on the wine industry, since each factor impacts the viability of growing winegrape varietals in any region (*3*).

The impacts of climate change will not be identical for all varietals and regions. Depending on the versatility of the local winegrape varietal, increasing the average temperature could improve grape yields in one region while impeding yields in another. Although the temperature increase could expand the range of varietals that can grow in a cooler region, it could also make growing winegrapes challenging, or even impossible, in a warmer region (*3*). Climate change will not only be manifested in changes in the mean temperature, but also in increasing temperature variability. This will cause more frequent extreme heat occurrences as well as more frequent extreme cold conditions (*3*). Significantly increased temperature variability could hinder, or completely inhibit, the growth of certain winegrape varietals. Other temperature-based metrics, such as growing season length and average **degree-days** per season, are also useful for analyzing the viability of a region for growing winegrapes. However, these metrics are all heavily dependent on, and therefore can be included in, mean temperature and variability (*10*).

The impacts of temperature change on wine quality will be most obvious in changes in phenological timing. Increased plant growth rates will lead to imbalanced ripening profiles (*3*). For a high quality, balanced wine, a longer maturation period (from **véraison** to harvest) is required. This gradual ripening allows sugars to accumulate while keeping acid levels moderate. In contrast, a warmer environment will cause the grapevine to progress through its phenological events more rapidly, resulting in earlier sugar ripeness and unbalanced acid levels. This produces lower quality wines with higher alcohol content (*11, 12*). In addition, these higher-alcohol wines typically will not age as well or as long as wines with lower alcohol levels, further reducing the quality of the wine produced.

Increasing temperatures further complicate the winegrape growing process by advancing the harvest date. Warmer climates cause grapes to ripen sooner, which may force the harvest to take place up to six weeks earlier (*3*). An earlier harvest will require a greater irrigation input to prevent dehydration of the fruit. This increased irrigation will require greater water usage, which affects both water availability for the winery and the environmental sustainability of the wine production process.

Implications of Temperature to Niagara Wine Region

As explained previously, the Niagara Region is a cooler region for growing winegrapes. The increase in average temperature associated with climate change (Fig. 4 and fig. 5) will cause many of the sturdier varietals such as Pinot Noir to be less suitable, and allow for the growth of other, warmer climate varietals such as Cabernet Sauvignon (*3*). Although this seems appealing upon first thought, the switching costs associated with the agricultural practices will be expensive for the Niagara wineries.

In addition, increased variability in temperature will threaten the ability to grow winegrapes in cooler regions. Particularly, during cold Canadian winters, extremely cold temperature occurrences can cause frost death in vines (*3*). Increased temperature variability will increase the frequency of these extreme frost events, which could cause more widespread vineyard death. Replacing vines that die over the winter is a costly process. Although roots that are more resilient to the cold can be grafted onto the vines, implementing this change across an entire vineyard would be very expensive (*9*).

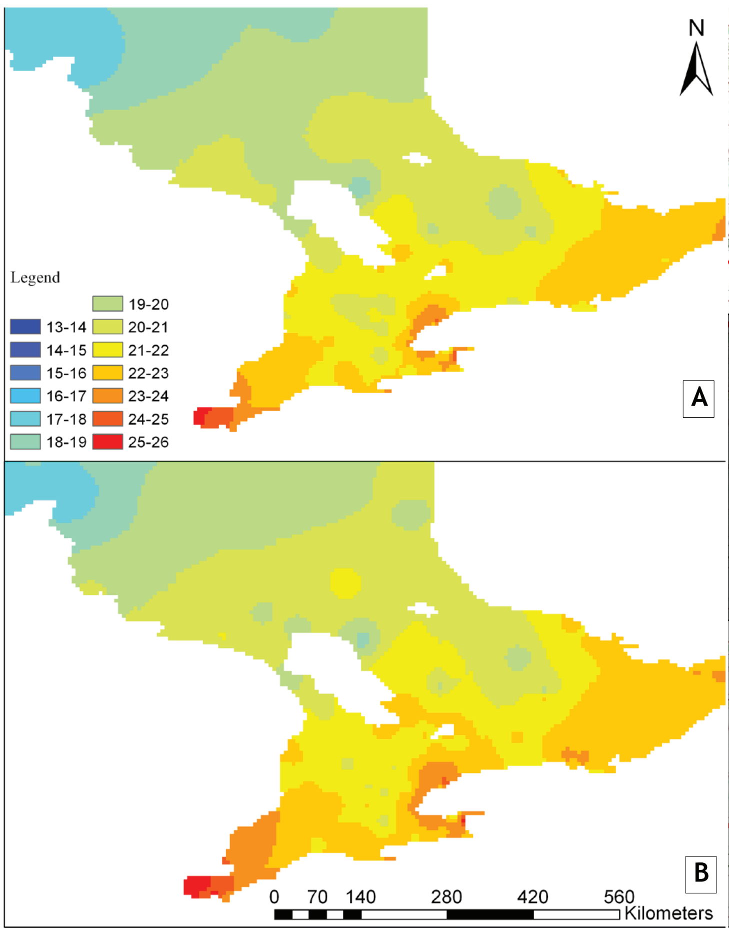

Fig. 4. Temperature gradients produced for southern and parts of northern Ontario for the months of July 2010 **(A)** (interpolated using data collected from over 150 weather stations) and July 2050 **(B)** (projected) show an increase in the average daily mean temperatures of about a degree across the province. The viability of growing different varietals must be assessed based on winery location.

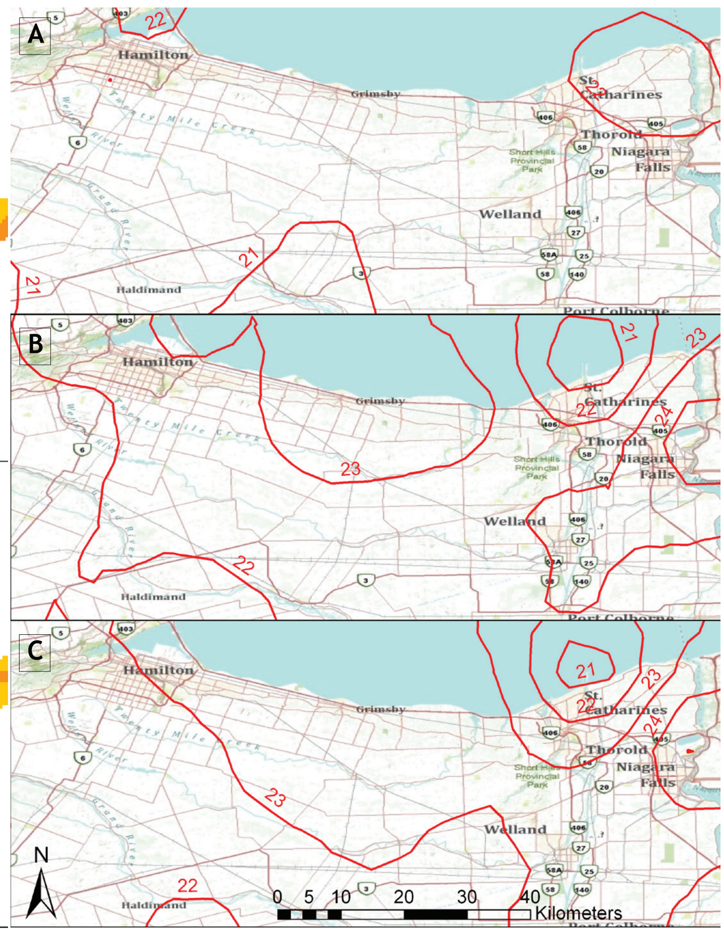

Fig. 5. The average daily mean temperature for July 1970 **(A)** and 2010 **(B)**, collected at several weather stations and interpolated to produce a temperature gradient across the Niagara Region, as seen from the isotherms (red lines). (**C**) shows the average daily mean temperature projected for 2050, based on linear trends observed across monthly weather data from 1940 to 2011. Data collected from the National Climate Data and Information Archive, Environment Canada.

Water Usage, Precipitation and Urbanization

Importance of Water

Water is essential to the operation of all wineries. Because an estimated 780 L of water are used to produce one litre of wine (*13*), water is an integral component of winegrape and wine production processes. Events such as floods and droughts are therefore of great importance to vintners. A changing climate implies a greater frequency of such events, which result in variance in the availability of water. Lake Ontario, precipitation, and groundwater in the Niagara Region are important sources of water for all winery processes in the region. Thus, water availability greatly influences the sustainability of the wine industry, and is an important aspect to consider when analyzing the viability of the Niagara wine industry.

Lake Ontario, Precipitation, and Groundwater

To understand how climate change and resulting changes in Lake Ontario water levels can affect the wine industry, the relationship between the lake and the industry must be examined. Niagara wineries benefit from having Lake Ontario thermally regulate cold north winds. These cold winds pick up heat from the lake, rise along the base of the escarpment and cycle back over the lake, providing vineyards with good weather conditions for growing grapes (*14*). Any change in the depth of the lake could affect both the amount of heat picked up by these winds and the paths these air currents take. Alterations to this cycle could prove devastating (*15*) to an industry that relies on the growth of sensitive plants.

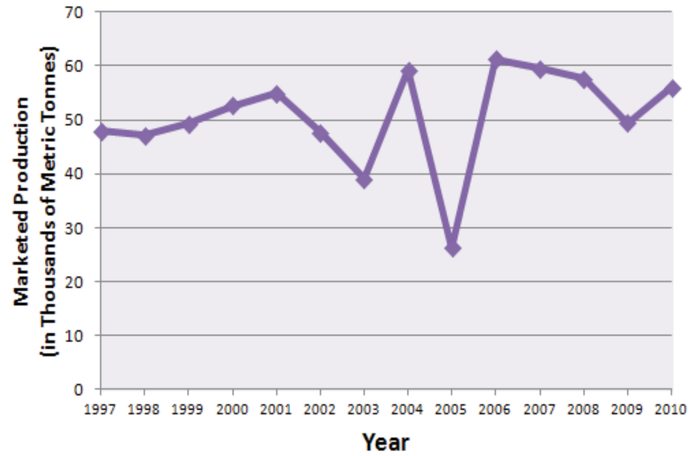

Fig. 6. The amount of winegrapes produced is related to the weather conditions. The years 2003 and 2005, with notoriously wet and unstable conditions, had a considerable effect on the amount of winegrapes produced, as well as the quality of those grapes. Modified from (*7*) with modern data from (*23*).

