Terroir

An Integrated Wine Science Publication

THE CHEMISTRY OF WINE
H_2O, et al.

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millennials and the wine market

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Terroir

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WINE SCIENCE

Working in small groups, students in ISCI 3A12 examine the science behind wine making, from the art of viticulture to its eventual consumption by the public. Students perform 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*.

This Publication is written by members of the ISCI 3A12 class of 2017.

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The Chemistry in Your Glass of Wine

Behind the complex flavours, lies a full body of science

Meghan Craughwell, Alexi Doan, Katie Graham, and Michele Lefebvre

Grapefruit, spicy, earthy, melon, blackcurrant, lavender, vanilla, grass. It seems as though wine can taste like just about anything. The taste can even be as absurd as leather, petrol, or wet dog. How do these complex flavours emanate from a single fruit? It is all in the science of winemaking. Many biochemical reactions, beginning with the ripening of the grape, continuing throughout fermentation, and ending in your glass of wine, are responsible for these diverse flavours. The underlying science can explain the variation in wine flavour across regions and open the door to innovation. Winemakers in the Niagara Region are creating a niche for Canada by capitalizing on its unique climate and their willingness to try something new.

Flavour is a result of the combination of two senses: taste and smell (Bakker and Clarke, 2012). It helps shape our likes and dislikes, and is extremely important in the food and wine industry. Unlike many other beverages, wine has the ability to take on countless flavours. When describing wine flavour, we usually refer to the smell as the aroma. Aroma is the pleasant response of the sense of smell, specifically the olfactory (smell) system, when stimulated by volatile aromatic compounds (Salo, 1970). There are a wide variety of wine aromas including orange blossom, passion fruit, and truffle, as seen in Figure 1. In contrast, the taste of wine is sensed by the gustatory (taste) system when stimulated by non-volatile compounds and distinguishes between a sweet or bitter wine (Polášková, Herszage and Ebeler, 2008; Bakker and Clarke, 2012).

Although taste plays an important role in wine flavour, aroma has the most significant effect on flavour perception (Polášková, Herszage and Ebeler, 2008). The aroma skeleton of wine consists of the major groups of volatile compounds: alcohols, esters, acids, aldehydes, and acetals (Romano et al., 2003). These compounds are perceived through both the smelling and tasting of wine due to a portion of compounds that travel retro-nasally through the back of the mouth to the olfactory organ (Bakker and

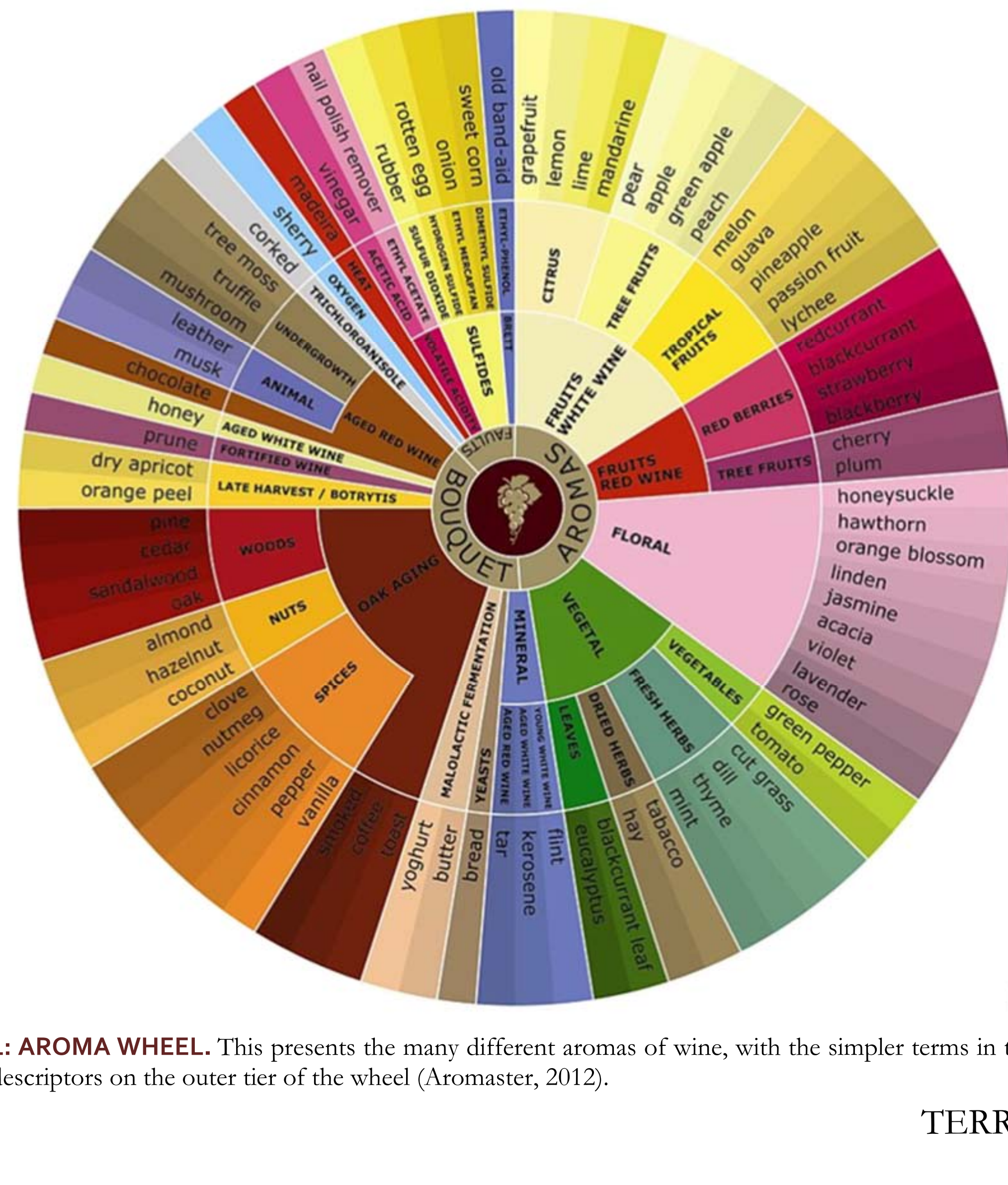

FIGURE 1: AROMA WHEEL. This presents the many different aromas of wine, with the simpler terms in the centre and complex descriptors on the outer tier of the wheel (Aromaster, 2012).

Clarke, 2012). This explains why the perceived flavour can often change drastically from the perceived aroma. Additionally, the perceived aroma is determined by the sensory threshold of the compound, which is defined as the minimal level at which a substance can be detected by a human (Salo, 1970).

Wine flavours can originate from the grape, others present themselves after fermentation, and a portion arise later throughout the aging process (Romano et al., 2003). In brief, these flavours are a complex cocktail of varietal, fermentative and post-fermentative flavours.

THE HUMBLE GRAPE

The grape plays a crucial role in determining wine flavour. Each grape is essentially a reservoir of sugars, acids, phenols, flavour compounds, and flavour precursors that influence wine character (Polášková, Herszage and Ebeler, 2008). The collection of compounds in the grape is a product of biochemical and physiological changes that occur during two stages of berry growth: development and maturation (Conde et al., 2007).

Several solutes accumulate in the berry during the initial development or growth period. The primary compounds are malic acid and tartaric acid, which determine the acidity of the berry and thus the acidity of the wine (Conde et al., 2007). Other solutes that develop include minerals, amino acids, micronutrients and aromatic compounds.

The second phase of growth involves the maturation or ripening of the grape, when the most dramatic changes in berry composition occur. As grapes mature, acid content decreases and sugar content increases (Robinson and Harding, 2015). The amount of acid and sugar in the final stages of ripening have a large impact on the final flavour of the wine, as well as the flavour compounds and precursors synthesized in this stage (Conde et al., 2007).

Flavour compounds produced during development and ripening vary in composition and relative ratios depending on grape variety, which explains the signature flavours of varietals (Polášková, Herszage and Ebeler, 2008). The large diversity across varietals and presence of flavour compounds in the grape are thought to fulfill an evolutionary role. This includes attracting insects to assist in pollination, defending the berry flesh from insects and microbes during development, attracting birds that eat and disperse the seeds, and inhibiting germination of competitive plant species (Robinson and Harding, 2015).

Growing conditions, including soil composition, sunlight, and climate, strongly influence the chemical composition of the grape and thus play an important role in shaping the final flavour of wine (Conde et al., 2007). The effect that climate can have on wine character is especially noticeable in regions, such as Niagara, with cooler grape growing conditions.