The increased volatility of rainfall in the Niagara Region caused by climate change (*1*) could cause destructive effects to the Niagara wine industry. The Niagara Region alternates between tropical and polar wind masses, which causes predictable changes from a high-pressure to a low-pressure system (*1*). A disturbance in the balance of the cycle could permanently swing the weather conditions to either extreme: droughts or excessive rainfall (*1, 6*). As evidenced by the 2003 and 2005 growing seasons, a deviation from the average distribution of precipitation can cause problems in winegrape development (Fig. 6).

In Niagara, the harvest season from September-October is most sensitive, where a major storm track from the Arctic running through the Great Lakes Region threatens to cause cool, wet weather (*1*). Excessive rainfall after véraison predisposes berry splitting, and coupled with weak winds and prolonged cool temperatures, this can cause the growth of rot and fungal disease. These heavy rains also dilute the juices, which reduces the sugar quality of the grapes. The devastations to quality by dilution and fungal diseases are expensive to combat, and would affect the economic sustainability of Niagara wineries.

Water quality and groundwater availability are also of importance. Clean water is essential to all agricultural industries, so changes in pH and rainwater content would threaten the wine industry. Plants uptake compounds present in the soil (*16*) and an increase in industrial

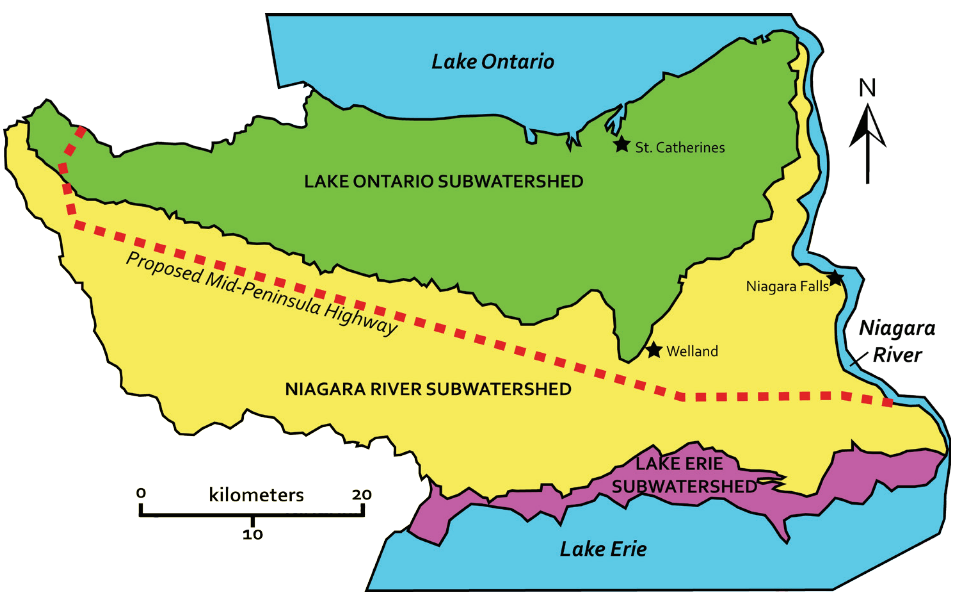

Fig. 7. Subwatersheds of the Niagara peninsula channel water into three water bodies - Lake Ontario, the Niagara River, and Lake Erie. Most Niagara wineries are located on watersheds that drain into Lake Ontario. Urbanization is a potential threat to wineries; suburban development threatens agricultural lands and groundwater flow. The Mid-Peninsula Highway (dashed red line) is proposed to be built along the top of the escarpment, through watersheds that drain North past wineries into Lake Ontario. The effect of leachate from the construction of such a project remains to be seen. Adapted from (*22,24*).

activity in the regions surrounding Niagara can concentrate heavy metals in the soil through industrial runoff or exchange through precipitation.

Urbanization

Urbanization and an increase in industrial activity are consequently major concerns for the wine industry in terms of groundwater quality and water availability. Road salts are a common contaminant in groundwater supplies: about 50% of the salts used end up dissolving in groundwater (*17*). The Niagara Peninsula is a growing urban region, and major road and infrastructure projects complement such urbanization – the proposed Mid-Peninsula Highway being a prime example (Fig. 7). If such a highway were built to divert traffic over the top of the Niagara Escarpment, the wineries at the base and benches of the escarpment may suffer from groundwater contamination. Escarpment watersheds feed wineries with groundwater, and leachate resulting from these roads could flow downslope towards wineries. This would mean that the groundwater available to the roots of grapevines will have a higher concentration of ions, ions that may affect the metabolism of grapevines through uptake. Salinasation of land is a major threat to world food production (*18*). Plant root cells generally maintain a negative electric potential gradient, and can thus easily absorb positive sodium ions via active and passive diffusion (*18*). Na+ ions are generally considered a toxin (*16*), serving as an added stressor to the plant by modifying pH; these ions are a primary byproduct of road salts.

Economic Sustainability

Niagara provides almost all of Ontario's wine revenue with 73 wineries and over 500 wine-growers (*1*). The potential revenues of this industry are closely linked to the quality of the grapes. For example, a particularly cool, wet season could reduce the sugar level of a Cabernet Franc by up to 40%, decreasing the price per tonne from $2300 to $300 (*1*). If quality was reduced any lower, the wines would fall below acceptable standards (*1*).

In general, wine sales are increasing in Canada. Since 1993, Canadians have been purchasing about 4 more liters of wine per capita, 40% of which is Canadian wine (*7*). However, in global markets, the Niagara wine industry is viewed as a small player with business strategies that are currently inhibiting the industry from reaching its competitive potential. For example, the region does not have the same unique brand identity or experience in the viticultural industry as more established wine-producing regions across the globe (*19*). Given these facts, the Niagara wine industry can benefit from taking a proactive approach to minimizing the impacts of climate change, in order to better compete domestically and internationally.

Conclusion and Future Directions

Awareness of the potential impacts of climate change is the first step for the Niagara industry, but proactive preventative techniques need to be employed, from adjusting winegrape growing techniques to creating financial safeguards. In order for the wine industry to sustain itself into the future, a multipronged approach is best. Such an approach could involve using Geographic Information Systems and other tools to predict risks (*20*). For example, research into sturdier rootstock grafts could be conducted to identify stocks that are more suited to cool climates (*9*). Similarly, further research into pest management for rots and fungal diseases would protect the industry against such problems. In all cases, proactive research is required.

Niagara is a particularly sensitive cool-climate viticultural area that has only experienced recent success in the wine industry. For winegrapes to grow effectively in the region, climate conditions must be fairly stable and follow certain patterns, and as such variability in rainfall or temperature can be devastating. The number of sunshine hours, amount of frost damage, and intensity of winds are all unique limiting factors in the Niagara Region (*20*). In addition, the wine industry continues to be affected by urbanization and global markets. Due to the wide range of contributing factors, it is near impossible to predict the future sustainability of the Niagara wine industry, as well as the future impacts of climate change. Despite this uncertainty, adaptability is essential to maintaining environmental and economic sustainability.

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Review

A Comparison of the Antioxidant Activity of Grape Juice and Red Wine

Cody Koykka, Viktoria Serkis, Hyuck Won, Rachel Young, Michelle Zhu

Epidemiological studies have identified a strong correlation between a lower incidence of coronary heart disease and the consumption of red wine. Experiments have shown that this relationship is due to the high antioxidant activity (AOA) of red wine. It is theorized that ethanol and polyphenols are the primary modulators of red wine AOA, although their relative contributions are unknown. To determine ethanol's contribution to the AOA of red wine, five studies comparing the AOA of red wine and its unfermented counterpart, grape juice, were analyzed. The *in vivo* studies generally reported that wine has a greater AOA than grape juice while the *in vitro* and *ex vivo* studies yielded conflicting results. Furthermore, for the purposes of this review, no conclusions could be made due to the limitations of each study. This review presents an ideal experiment that could determine the relative AOA of the two beverages, and thereby ethanol's role in affecting the AOA of red wine. Future studies that can generate conclusive results would likely affect the economics of the Canadian wine industry.

Introduction and Background Information

Decades of epidemiological studies (*1-5*) have indicated that moderate alcohol consumption, particularly red wine, is strongly correlated with reduced coronary heart disease (CHD) mortality. For example, researchers discovered that although the French consume significantly more saturated fatty acids than the Americans, the incidence of CHD is 2.5 times greater in America than in France (*6)*. Dubbed the French Paradox, scientists have found evidence to suggest that this relationship can be explained by a higher consumption of red wine in France. In addition, when epidemiological studies supporting the health benefits of red wine were first made public in 1991, consumption of the beverage increased by 44% in the US (*7*). The increase in sales suggests that a significant percentage of the population drinks wine for its supposed health benefits.

Many of these health benefits have been associated with the intake of polyphenols – chemicals that are characterized by an abundance of phenol structures – which are found in wine at a particularly high concentration (*8*). Polyphenols are strong antioxidants that are capable of protecting one's bodies from oxidative damage caused by reactive oxygen species (ROS). It is well established that the oxidation of low-density lipoproteins (LDL) in the blood increases the risk of developing CHD (*9*). Oxidized LDLs, after uptake by macrophages, are able to promote foam cell formation, which is a known precursor to CHD (*10*) (Figure 1). Antioxidants interfere with this oxidation process by neutralizing free radicals. It has therefore been hypothesized and confirmed that the high antioxidant activity (AOA) of red wine causes this pronounced reduction in incidence and mortality rates of CHD (*3*). In addition, the AOA of wine is responsible for inhibiting the progression of neurodegenerative diseases (*11*) and decreasing the incidence of cancer (*12*) and diabetes (*13*) (Figure 2).

Modern research indicates that two major components of wine, ethanol and polyphenols, alter its AOA. However, studies concerning their relative contribution to the overall AOA of red wine tend to contradict one another (*14,15*). Previous studies have attempted to calculate the relative contribution of polyphenols by measuring the AOA of each individually, but this neglects the possibility of synergetic effects from other chemicals, notably ethanol (*16*). On its own, ethanol has been correlated with a lower incidence of CHD, but additional studies have indicated that ethanol has a pro-oxidant effect (*17*). It is therefore unclear whether the ethanol, polyphenols or the combination of the two in red wine are responsible for lowering the risk of CHD. This review will compare the AOA of red wine and grape juice, a beverage high in polyphenols but containing no ethanol, to learn more about which component is responsible for the health benefits. Furthermore this article will attempt to ascertain which beverage is best for lowering the incidence rates of a wide variety of diseases, including CHD.

Analysis

Numerous studies looking at the AOA of red wine and grape juice have been previously conducted; however, only studies that directly compared the AOA of these two beverages were included in this review. Five studies − two *in vitro* studies, two *in vivo* studies and one *ex vivo* study − were chosen based on this criteria. This review will analyze and compare these studies in order to assess their validity in determining the relative AOA of red wine and grape juice. Additionally, the comparison of the AOA of these beverages will determine the contribution of ethanol to the health benefits associated with the consumption of red wine.

In vitro studies

Phenolic content and antioxidant activity of red wine and grape juice

A study conducted by Seeram *et al*. (*18*) directly compared the AOA and total polyphenol content of twelve different beverages including red wine and grape juice. AOA was determined by four different standardized assays: the Trolox equivalent antioxidant capacity (TEAC), total oxygen radical absorbance capacity (ORAC), free radical scavenging capacity by 2,2-diphenyl-1-picrylhydrazyl (DPPH)

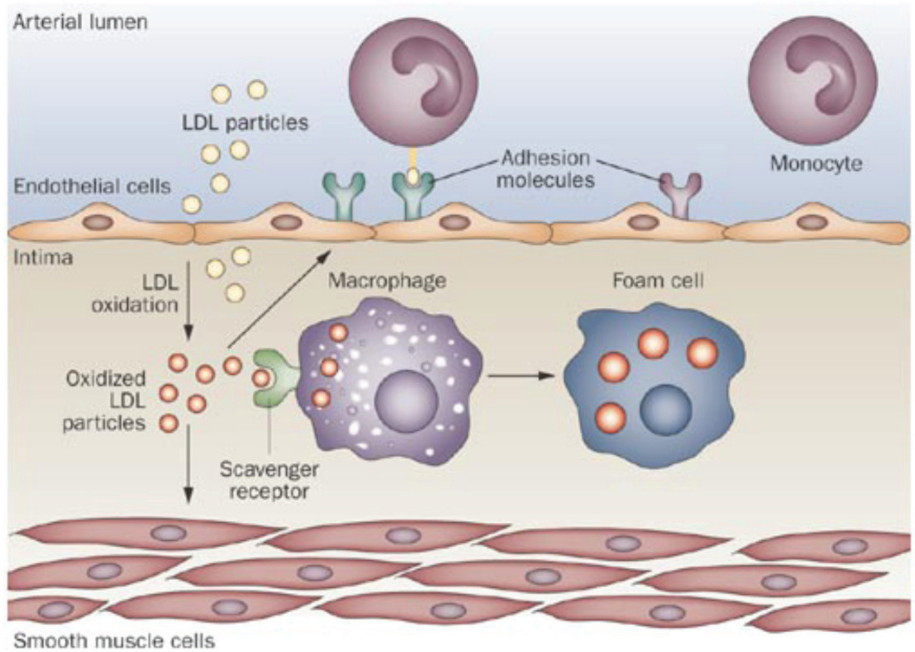

Figure 1. Oxidized LDL particles can induce activation and expression adhesion molecules which could increase plaque formation on blood vessel walls. When oxidized LDL particles are taken up by macrophages through their scavenger receptors, the macrophages can turn into foam cells, which is a key event in the development of atherosclerotic plaque. Oxidized LDL particles can also induce proliferation of smooth muscle cells, which helps stabilize the plaque forming on arterial walls. [Source: **Figure 1**. Rocha and Libby (*27*)]

and ferric reducing antioxidant power (FRAP). AOA was also measured by the ability of each beverage to inhibit the oxidation of LDL in a healthy human donor by both the peroxide and malondialdehyde methods. Finally, the total polyphenol content was determined spectrophotometrically. The AOA and polyphenol content of three different brands of each beverage were tested; the results were then averaged according to the beverage and subsequently compared.

Seeram *et al*. (*18*) found that the total phenolic content was greater in red wine than in grape juice despite the fact that both contained the same active polyphenols. Moreover, red wine was shown to be over one and a half times more efficient in inhibiting LDL oxidation than grape juice in both the peroxide method and the malondialdehyde methods. Inconsistent results were derived when testing AOA; red wine was only shown to have significantly greater AOA than grape juice in the DPPH test, while values were less widely distributed in the other three assays used to measure AOA.

Overall, the study by Seeram *et al*. (*18*) concluded that red wine has greater AOA than grape juice. In order for this conclusion to be made, it had to be assumed that all three tests and seven assays should be given equal weight. Each assay alone was fair as they used six replicates of each of the three brands chosen for each beverage, however their overall conclusion may not be. Each assay would need to be tested for accuracy and weighted accordingly. For example, Seeram *et al.* discuss that the ORAC method of determining AOA has increased variability due to temperature variation in required equipment. This suggests that the ORAC method may need to have a lower weighting in the comparison of different beverages.

In addition, this study fails to account for differences in AOA that could have been attributed to variations in the polyphenolic profiles of each beverage, as a result of using different grape varieties for each product. However, similar results were found in a study by Sanchez-Moreno *et al.* (*19*) which controlled this variable by comparing grape juice and red wine produced from grapes of the same vineyard. This study confirmed that red wine had a higher polyphenol content than grape juice. Then, using similar antioxidant assays as Seeram *et al.* (*18*), with the addition of the ferric thocyanate assay (FTC), the study by Sanchez-Moreno *et al.* also found that the AOA of red wine was much higher than that of grape juice.

These two studies both concluded that red wine has a much greater AOA than grape juice, which seems to suggest that the main difference between these two beverages, ethanol, must be responsible (*18,19)*. The main, limitations with these findings is that the conclusions are only based on *in vitro* tests and it is impossible to determine how well these tests model *in vivo* conditions without performing additional *in vivo* studies.

In vivo studies

Inhibition of atherosclerosis in a hamster model

A study by Vinson *et al.* (*20*) sought to determine the relative AOA of red wine and grape juice *in vivo*. Researchers induced atherosclerosis – the condition of blocked, hardened arteries which contributes to CHD (*21*) – in hamsters in order to measure how effectively the progression of the disease was inhibited by the intake of various beverages. This, in turn, tested the relative AOA of the polyphenols in red wine, dealcoholized red wine, and red grape juice.

To induce atherosclerosis, hamsters of the same gender and weight class were given a diet that significantly increased the levels of fatty acids in their systems. The hamsters were then divided into four groups of nine: one group was given pure grape juice; the second drank only red wine; the third received red wine that was dealcoholized without the loss of polyphenols; the last was given only ethanol. After 10 weeks, Vinson *et al.* (*20*) measured the AOA of the beverages by determining the oxidation levels of cholesterol, high-density lipoprotein (HDL), and LDL in the hamster blood plasma.

The level of oxidized products declined in all four test groups, suggesting that every beverage in this study had high AOA. Vinson *et al.* (*20*) also measured the polyphenol concentration present in each substance given to the hamsters and then normalized the data to make each beverage contain an equal polyphenol dose per volume. Based on this normalization, they found that red grape juice was more than twice as effective in lowering cholesterol and 2-6 times as effective at lowering LDL compared to red wine and dealcoholized wine. Red grape juice was also twice as efficient as red wine in inhibiting atherosclerosis. Since red grape juice inhibited atherosclerosis more effectively than red wine, the study concluded that red grape juice had higher AOA.

Despite using hamsters of the same weight class, Vinson *et al*. (*20*) never directly measured the quantity of beverage that each hamster consumed and therefore a relationship between the per volume AOA of each beverage cannot be ascertained. Additionally, with a sample size of only 9 per group, it is difficult to assess whether these results were statistically significant. The hamsters were also limited to only one gender, and therefore Vinson *et al*. did not account for the possibility that males and females could absorb antioxidants differently. An additional limitation is that the polyphenol content was normalized such that each beverage contained the same concentration of these compounds. In order for the results in this study to be reproduced in humans, without normalization of polyphenol content per volume, one would have to drink nearly four times as much grape juice as red wine. Since this experiment was performed on hamsters, it remains unclear whether the results can be extrapolated to human subjects.

Effects of ethanol on human LDL

To determine whether the results of the previous *in vitro* and *in vivo* studies could be reproduced in humans, a study by van Golde *et al.* (*22*) examined the effect of red wine and grape juice on human LDL oxidation was chosen for analysis. van Golde *et al.* specifically used a combination of *in vitro* and *in vivo* studies to determine the effect of ethanol on the antioxidant effects of wine.

The study was conducted with seven healthy, non-smoking male volunteers between the age of 24 and 30. After a week of abstaining from beverages containing high polyphenol concentrations, each volunteer consumed 375 mL of red wine daily for 14 days. Blood samples were taken from the subjects before and after the two weeks of wine consumption. Researchers extracted the LDL from blood samples and compared the inhibition of LDL oxidization, by copper (II) sulphate, of red wine to diluted grape juice and a