COOL CLIMATE WINES

The climate in which grapes are grown can have a noticeable impact on flavour compounds and precursors. Many vineyards are located in regions with warm climates to allow for maximal growing seasons, but some vineyards are located in cool climate regions, such as the Niagara Peninsula in Ontario (Shaw, 2005). This popular wine region is considered to have a semicontinental climate, moderated by Lakes Erie and Ontario, creating an area with a favourable climate for grapes. Even though Niagara vineyards grow approximately 50 different varietals, common flavour characteristics unite many of the wines, which can be attributed to the cool climate (Robinson and Harding, 2015).

Cool climate wines are usually described as delicate and refined with a higher acidity that gives freshness (Tarko et al., 2014). Since the growing season is shorter, the chemical composition of the grapes differs slightly from those grown in warm climates. Often these grapes ripen later and sometimes incompletely, resulting in a lower sugar content, and thus a slightly lower alcohol content. Additionally, the fruit has a higher acidity due to excess quantities of malic acid, which acts as protection from bacterial attack during the harvest season. This increase in acidity affects final wine character as it usually means that winemakers will allow for a secondary fermentation process involving bacteria. Winemakers in cool climate regions use this process as a means to reduce the final acidity of the wine and create a unique flavour profile (Tarko et al., 2014).

Another characteristic of Niagara wines is the often-described mineral flavours (Maltman, 2013). Interestingly, these flavours are becoming more popular but the term wine minerality only recently originated. This new term creates a common misconception that the minerals in the soil are causing the flavour, but these minerals are known to have no direct influence on the taste and aroma of wine (Maltman, 2013). Recent research has shown that mineral flavours may be caused during primary fermentation when the yeast are under nutritional stress, leading them to produce

FIGURE 2: ALCOHOLIC FERMENTATION. Pinot noir grapes undergoing primary fermentation, as indicated through the carbon dioxide foam atop the grapes (Smith, 2010).

different compounds, such as succinic acid (Baroň and Fiala, 2012). Although the direct cause of minerality is not yet known, it provides a unique flavour to cool climate regions. For instance, cool climate Rieslings often tend to be described as having mineral or flint characteristics, whereas warm climate Rieslings often have more melon flavours (Douglas, Cliff and Reynolds, 2001). Despite the differences in grape characteristics between cool and warm climates, wines produced in both climates heavily rely on fermentation to develop complex flavour profiles.

FROM GRAPES TO WINE

Although there are various processes that impact the flavour of wine, microbes have the greatest influence. Once the grapes are harvested and pressed, they undergo fermentation, which involves yeast and occasionally bacteria (Cappello et al., 2017). The crushed grapes first undergo primary, or alcoholic, fermentation which is carried out by various species of yeast after which secondary, or malolactic, fermentation (MLF) is performed by bacteria. This provides two opportunities to influence wine character.

Primary fermentation, shown in Figure 2, is an essential stage of winemaking as it increases alcohol content. This process can be initiated spontaneously by *Saccharomyces cerevisiae* and non-*Saccharomyces* species of yeast that are present on the grape. In contrast, inoculated fermentation can be performed, where a starter culture of *S. cerevisiae* is added (Fleet, 2008). *S. cerevisiae* dominates during alcoholic fermentation as it is able to withstand the high ethanol concentrations and low pH of the wine at that time. However, winemakers are more interested in the presence of non-*Saccharomyces* species during this process due to the role they play in the development of flavour (Fleet, 2008).

The main role of yeast in the fermentation stage of winemaking is to convert sugars found in the grapes into ethanol and carbon dioxide (Robinson and Harding, 2015). However, this process also produces a large variety of minor compounds that influence flavour. Enzymes produced by yeast transform flavour-inactive compounds found in the pressed grapes into the corresponding flavour-active compounds through hydrolysis, which contributes to the sensory profile (Fleet, 2008).

After primary fermentation is completed, some wines undergo MLF, where lactic acid bacteria (LAB) convert malic acid to lactic acid through the removal of a carboxyl group. This mechanism reduces wine acidity, provides microbial stability to prevent wine spoilage, and similar to alcoholic fermentation, causes modifications to aroma (Cappello et al., 2017). Researchers have found that LAB produce a wide variety of enzymes, which are of interest to winemakers as they are essential for the further modification of flavour-active compounds in the wine. Since MLF follows alcoholic fermentation, it is directly affected by compounds that are released by yeast.

The impact of yeast and LAB on wine character is much greater than previously thought, which creates the opportunity for winemakers to purposefully select specific microbes to alter wine profiles (Swiegers et al., 2005). By selectively choosing microbes for fermentation, winemakers can influence the levels of certain volatile compounds responsible for characteristic wine flavours such as berry, apple, and butter.