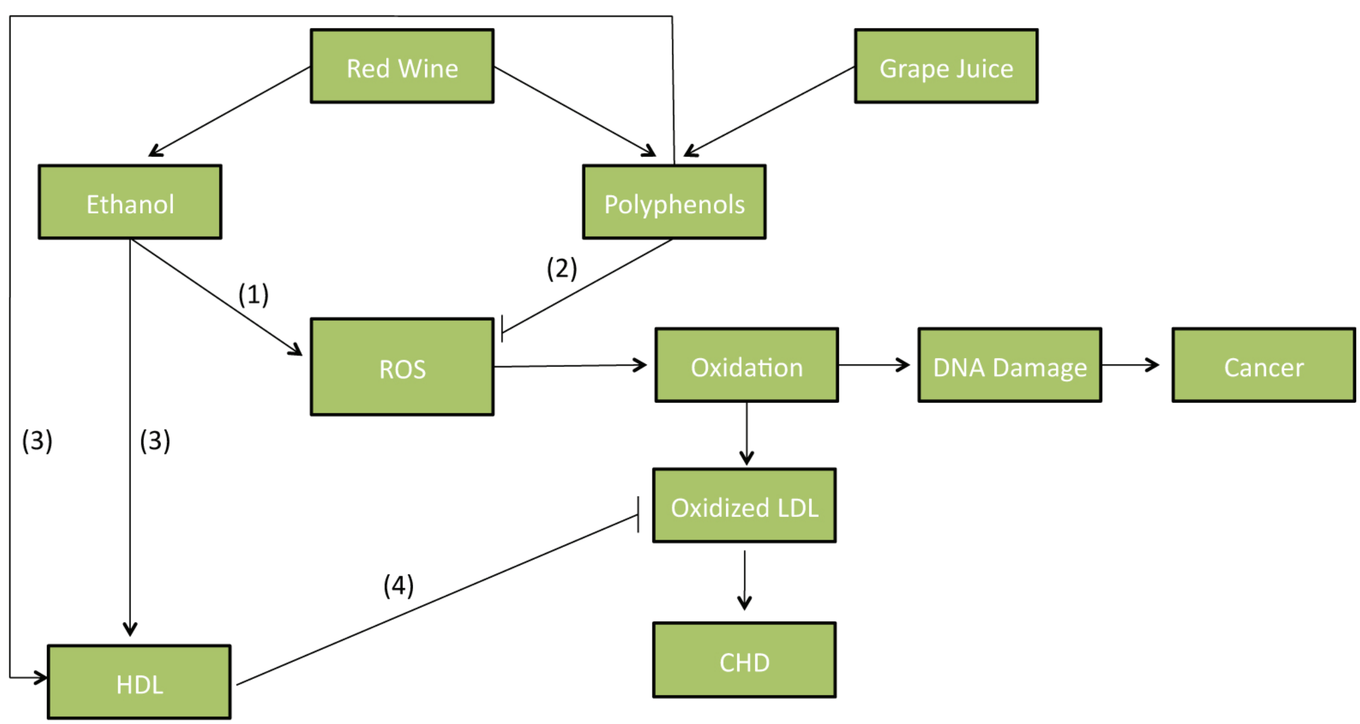

Figure 2. Factors in wine and grape juice that affect oxidative damages. (1) The presence of ethanol in wine can elevate the levels of reactive oxygen species (ROS) that can cause DNA and LDL oxidative damage. (2) Polyphenols have the ability to scavenge the ROS to decrease the oxidative damages. (3) Both polyphenols and ethanol can elevate the levels of HDL in the plasma. (4) HDL can in turn protect LDL from oxidative damage, thus lowering the risk of CHD. [Adapted from **Fig. 1**. Covas *et al.* (*9*)]

12% ethanol solution *in vitro.*

The AOA of each beverage was measured through comparison of the lag time of LDL oxidation prior to and after red wine consumption. Lag time is the period between the addition of copper (II) sulphate to extracted LDL samples and the first observed rapid formation of conjugated diene. Accumulation of conjugated dienes are closely linked to the formation of lipid hydroperoxides, a product of lipid oxidation (*23*). van Golde *et al.* (*22)* found that red wine increased the lag time and had a greater AOA than red grape juice. However, with ethanol alone the researchers found that the LDL particles had a decreased lag time, indicating ethanol had a pro-oxidant effect. They also determined that the higher AOA in red wine could be attributed to the differences in polyphenol content between the beverages. This conclusion was tested by adding ethanol to red grape juice, which did not result in a significant increase in AOA.

For the purpose of determining the role of ethanol in AOA, this study has a major limitation. The *ex vivo* tests of AOA for all beverages were performed using LDL molecules extracted from patients that drank red wine for two weeks. This could influence the results obtained for the AOA of grape juice. For the purpose of this review, more conclusive results would have been obtained if the AOA of grape juice was measured using LDL extracted from subjects drinking this beverage. Another limitation is that the test subjects were all male, thus the results may not be applicable to the female population.

Bioavailability and biokinetics of anthocyanins in human subjects

In order to make any conclusions regarding the efficacy of antioxidant compounds in humans, it is crucial to evaluate how well these compounds are absorbed *in vivo*. A study by Bitsch *et al.* (*24*) sought to quantify and compare the bioavailability and biokinetics of anthocyanins – a particular subset of polyphenols – from wine and grape juice.

The study (*24*) was conducted with nine healthy volunteers, each of whom was given a single 400 mL dose of red wine and then the same volume of grape juice four weeks later. Grape juice samples were diluted to ensure that both beverages contained the same concentration of anthocyanins. Biokinetic and bioactivity assays were then performed on the set of plasma and urine samples collected over a period of time after injestion. Calculation of pharmacokinetic quantities of individual anthocyanins in the blood plasma revealed a general trend wherein anthocyanins from grape juice reached a higher peak plasma concentration in a shorter period of time, indicating better absorption. Biokinetic measurements obtained from urine samples also suggested greater absorption of grape juice anthocyanins. Further substantiating the increased absorption from grape juice, the peak plasma concentration of all polyphenolics reached a greater level after grape juice consumption. This indicated that polyphenols other than anthocyanins were also better absorbed. Finally, to assess the bioactivity of all absorbed polyphenolics in the plasma, the researchers measured plasmatic AOA using the TRAP assay, where the levels achieved after grape juice ingestion surpassed those of wine.

Taken together, the data regarding the biokinetics of individual anthocyanins and the AOA of all the polyphenols suggest that anthocyanins with a stronger AOA were better absorbed from grape juice. Consequently, the plasmatic AOA was higher after ingestion of grape juice. To account for the trend noted in the plasma biokinetics and excretion rate, Bitsch *et al*. (*24*) hypothesized that anthocyanin absorption may be improved by the glucose content of grape juice.

Although the study by Bitsch *et al*. (*24*) provided valuable data regarding the metabolism and absorption of polyphenols, their experimental design does not allow investigation into possible reasons for better absorption. The biokinetic trends imply that anthocyanins and other polyphenols from red grape juice were better absorbed, but it remains uncertain whether absorption is enhanced by the glucose content of juice or hindered by the ethanol in wine. It is possible that compounds evolved during the fermentation processing could interfere with anthocyanin absorption.

Discussion

A primary objective in selecting studies which compare the AOA of grape juice and red wine was to draw conclusions regarding the role of ethanol in modulating AOA (refer to Table 1 for a summary of the studies investigated). Although the experimental designs of the selected studies allow for insight into this query, the results are conflicting. The investigation by Seeram *et al.* (*18*), among other *in vitro* studies, consistently reported that wine has a greater AOA than grape juice. However, with experiments performed *in vivo*, it is much more difficult to arrive at any conclusion. Much of this uncertainly arises from the method of measuring AOA, as well as an inability to account for and understand all interactions that occur in a living system. Through the measurement of LDL and cholesterol levels in atherosclerotic hamsters, Vinson *et al.* (*20*) observed that red grape juice had a significantly greater AOA compared to red wine and ethanol. Similarly, the investigation of biokinetics and bioavailability conducted by Bitsch *et al*. (*24)* recorded that grape juice exhibited a greater AOA. However, van Golde *et al.* (*22*) found that red wine had a higher AOA than grape juice *ex vivo*.

Each of the studies examined in this review either made assumptions or did not account for certain variables that could ultimately affect the results of their experiments. An ideal experiment would have a statistically large sample size containing human subjects. Both genders of the same weight class should be represented to help control for metabolism. Another variable that was not taken into account by the studies investigated was the time over which each beverage was consumed. As wine is often consumed much more slowly than grape juice, the biokinetics and absorption of the polyphenols would further differ between the two beverages. Ideally, a study would test the relative AOA of red wine and grape juice composed of grapes from the same vineyard in order to minimize the possible variation in the polyphenolic profile of the two beverages, as done by Sanchez-Moreno *et al.* (*19*). In addition, AOA should be measured both *in vivo* and *in vitro* in order to identify and eliminate

Reference	Study Design	Subjects	Methods	Results
Seeram *et al.* (*18*)	*in vitro*	N/A	Compared AOA of grape juice and red wine through four different antioxidant assays. In addition, the ability of each beverage to inhibit the oxidation of LDL was measured.	Red wine had greater AOA than grape juice.
Sanchez-Moreno *et al.* (*19*)	*in vitro*	N/A	Compared AOA of grape juice and red wine produced from grapes grown in the same vineyard by measuring inhibition of LDL oxidation and two other antioxidant assays.	Red wine had greater AOA than grape juice.
Vinson *et al*. (*20*)	*in vivo*	36 hamsters	Determined the AOA of red wine, red grape juice, and dealcoholized red wine by measuring the oxidation level of cholesterol, HDL, and LDL in the blood plasma of atherosclerotic hamsters.	Red grape juice had greater AOA than both red wine and dealcoholized red wine.
van Golde *et al.* (*22*)	*ex vivo*	7 human males	Examined the oxidative effect of red wine, grape juice and a 12% alcohol solution on human LDL extracted from subjects' blood.	Red wine had greater AOA than red grape juice and grape juice with 12% ethanol. Both red wine and grape juice had much higher AOA than ethanol alone.
Bitsch *et al.* (*24*)	*in vivo*	4 human males and 5 human females	Blood and urine samples collected from subjects after a single dose of red grape juice or wine were used to measure plasmatic AOA of total polyphenolics and pharmacokinetic properties of single anthocyanins.	Bioavailability of anthocyanins and plasmatic AOA of all polyphenols and their metabolites are higher in grape juice than red wine.

Table 1: Summary of the studies examined for analysis of the role of ethanol in red wine AOA.

any discrepancies between the two experimental conditions.

No definitive conclusion about the relative contribution of ethanol to the AOA of red wine can be drawn due to these conflicting results, as well as the limitations of each study. Moreover, these studies cannot be used to conclusively determine whether or not red wine has a greater AOA than grape juice.

Future Studies and Conclusions

By controlling the variables discussed previously, future studies will better answer the questions posed in this review. However, since these beverages are so complex a multitude of other factors should also be investigated, most notably the effect of polyphenol metabolites on AOA. Recent studies (*25*) have shown that there are very few polyphenols found in their natural form and the majority exist in a conjugated state *in vivo* due to metabolism. However, these conjugated states are found to have a lower AOA than their natural form. Additionally, current studies have revealed that consumption of wine after food intake could result in a more pronounced antioxidant effect (*9*). The relevance of metabolism thus warrants further studies examining the bioavailability of polyphenols as well as their AOA which would have implications for the health benefits of two beverages considered in this review.

Historically the United States has received 80-95% of all yearly Canadian wine exports by volume (*26*). Thus, given the fact that a significant percentage of people in the United States consume red wine for its supposed health benefits, the Canadian wine market could be significantly affected by the results of a study that could definitively conclude which beverage has a higher AOA. Finally, these results could have a significant impact on the health care industry, as high AOA can lower risk of chronic diseases, such as cancer, neurodegenerative conditions and CHD (*12*).

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Challenges of natural winemaking in the Niagara region

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ABSTRACT

Prior to the industrialization of wine, its production was a completely natural process that did not involve the addition of synthetic chemicals. Recently, there has been a movement towards natural winemaking in Europe and California. Natural wine differs from organic wine; the former uses only indigenous yeast and no synthetic additives. This review evaluates the feasibility of producing natural wine in the Niagara region from three aspects: the maintenance of grapes, the extraction of phenolics, and the fermentation process. We conclude that natural winemaking is not feasible in the Niagara region based on the relatively cool and wet climate, and the unpredictability of natural fermentation.

INTRODUCTION

The history of winemaking spans thousands of years. Its earliest recorded evidence can be traced back to the time of ancient Egypt (*1*). Since then, many agricultural and technological advances have helped optimize the quality and production of wine. In modern viticulture, the use of pesticides has become a common practice, while the development of genetically modified organisms (GMOs), specifically yeast, has allowed for better control and prediction of the fermentation outcome (*2*). In addition, additives such as enological enzymes and grape tannins have been used to improve the colour and sensory characteristics of wine (*3*).

It is important to distinguish between the organic and natural winemaking processes. Natural winemaking strictly prohibits the use of any synthetic chemicals or non-indigenous yeasts. Organic wines are made through conventional processes using organically grown grapes, provided that no GMO yeast is used during fermentation (*4*).

Recently, winemakers have displayed increasing interest towards the use of natural and integrated methods for pest control.

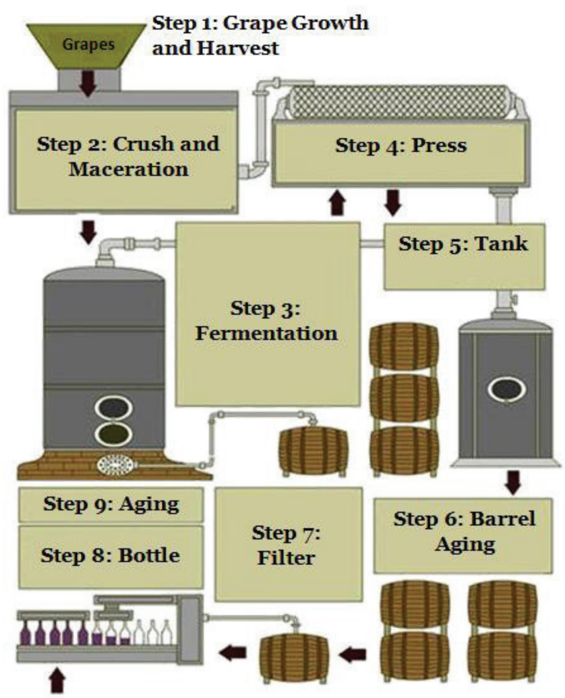

Figure 1. Schematic diagram of the general processes involved in winemaking. This review will focus on comparing steps 1 to 3 in natural and conventional winemaking (*32*).

Natural wine is also gaining attention in the industry due to its lack of synthetic additives, making it more attractive to many consumers. This movement is especially noticeable in regions of France, Italy, and the United

Kingdom, where the temperate climate allows for easier maintenance and better control of the natural winemaking process (*4*). Nonetheless, natural wine has gained very little attention in Canada. Here, we present a review on the viability of producing natural wine in the Niagara region.

PEST CONTROL AND MAINTENANCE OF GRAPES

There are many factors involved in the field of viticulture, two of which include methods for growth and maintenance. The practice of winemaking begins with the growth of grapes, which is a process in and of itself that will not be discussed in this review. When maintaining a vineyard, winemakers must manage the biological stresses imposed on their grape vines. Animals and fungi are two types of pests that most vineyards encounter.

A strategy that can be implemented to limit or rid the use of synthetic pesticides is known as Integrated Pest Management (IPM). IPM is an environmentally and ecologically conscious approach to pest control (*5, 6*). The system reduces pest damage through highly economical means by using the knowledge of pest life cycles and pest-environment interactions (*5, 7*). IPM is employed by the majority of both conventional and organic farmers in today's agricultural world (*5*). Conventional and organic IPM strategies differ in that the conventional IPM uses synthetic chemicals and pesticides, while organic farmers use natural chemicals and pest-environment interactions to manage pests in the vineyard (*8*). For instance, the use of insect predators, parasitoids, and disease-causing pathogens specific to certain pests, a method known as biological control, is often employed in organic viticulture (*9*).

In a study done by Jenkins and Isaacs (*8*), IPM was demonstrated in the control of the grape berry moth (GBM), *Paralobesia viteana* in the Eastern USA and Southern Canada, including the Niagara peninsula. The study showed that IPM strategies, which utilized reduced-risk insecticides such as pheromones for mating disruption in the control of the GBM, obtained similar or greater control when compared to strategies that used only conventional and synthetic insecticides (*8*). However, conventional pesticides sprayed on large scales can contaminate groundwater and surrounding systems. This causes damage to the health of the vineyard and creates potential harm to the owners and people who work in the vineyard. Thus, IPM increases the feasibility of natural winemaking in the Niagara region as it involves organic methods that can be applied to help regulate pests in the vineyards.

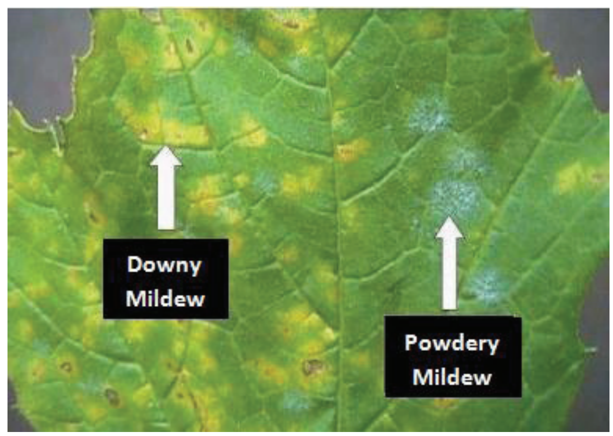

Figure 2. Downy and powdery mildew on a grape leaf (*33*).

Fungal infections are a major concern for Niagara vineyards due to the region's cold climate. In particular, the powdery (*Uncinula necator*) and downy (*Plasmopara viticola*) mildews that form in poorly aerated vines pose a significant problem (refer to Fig. 2) (*10, 11*). Traditionally, a mixture of fungicides such as Propiconazol, Metalaxil, and Mancozeb are used to combat these mildews. A natural alternative is a preparation called Urticum, which consists of a combination of bioactive oil extracts from the spice *Lumbrico humus* (*12*). A five-year study in Italy showed that Urticum was able to prevent the effect of powdery mildew at a rate between 90.80% and 97.10%, and downy mildew at a rate between 85.40% and 94.80%, which were comparable to the conventional methods of fungicidal control. In terms of grape yield, there was a reduction by 25% in organic methods when compared to conventional values in the first year. However, the last two years of the study found a difference of only 4% (*12*).

The use of a biological control, such as the tydeid mite, has also proven effective in controlling powdery mildew, although this particular mite is not very hardy (*13*). Another approach in mildew management involves controlling the canopy vegetation via leaf removal and pruning, which allows for better aeration of the berries. This reduces the dampness within the bunches of berries and helps prevent the growth of many different fungi (*10*).

No natural, copper-based treatments have been investigated and proven successful, but the accumulation of copper in soil can increase the soil toxicity. In addition, organic viticulture has recently experienced a movement towards the reduction of copper usage (*11*).

Although IPM has been fairly successful in controlling the animal pests of the Niagara region, fungal infection is still a prevalent issue due to the cold and wet climate. This may be the reason there is only one fully certified, exclusively organic winery in the Niagara region. As more effective biocides and organically approved fungicides emerge in the future, however, we may observe a change in this trend.

MACERATION AND EXTRACTION OF PHENOLICS

After harvest, grapes are crushed to release the juice and contents of the berries. This resulting mixture, which contains all the freshly pressed components of the grapes, is called "must." In a process known as maceration, grape skin, pulp, and seeds are immersed in the juice to extract the chemicals within the grapes (*1*). Among the many chemicals extracted, phenolics play the most important role affecting the colour, taste, and antioxidant activities of wine. An example of phenolics is anthocyanins, which are the compounds responsible for the colour of red wine. The phenolics extracted during maceration are often unstable and volatile, and require further chemical stabilization during fermentation (*3*).

There are many commercially available additives that can be introduced to the must during maceration to increase the extraction of phenolics. The most common additives are enological enzymes, which are pectinases that rupture grape skin cell walls to extract chemicals from the berries (*3*). Naturally, these enzymes are present only in trace amounts in mature grapes. The addition of enological enzymes increases the rate of extraction, but its effect on the extent of phenolics extraction is still under debate. Some studies observe a significant increase in the phenolics content with the addition of enological enzymes (*14, 15*), while other studies show no significant difference between wines made with and without enological enzymes (*16, 17*). The latter observation can be explained by the idea that an equilibrium between the phenolics in the must and those in the juice establishes after a certain amount of extraction (*18*).

Grape seed tannins are another commercially available additive that increases the extraction of phenolics. They have been shown to significantly increase the amount of phenolics content and antioxidant activities of wine. The effect of grape seed tannins is especially obvious in red wines, because the red colour is obtained from the anthocyanins and tannins (*17*).

Without the aid of enological enzymes and grape seed tannins, natural winemakers must seek other methods to optimize the extraction of phenolics. These methods include prolonged maceration, cold maceration, or heating of the must.

The heating of must during the last few days of maceration encourages extraction by high temperature. Heat increases the kinetic energy of the must, which helps to break down and extract phenolics from the grape skins. This technique has been shown to produce a high phenolics content immediately after pressing. However, the phenolics extracted using this method are chemically unstable and cannot be stabilized effectively during fermentation. Additionally, the heating of the must leads to low sugar content in the final wine, which directly influences its taste (*17*).