VERY BERRY

Berry is arguably one of the most commonly described wine flavours, especially for red wines, such as Cabernet Franc, Pinot Noir, and Muscat. Typical berry flavours include strawberry, blackcurrant, blueberry, and raspberry, although this does not imply that the winemaker has added berries to the fermenting wine (Hein, Ebeler, and Heymann, 2009).

The two compounds commonly responsible for berry aromas in wine are esters, which are formed through the reaction of an acid and an alcohol, and thiols, defined as organic, sulphur-containing, volatile compounds

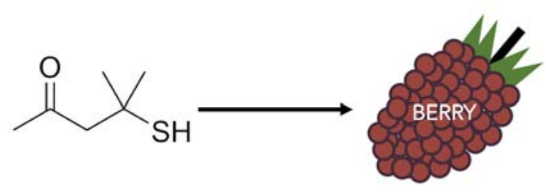

Figure 3: BERRY. The chemical structure of 4MMP, which corresponds to blackcurrant flavours, is released by yeast during fermentation (iChem Labs, 2017; Microsoft, 2017).

(Sáenz-Navajas et al., 2010). Some notable esters are ethyl isobutyrate and ethyl octanoate, which impart strawberry and fresh fruit aromas, respectively (Sáenz-Navajas et al., 2010). A wide variety of thiols have been known to produce blackcurrant flavours in many different wines (Parker et al., 2017). Most of the esters and thiols responsible for berry aromas are produced during alcoholic fermentation, and winemakers can influence the berry aromas of their wines by differentiating the type of yeast used for fermentation (Dubourdieu et al., 2006; Parker et al., 2017).

Depending on the type of yeast used in fermentation, the berry aroma profile of wine is subject to change. Several of the most popular commercial yeast mixtures of *S. cerevisiae* and non-*Saccharomyces* yeast produce significantly variable levels of the thiol 4-mercapto-4-methylpentan-2-one (4MMP), as shown in Figure 3 (Howell et al., 2004). In low concentrations, 4MMP imparts a pleasant blackcurrant flavour to wine (Howell et al., 2004). However, high concentrations of 4MMP result in a flavour akin to cat urine, which is why winemakers must be mindful of its concentration (Howell et al., 2004). 4MMP is not only influential for the flavour it imparts, but also for its ability to negate negative aromas, such as vegetative or bell pepper (Berger, 2009).

AN APPLE A DAY...

Although apple juice or cider are not generally associated with wine, apple aromas are an extremely popular descriptor for wine labels, especially in white wine varietals. The volatile compounds associated with apple aromas are produced from microbes, although these aromas predominantly develop from yeast during alcoholic fermentation.

The degradation of glucose in primary fermentation largely produces ethanol, but byproducts also accumulate throughout this process (Liu and Pilone, 2000). These products primarily consist of volatile compounds including aldehydes and esters. Aldehydes have been found to emit apple-like aromas with low sensory thresholds. Of this group of compounds, acetaldehyde (Figure 4) is dominant as it contributes to more than 90% of the aldehydes identified in wine (Liu and Pilone, 2000). Acetaldehyde is a byproduct formed in the last step of alcoholic fermentation, prior to the production of ethanol. In low quantities, acetaldehyde has been found to impart fruity, apple-like aromas; however, in high quantities it can emit bruised apple, vegetative or grassy aromas (Padilla, Gil and Manzanares, 2016).

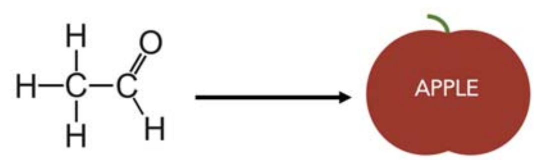

Figure 4: APPLE. Acetaldehyde, shown above, is responsible for apple aromas in wine but is also in present in apple juice and apple cider (iChem Labs, 2017; Microsoft, 2017).

There is great variation in the aroma profile attributed to acetaldehyde due to the differing concentration of this byproduct between wine varietals. Apple aromas are identified primarily in white wines, which corresponds to an average acetaldehyde concentration of 80 mg/L. On the other hand, red wines only have an average concentration of 30 mg/L (Liu and Pilone, 2000). Different species of yeast have a great influence on the quantity of acetaldehyde produced, with *S. cerevisiae* producing higher levels of acetaldehyde compared to non-*Saccharomyces* species (Padilla, Gil and Manzanares, 2016).