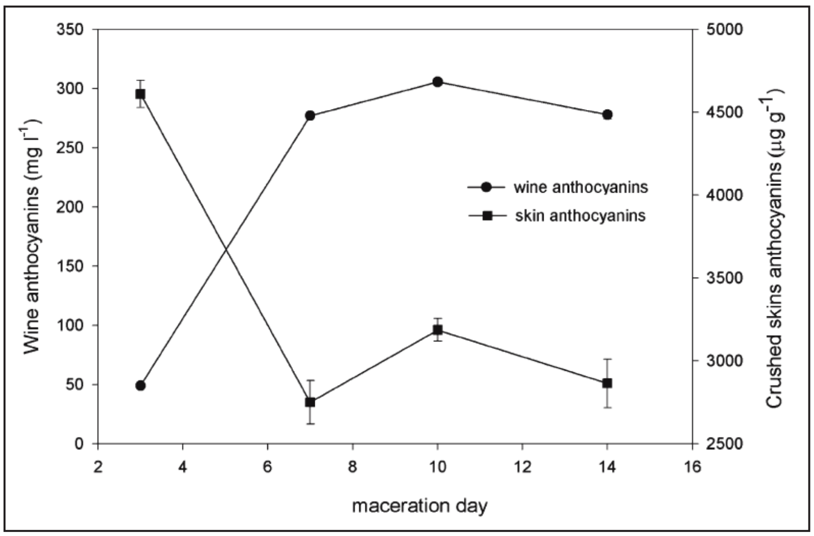

Figure 3. Total anthocyanin content of V. Vinifera (Varietal Monastrell) grapes and must during maceration. The wine anthocyanin content reaches a maximum at day 10 and slowly declines afterwards (*19*).

Conventional wines are usually macerated for ten days before fermentation; to increase phenolics extraction, natural winemakers could employ a prolonged maceration of twenty days. However, the effectiveness of this technique is still under debate. The total anthocyanin content of wines has been shown to reach a maximum after ten days (Figure 3) (*19*). Additionally, prolonged maceration decreases the antioxidant activities of wine, which is a characteristic that attracts many consumers. Moreover, prolonged maceration increases the acetic acid content that leads to an unfavourable sour taste of the wine (*20*).

In cold maceration, or cryo-maceration, must is kept at -5 °C for twenty-four hours during the extraction of chemicals. Cryo-maceration has attracted some attention over the past few years because it occurs at low temperatures, which prevents the escape of volatile phenolics. Although cryo-maceration can extract more volatile compounds than the conventional method, it cannot effectively extract all the phenolics in the grapes (*21*). Furthermore, wines produced from cryo-maceration demonstrate low antioxidant activities and colour intensity (*17*).

FERMENTATION OF GRAPE JUICE

By initiating fermentation, yeast plays a crucial role in the production of wine; the organism is responsible for the evolution of grape juice to an alcoholic beverage (*22*). This process begins when the must is transferred to large, temperature-controlled, and sealed vats. These vats create anaerobic conditions, causing the yeast to convert glucose in the grape musts to ethanol and carbon dioxide (*23*). In addition, the yeast produces a number of active compounds, including acids, esters, higher alcohols, and other volatile compounds that contribute to the overall flavour and aroma of wine (*24*).

The *Saccharomyces cerevisiae* yeast strains found within the grape almost always dominate during fermentation despite their low presence in the initial grape musts (*2, 25, 26*). Non-*Saccharomyces* strains in the grape are able to dominate fermentation at the beginning, but as toxic ethanol concentrations increase, these strains tend to reduce in population. It is at this point that the indigenous *Saccharomyces* strains, which have higher ethanol tolerance, begin to control the latter portion of fermentation (*25, 27*).

In grape must, fermentation can occur both spontaneously and inductively. Many winemakers add yeast to the must to obtain a desired aroma or flavour and to accelerate the process. In general, spontaneous fermentation takes significantly longer to occur than inoculated fermentation, with an average of 47 days and 14 days respectively (*28*). While it has been found that the sensory effects of wine made from spontaneous fermentation are generally more favourable, inoculated yeasts produce a more predictable wine (*28, 29*).
Furthermore, there is a great risk associated with spontaneous fermentation. Using only indigenous yeasts brings the risk of spoilage including stuck fermentation, browning, and the production of large amounts of undesirable aroma compounds (*2, 28, 30*). Stuck fermentation occurs when the conditions of the must are no longer conducive to yeast fermentation. This could lead to the unwanted presence of lactic acid bacteria, moulds, and ultimately an unfinished wine product (*2, 27*). There are many factors that contribute to stuck fermentation. These include high initial sugar concentration of the must, deficiencies in vitamins or nitrogen, the presence of anti-yeast factors, pesticide use, aerobic conditions, high temperature, high levels of fatty acids and their esters, and most of all, the accumulation of ethanol (*30*). A number of these factors arise from the conditions during grape growth, such as high sugar concentrations in over-ripened grapes, pesticide residues, and mould infestations (*30*).

During fermentation, the yeast produces a number of compounds that, in a high enough concentration, are toxic to the organism (*27*). In the initial phases, the ethanol concentration reaches a level that is toxic to the non-*Saccharomyces* strains in the must, leaving the *Saccharomyces* strains to complete the process. However, as fermentation continues, the ethanol concentration reaches a point where it is too high for even the indigenous *Saccharomyces* strains, killing all the remaining organisms (*30*). In addition, *Saccharomyces* yeasts produce fatty acids such as octanoic and decanoic acids, which are toxic to the organism, throughout fermentation (*31*). The decoanoic acid builds up in the cell wall of the yeast and impacts membrane function. Consequently, sugar metabolism diminishes and fermentation ultimately stops (*30*).

Condition	Wt of sugar consumed (g/liter) when fermentation stops[a]		
	Must 1[b]	Must 2[c]	Must 3[d]
Control	191	201	192
Addition of yeast ghosts (g/liter)			
0.2	232	218	200
0.5			237
1	247	243	

[a] Initial sugar concentrations: musts 1 and 2, 250 g/liter; must 3, 320 g/liter. Initial viable yeast level, 10^6 cells per ml; dry yeast, *S. cerevisiae*; temperature of fermentation, 19°C.
[b] Containing Euparene (dichlorofluoromethyl thiodimethyl phenyl sulfamide [Bayer]), 4 mg/liter.
[c] Containing Mikal (tris-*o*-ethylphosphonate-aluminum plus trichloromethylthio-iso-indolinedione [Rhône-Poulenc]), 10 mg/liter.
[d] From grapes infected by *B. cinerea*.

Figure 4. Lafon-Lafourcade studied the stimulation of alcoholic fermentation in grape musts containing inhibitory substances by adding yeast ghosts to the solution. The amount of sugar consumed is a measure of alcohol produced (*30*).

In some cases, an excess of acetic acid can be produced through natural fermentation causing an undesirable vinegar flavour in the wine. In addition to a higher alcohol tolerance, it has been shown that *Saccharomyces* strains produce less acetic acid than non-*Saccharomyces* strains, causing winemakers to prefer Saccharomyces strains over non-Saccharomyces strains (*25*).

The use of indigenous yeast may also impart an undesirable "browning" of the must before the completion of fermentation (*2, 28*). This would significantly decrease the profitability of the wine product due to its lowered aesthetic appeal. However, this characteristic can be reversed through methods of racking and detartration with cold stabilization. The final product would then have no visual difference to a conventional wine (*28*).

Stuck fermentation is a major problem associated with spontaneous fermentation, making natural winemaking unviable for many wineries. Using activated charcoal is a well-known method to restart stuck fermentation (*30*). Activated charcoal removes the toxic fatty acids, such as decanoic acid, and their esters that are produced at the end of fermentation (*30*). Although this method has been shown to be effective, its use is highly limited because of legislation and the difficulty involved in the removal of charcoal from the wine (*30*).

Many conventional winemakers inoculate grape juice with specific starter yeasts to prevent stuck fermentation and other problems that occur with natural fermentation. GMO yeasts can also be added to further accelerate the process and decrease the risk of spoilage. However, organic wineries, such as Frogpond Farm in the Niagara region, are limited to the use of only non-GMO strains (23).

In a study by Lafon-Lafourcade, et al., it was found that adding the cell wall/membrane complex of the yeast, also known as "yeast ghosts," helps to avoid fermentation stoppage (*30*). As seen in Figure 4, the amount of sugar consumed, which is representative of the amount of alcohol produced, increases significantly when yeast ghosts are added to grape musts containing inhibitory substances (*30*). This process works in a similar manner to that of the activated charcoal; yeast ghosts adsorb the fatty acids to reduce their inhibitory effect. The use of yeast ghosts permits the survival of a higher number of viable cells during the latter part of fermentation, making it the most effective activator of wine fermentation found to date (*30*). Since yeast ghosts have no effect on taste or aroma, and help the yeast fulfill their potential fermentation capacity, it is possible that the addition of yeast ghosts could replace that of inoculated yeasts in grape must.

CONCLUSION

Despite the movement towards natural winemaking in Europe, it is not a feasible method in the Niagara region for several reasons. Firstly, the cold and humid climate of the Niagara peninsula makes grapes susceptible to fungal infections. Additionally, natural winemaking limits the methods through which phenolics can be extracted during maceration. To date, no natural method has been found to produce wines containing as high a content of phenolics as those made through conventional methods. Moreover, the lack of inoculated yeast in natural winemaking can lead to an unpredictable final product, as well as stuck fermentation, browning, and the production of undesired aromatic compounds. In conclusion, the growing of organic grapes will be plausible with the development of effective organic fungicides. The use of only indigenous yeast and no tannin additives, however, hinder the economical production of natural wines in the Niagara region.

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Factors Affecting the Taste of Niagara Region White Wines

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Abstract

The factors affecting the characteristics of Niagara region white wines are examined in this paper. The cool climate of the Niagara region causes a short growing season, creating white wines with low sugar levels and high acidity levels. Once harvested, the grapes provide the basis of wine flavour through their contribution of sugars, aldehydes, esters and terpenes. Taste is also affected by fermentation, a process that requires the management of various bacteria and yeast. Yeast are the most important microorganism in the fermentation process because they are responsible for creating alcohol from sugar. Bacteria are often detrimental to wine flavor because they generate vinegar and other off-flavours depending on their metabolic processes. However, the lactic acid bacteria *O. oeni* is responsible for reducing the acidity in wines, which is especially important for Niagara white wines with low sugar content. Aging, which follows fermentation, uses oak barrels to introduce flavourful compounds such as furfural to the wine. In bottled wine aging, care must be taken to avoid oxidative spoilage of wine. Apart from these physical considerations, a psychological component associated with perceived cost also influences the taste perception of wines. The same wine, when priced higher, triggers a stronger positive taste sensation.