As described previously, the process of secondary fermentation involves the conversion of malic acid into lactic acid using LAB. Malic acid is an organic acid attributed to the sour taste of many fruits, including apples (Volschenk, van Vuuren and Viljoen-Bloom, 2006). In wine production, excess quantities of malic acid following MLF can increase the acidity of wine, resulting in a sour apple taste. Unlike most sweet aromas, the sour tastes are heightened as the low pH of wine increases the acidic character of malic acid (Noble, 1998).

BUTTER UP!

If you ever find yourself buying a Chardonnay, it is likely that the label description will include the word buttery. This specifies that the wine either has a buttery nose, making it smell like movie theatre popcorn, or has butter or butterscotch flavours. However, this does not indicate that the winemaker has added a pound of butter into the wine barrels. This process is instead reliant on LAB during wine production.

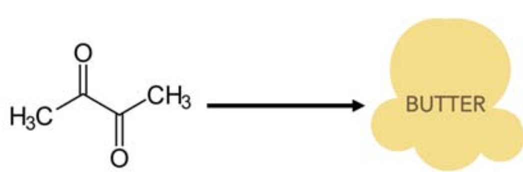

Figure 5: BUTTER. The chemical structure of diacetyl, a volatile compound which emits buttery aromas similar to that of popcorn (iChem Labs, 2017; Microsoft, 2017).

The buttery aromas found in cheese, yogurt, wine, coffee, and beer are attributed to diacetyl, shown in Figure 5. This is one of the several volatile compounds produced when LAB undergo citrate fermentation, in conjunction with MLF. In the wine industry, production of diacetyl during MLF has a great influence on the aroma profile of wine. At low concentrations, diacetyl transmits yeasty, nutty, and toasty aromas, although at high concentrations, characteristic buttery aromas dominate (Swiegers et al., 2005).

While diacetyl is found in most red wines, predominantly Pinot Noir and Cabernet Sauvignon, buttery flavours in wines are most often attributed with Chardonnay, a popular white wine varietal. The lack of acknowledgment of buttery aromas in red wines is primarily due to different sensory thresholds between wine varietals. For Chardonnay, a diacetyl concentration of 0.2 mg/L can impart buttery aromas, whereas concentrations of 0.9 mg/L and 2.8 mg/L are required for Pinot Noir and Cabernet Sauvignon, respectively (Swiegers et al., 2005). During secondary fermentation, there are many factors that influence the production of diacetyl, such as temperature, pH, oxygen availability, and length of the fermentation period. Although temperature and pH can be adjusted for optimal diacetyl production, the other two factors are not as easily controlled. Oxygen availability is limited during fermentation and long fermentation periods can lead to degradation of diacetyl by yeast (Swiegers et al., 2005). Following MLF, the concentration of diacetyl is less than 1 mg/L on average, which gives rise to the buttery aroma in Chardonnay; however, this concentration has minimal effect on the sensory profiles of red wines (Martineau and Henick-Kling, 1995).

The buttery aromas that diacetyl imparts on wine can be altered based on several chemical interactions that occur during secondary fermentation. Diacetyl contains two carbonyl groups, which interact with other components of the wine. Cysteine, one of the twenty amino acids, has the ability to react with the carbonyl group of diacetyl. This can produce aromas aside from buttery, such as the addition of floral, fruity, toasted, and roasted notes (Pripis-Nicolau et al., 2000). Further, the presence of sulphur dioxide in wine, which is added for antioxidant and antimicrobial purposes, can reduce buttery aromas (Nielsen and Richelieu, 1999). For the reasons stated above, the incorporation of diacetyl in wines must be carefully considered during production in order to positively enhance buttery notes of the aroma profile.

AS WINE GROWS OLD

FIGURE 6: OAK BARRELS. Oak barrels are meticulously crafted and have been used to age wine for centuries (Reynermedia, 2003).

Aging wine in oak barrels, as shown in Figure 6, imparts unique flavour compounds not present within the grape nor able to develop during fermentation. These flavour compounds, formed through the breakdown of plant structural materials during the construction and toasting of the barrel, give wines a bolder and more mature flavour (Spillman et al., 1997; Pe et al., 2002). The two main types of oak barrels used to age wine are American oak and French oak. American oak has lower porosity and larger grain structure than its French counterpart, and is also significantly cheaper (Garde Cerdán, Rodriguez Mozaz, and Ancin Azpilicueta, 2002). The decision as to whether to use American or French oak, or a combination of the two, lies in the discretion of the winemaker as the characteristic oak flavours extracted by the wine, such as vanilla, vary depending on oak type.