Keywords: grape, white wine, taste, yeast, fermentation, aging, barrel, Niagara region, oxidation, terrior

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INTRODUCTION

The Niagara region, located in Ontario, Canada, has a wine industry that is well regarded world-wide, with particular respect given to its white wines. Wine taste results from a myriad of interacting compounds. Many of these compounds are intrinsic to the grape, but many more compounds are created during the fermenting and aging processes. The taste of Niagara wines is also affected by terroir, defined as the special characteristics that the climate, physiography and soil of the region impart to the wine. Furthermore, the perceived taste of wine has a very strong psychological factor that is related to how the wine is presented to the consumer. This review analyzes effectors of Niagara white wine taste by explaining the influence of terroir, summarizing the contribution made by the grape itself, discussing the fermentation and aging process, and then addressing psychological factors that affect how wine is tasted.

INFLUENCE OF GEOLOGY AND CLIMATE

The Niagara region is located in southwestern Ontario, and is adjacent to Lake Ontario. The region is comprised of two major areas – the Lake Iroquois Plain and the Escarpment (See Fig. 1). Glaciations in the Quaternary period were responsible for carving the cuesta landform of the Niagara escarpment. A cuesta is a ridge with a gentle slope on one side, and a cliff on the other. River valleys and waterfalls in the region were created by Holocene era erosion (*1*). The sediments of the region are proglacial and subglacial, and they eroded during the Late Pleistocene to Early Holocene epochs (*1*). The sediments have since broken down into soil as a result of organic factors and weathering. The soils in the Niagara region range from massive clay to sand (*1*). Currently, there is no evidence that the parent material of a soil is related to wine character, or that grapevine mineral uptake impacts fruit quality (*2*). Therefore, it is important to look at how the geology indirectly affects wine flavour through water availability and drainage (*3*). Clay is very effective at storing water so there will always be water available for grapes vines grown on clay. On the other hand, if the vines have too much water, vegetative growth will be

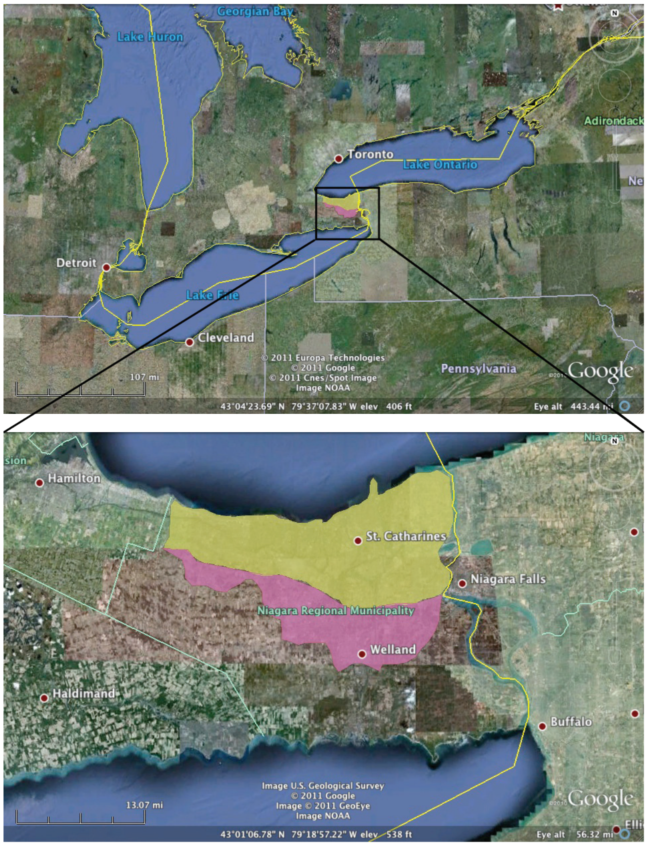

Figure 1: The Niagara region is located adjacent to the south-east side of Lake Ontario. The two major areas in this region are the Lake Iroquois Plain (the solid yellow area) and the Niagara Escarpment (the solid pink area) (*4*).

too high between the stages of flowering and veraison (berry ripening). The shade caused by the extra foliage from the grape plant will inhibit the grapes from ripening and ultimately create wine that is not sufficiently sweet. Because of the sloped escarpment and the many streams in the Niagara region, Niagara vineyards have well-drained surface and ground water. Therefore excessive vegetative growth is not an issue (*1*).

In addition to geology, the climate of the Niagara region also contributes to the terroir of Niagara white wines. The region is characterized by a cool climate with lots of sunlight during the growing season and substantial shifts in day-night temperature; the temperature frequently drops more than 10 degrees after the sun sets (*5*). The minimum temperature required for grape vine activity (around 20°C) is reached less frequently in the Niagara region than it would be in a warmer climate, and therefore grape vines have less opportunity for metabolite accumulation (*6, 7*). This results in grapes with decreased levels of sugar, amino acids, phenolic compounds, and potassium and increased levels of organic acids (*6*). As such, grapes grown in cool climates like the Niagara region have decreased potential alcohol levels and higher acidity levels (*6*).

Although geology and climate do provide Niagara region wines with a characteristic taste, the contribution of terroir is still relatively abstract. It's difficult to look at trends in a large region and pinpoint specific effects on wine taste. The effect that certain grape compounds have on wine is much more concrete, as are the affects of fermentation and aging.

INFLUENCE OF THE GRAPE

It is important to address the original compounds found in grapes before looking at how fermentation and aging modify wine taste. In this analysis, compounds that contribute to favourable and unfavourable tastes will be examined. Although some differences exist between wine varietals, many important volatile compounds are common to all white wine grapes. Only the most important compounds will be mentioned in this review as the list of volatile compounds is extensive.

Alcohol is the primary contributor to wine taste. While the majority of the alcohol present in the final wine product is a result of the fermentation process, important alcohol precursors exist in the berries. Since ethanol is produced from the fermentation of the grapes' glucose and fructose, the concentration of these sugars affects the final alcohol content of the wine (*8*). Apart from ethanol, other alcohols are present in the final product and these also affect taste. These alcohols are derived from aldehydes such as (Z)-2-hexenal. It has been noted that wines with large quantities of six carbon aldehydes and alcohols, such as Sauvignon Blanc, have a green, leafy aroma (*8*). Contrarily, wines with higher concentrations of esters and terpenes, such as Reislings, have fruity and floral characteristics.

Acid concentration also plays a role in taste. Key acids in wine include tartaric and malic acid (*9*). As already noted, the concentration of these acids in grapes depends on climate and growing conditions. pH is a very recognizable trait in wine tasting. Acids can also mask sweetness from sugars, so it is important to look for balanced sugar and acid content before grapes are harvested (*9*).

Certain compounds present in the berries at harvest have negative effects on taste. One such compound is furaneol, which produces a strawberry taste that is considered undesirable by wine makers (*9*). This compound is most prevalent in crosses between *vinifera* and *labrusca* grape species . Potato, grassy and green pepper tastes sometimes found in Sauvignon Blanc grapes are due to certain isobutyl methoxypyrazone compounds (*9*). These compounds develop during ripening and their taste is easily detectable in the wine product, making them especially problematic.

Careful monitoring and regulation of the concentration of sugars, acids and other compounds in the grape during growth are critical for timely harvest and the success of the fermentation process.

INFLUENCE OF FERMENTATION PROCESS

The fermentation process in all wine is a complex interaction between various microorganisms, mainly yeasts and bacteria. The most important microorganisms in the fermentation process are yeasts because they are responsible for the conversion of sugars into ethanol (*10*). Yeasts also remove much of the sugars and nutrients from grape juice early in the fermentation process, which, combined with the production of certain inhibitory metabolites, make it more difficult for other microorganisms to grow (*10*). Even with competition from yeasts, bacteria can be significant contributors to wine flavour because damaged grapes provide an excellent substrate for bacterial growth (*10*). Overall, both bacteria and yeast can contribute positively and negatively to the flavour of wine during the fermentation process.

The two main types of bacteria involved in the fermentation process are those which produce acetic acid and those which produce lactic acid. Acetic acid bacteria such as *Acetobacter aceti* and *Acetobacter pasteurianus* are particularly problematic for wine taste because they produce acetic acid, giving wines a vinegary taste (*10*). Acetic acid can also inhibit proper yeast growth, thereby halting alcohol fermentation at unacceptably low alcohol levels (*11*). Lactic acid bacteria can also be very detrimental to wine flavor. For example, many species within the Lactobacillus and Pediococcus genus can cause severe off-flavours in wine such as bitterness, rancidness, mousiness (described as tasting similar to the scent of rodent urine), and a geranium taint (*12*). In general, preventing the growth of spoilage bacteria in wine depends on good hygiene in the wine making facility, the use of healthy grapes, and using proper conditions for yeast proliferation.

Though many bacteria produce undesirable flavours in wine, the lactic acid bacteria *Oenococcus oeni* are actually beneficial to wine because they reduce its acidity. Immediately after fermentation, wines tend to be overly acidic, a result of tartaric and malic acid naturally present in grape juice. Fortunately, *O. oeni* are capable of enzymatically decarboxylating L-malic acid into L-lactic acid, which is significantly less acidic (see Fig. 2) (*12*). This can be particularly beneficial for white wines from the Niagara region, where the grapes often have low sugar and high acidity levels (*6*). Since *O. oeni* is necessary for reducing the acidity of wines, starter cultures are often added to fermentation mixtures. This has the added benefit of increasing nutrient competition for many spoilage bacteria (*12*).

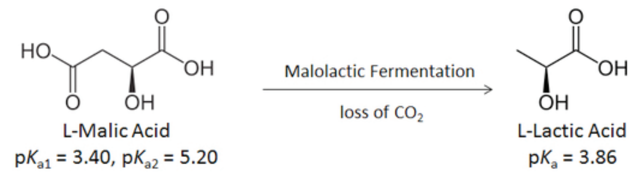

Figure 2: *O. oeni* are capable of enzymatically decarboxylating L-malic acid into the significantly less acidic L-lactic acid.

Aside from fermentation, yeasts contribute to the flavor of wine in many ways (see Fig. 3). Although there are many natural yeasts from the grape surface present during early fermentation, as the alcohol levels reach 5-7%, many yeast species die off until the predominant species is the wine yeast, *Saccharomyces cerevisiae* (*10*). *S. cerevisiae* and other yeasts contribute a plethora of compounds that give wine flavour. Volatile esters are one of the main groups of compounds present in wine as a result of yeast metabolism. The main ester is ethyl acetate, which is pleasant at low concentrations but contributes a solvent or vinegar aroma at high concentrations (*9*). The other main esters are isoamyl acetate, hexyl acetate, 2-phenylethyl acetate and ethyl caproate, all of which give pleasant fruit or floral flavours to wine (*12*). Yeasts are also largely responsible for the generation of glycerol in wine. Glycerol is a liquid that has a sweet flavor and high viscosity which affects the body and mouth-feel of a wine.

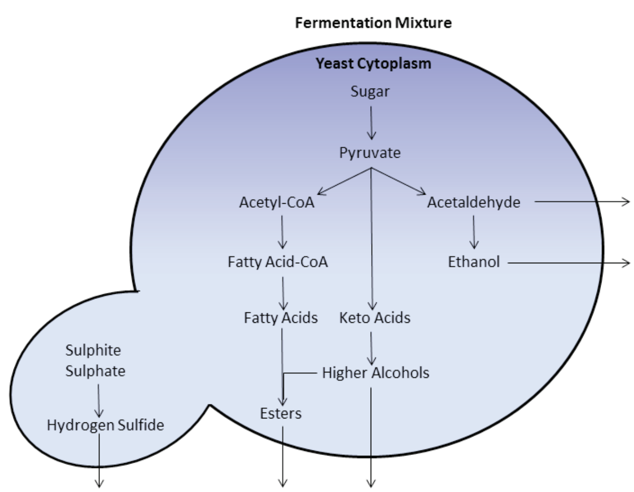

Figure 3: Yeasts contribute a variety of compounds to the fermentation mixture as a result of sugar, sulphate and sulphite metabolism.

While yeasts are generally regarded as beneficial to wine flavor, they can also cause serious faults in the wine. One common example is the production of extremely foul smelling sulphur compounds such as hydrogen sulphide (*10*). Hydrogen sulphide and sulphur dioxide are produced primarily as the result of sulphate metabolism in yeast. Hydrogen sulphide can also react with other organic components in wine to produce mercaptans, disulphides, and thiols, all of which usually have unpleasant garlic, onion or rubber aromas (*12*). Furthermore, wines are often ruined by certain *Brettanomyces* strains of yeast, which can be present on contaminated barrels. These strains cause mousy or medicinal flavours in wine due to the production of tetrahydropyridines, 4-ethyl guaiacol and 4-ethyl phenol (*10*). Despite the fact that yeasts are the most important microorganism in wine production, it is clear that they can also ruin the quality of a wine.

Both yeasts and bacteria contribute significantly to the flavour of wine in the fermentation process. Most bacteria are detrimental to wine flavour, except for *O. oeni* which is responsible for decreasing the acidity of wines. This is especially useful for white wines in the Niagara region, which have high acidity and low sugar content as a result of the generally cool climate. Yeasts are the most important microorganisms in the fermentation process due to their production of alcohol and a wide variety of pleasant flavour-active compounds. However, certain yeasts can also taint wine with various disagreeable sulphur compounds and other off-flavours. Overall, the taste of wine is strongly influenced by the processes carried out by various microorganisms in the fermentation process.

INFLUENCE OF AGING PROCESS

While fermentation is the key process in transforming grape juice to wine, the aging process can influence the taste of wine to produce desired traits. Many factors contribute to the development of flavour in white wines during the aging process. Different tasting white wines can be made from the same grape varietal through the use of different aging techniques. Two of the most influential aging techniques on wine flavour that are used by the Canadian wine industry are oak barrel aging and wine bottle aging (*13*). Within each of these treatments, many factors can be manipulated to produce a specific type of white wine.

Oak barrels influence the flavour and aroma of wine because oak wood contains many compounds that are extracted by the wine during the aging process. The extent of oak treatment is an important factor for determining the concentration of a compounds in wine (*14*).

Each oak compound has a specific extraction trend associated with oak chip and oak barrel treatment. Furfural, a compound that results from the degradation of monosaccharides in hemicellulose – a component of oak wood – is responsible for the dried fruit and burned almond character in white wine (*14*). Furfural has a fast extraction rate. White wine treated with oak chips has a much higher concentration of furfural than wine treated in an oak barrel in the same time span. This same trend is observed in the extraction of syringaldehyde, a compound that is responsible for vanilla flavours and formed by the breakdown of lignins during oak toasting (*14*). Syringaldehyde, unlike furfural, has a slow extraction rate. After an extended aging time, oak chips provide wine with a higher syringaldehyde and furfural concentration than barrels (*14*). This information suggests that oak chip treatment allows for more compound extraction compared to the oak barrel treatment. This is likely due to the fact that oak chips are completely submerged in wine and the entire surface area of the chip is available for extraction while only the inside surface of an oak barrel is exposed to wine (*14*).

Figure 4: Example of roll on tamper evident (ROTE) wine closures (*15*).

Factors involved in wine bottle aging include temperature, pH, light exposure, and oxygen exposure. Of these factors, oxygen exposure is most difficult to control and has the most significant effect on the taste of wine (*13*). If oxygen exposure is too high, oxidative spoilage can occur and result in foul tasting wines. For example, a high quality aged Riesling wine typically has toasty and cooked citrus characteristics. Oxidation of a Riesling wine replaces these flavours with nutty and cooked vegetable characteristics (*13*).

The choice of closure type and bottle orientation are two important decisions that influence the level of oxygen exposure of wine. Some common choices of closure type include roll on tamper evident (ROTE) closure, synthetic closure, and natural bark corks (see Fig. 4). ROTE closures provide wine with a successful barrier from oxygen and wines bottled with this closure typically experience very little oxidation (*13*). Synthetic closures are inefficient at blocking air at the bottle opening which causes high levels of oxidation. Wines sealed with synthetic closures also experience oxidation early in the aging process and for this reason cannot be stored for an extended time (*13*). This short storage time inhibits the development of certain wine characteristics. When natural corks are used for sealing white wines, bottle orientation is an important factor to consider. Natural corks are known to shrink when dry, and this shrinkage allows for oxygen to enter the bottle and oxidize the wine. Wine bottles placed in an inverted position experience less oxidation because the natural corks are wet with wine and as a result do not shrink and allow oxygen to pass through the bottle opening (*13*). Oxidation has a significant impact on the flavour and aroma of white wine but the level of oxygen exposure can be controlled through different closure types and bottle orientation.

INFLUENCE OF PRICE

The taste of wine is not strictly dependent on the intrinsic chemical properties of the wine. It is also influenced by other factors such as food pairing and wineglass shape. An analysis of all these factors is beyond the scope of this text. However, one surprising and powerful external factor that can be discussed is the price of the wine. In one study, subjects were scanned using functional magnetic resonance imaging (fMRI) while they sampled different Cabernet Sauvignons wines. While the sample was being administered, the retail price of the wine sample was displayed on a screen. However, these prices were fictitious and several of the samples were actually the same wine (*16*).

When the subjects were asked to rate the pleasantness of the wine, they consistently ranked cheaper wines as less pleasant than more expensive wines, even when the wines were identical. A follow up study showed that when price information is not provided there is no difference in reported pleasantness in similar wines. When subjects were sampling the apparently more expensive wines, fMRI showed increased activity in the medial orbitofrontal cortex (mOFC) (see Fig. 5), showing that subjects truly believed that the more expensive wines tasted more pleasant (*16*). The correlation between pleasantness and mOFC activity has been documented extensively, even for senses other than taste, though the mechanisms involved in this interaction remain speculative (*17, 18*).

When subjects were asked to rate the intensity of the wine, their ratings were independent of the displayed cost of the wine samples. This complements an fMRI analysis that shows that price has no effect on the parts of the brain directly involved in sensing taste, such as the insula cortex and the ventroposterior medial nucleus. They then concluded that the flavour expectancies generated from cognitive processes are combined with the sensory information to generate the conscious perception of pleasantness (*16*).

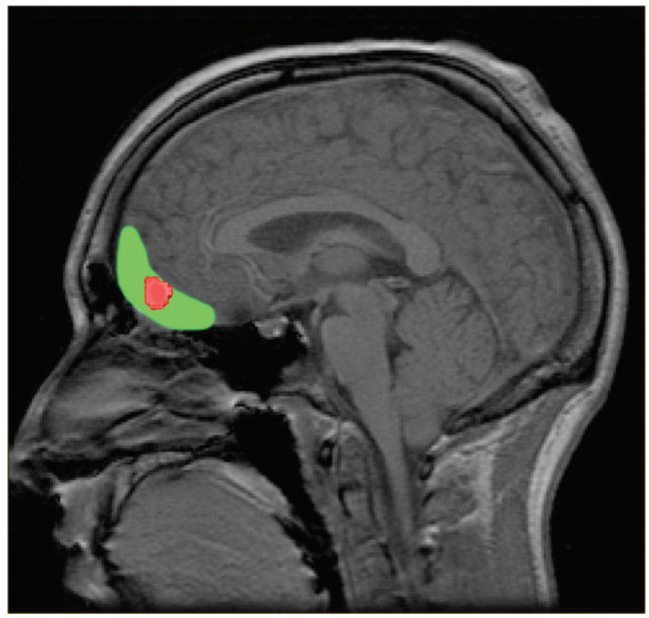

Figure 5: The mOFC (shown in red) is part of the larger orbitofrontal cortex (shown in green). They are located at the front of the brain (*19*).

This study has significant implications for the Niagara wine industry as it stresses the importance of marketing and product presentation. The current economic model is based on the assumption that the pleasantness of a wine, and by extension the demand, is based on the chemical composition of the wine (*16*). However, customers' preconceived, though unconscious, notions of taste are also very important to the overall pleasantness of the wine. The study discussed above demonstrates the importance of strategic price points. For the relatively young Niagara industry to keep up with the more-established French and California wine industries, it needs to take advantage of fact that marketing techniques, such as price point, can greatly affect the consumer demand.

CONCLUSION

As this review has demonstrated, the taste of the final wine product is the result of multiple factors and processes. The region where the grapes are grown provides wines with a characteristic taste that is dependent upon the soil's water drainage capabilities and the climate. The grapes determine the initial concentration of sugars and flavourful compounds available for modification in the fermenting stage. The fermentation process involves coordinating and controlling the actions of microoganisms to produce ethanol and other desirable flavour compounds. Bottle and barrel aging process allow for additional modifications of wine flavour. Finally, a taster's perception of the wine can be influenced by completely extrinsic qualities such as price. All of these factors are important to consider in relation to the final taste of a wine. The Niagara region is well known around the world for the quality of its wines, which is a tribute to the region's skillful managing of all stages of wine making. Further investigation can only be of benefit to wine makers, the wine industry, and consumers.

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