VANILLA: BEAN THERE, DONE THAT

Vanilla is a flavour that is usually associated with baked goods, not wine. However, it is a flavour that is present across a diverse selection of oaked red and white wines, primarily Sauvignon Blanc, Pinot Grigio, and Pinot Noir (Garde Cerdán, Rodriguez Mozaz, and Ancin Azpilicueta, 2002).

Regardless of the type of wine, vanilla flavour relies on the presence of two main volatile compounds: vanillin and syringaldehyde (Garde-Cerdán and Ancín-Azpilicueta, 2006). Vanillin, as depicted in Figure 7, has the greatest influence on flavour due to its low sensory threshold, which allows quantities as low as 320 μg/L to impart a noticeable vanilla flavour (Garde-Cerdán and Ancín-Azpilicueta, 2006). As vanillin is not a compound commonly present in grapes, it must be introduced during oak barrel aging (Spillman et al., 1997).

To extract the greatest amount of vanillin, winemakers typically age wines in new American oak barrels for less than one year

(Pe et al., 2002; Garde Cerdán, Rodriguez Mozaz, and Ancin Azpilicueta, 2002).

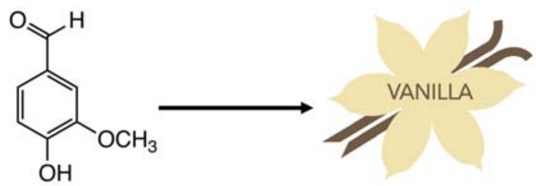

FIGURE 7: VANILLA. Vanillin, the volatile compound above, is also the main compound extracted from vanilla pods (iChem Labs, 2017; Microsoft, 2017).

However, French oak barrels, used five times or more, are able to impart greater amounts of vanillin than American oak barrels, previously used for the same amount of time (Garde Cerdán, Rodriguez Mozaz, and Ancin Azpilicueta, 2002). Although vanillin in wines is mostly influenced by different types of oak barrels, it can also be influenced to a lesser extent through MLF.

Wines which undergo MLF in oak barrels tend to have an increased concentration of vanillin than those in oak barrels which do not (Styger, Prior, and Bauer, 2011). This is thought to be due to the LAB involved in MLF. Researchers believe that LAB are able to transform other volatile compounds extracted from the oak, such as ferulic acid, into vanillin (Bloem et al., 2006). These compounds are referred to as vanillin precursors, because they can be transformed into vanillin through various chemical reactions (Bloem et al., 2006).

NEW IDEAS IN AN AGED ART

Since aroma is a key component of wine to consumers, winemaking processes are manipulated to appeal to the current market. Specifically, the Niagara Region is innovative in their use of fruit type, fermentation, and origin of oak barrels used to alter flavour. The Niagara Region is classified as a wine tourism cluster, with over 50 different wineries within driving distance from one another (Telfer, 2001). The close proximity of wineries encourages innovation in both oenology and viticulture.

Some wineries in Niagara, such as Harvest Estate Wines, produce fruit wines that use peaches, rhubarb, or cranberries rather than grapes. This drastically affects the flavour of the wine as they are exchanging the fruit (Jackson, 2017). Several wineries are also experimenting with spontaneous fermentation rather than inoculated, as this is now known to create greater variation and complexity in wine aroma (Corrigan, 2017). This allows Niagara wineries to showcase their uniqueness through the use of naturally occurring yeast species, which leads to the production of a more "natural" wine. Since wine flavour is affected by the aging process, some Niagara wineries, including Featherstone Winery, are exploring the use of Ontario oak rather than the traditional American or French oak (Jackson, 2017). Others, such as Rosewood Estates Winery, have also experimented with reusing spirit-infused oak barrels, such as bourbon barrels, which release different aromatic compounds into the wine (Corrigan, 2017).

To enjoy your favourite glass of wine, you do not necessarily need to understand the complex processes that produce each flavour. However, these processes are very important to winemakers, as it provides an area of opportunity for innovation to generate new or modified flavours. So the next time you open a bottle of wine, take a second to appreciate the little nuances on the nose and palate that make wine so appealing.

MORE TO EXPLORE

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What are Millennials Wine-ing about now?

Sommer Chou, Victoria Coles, Bryce Norman, Jeneva Smith

Millennials like to have fun. Some of the younger individuals in this generation are just discovering the world of alcohol and there is no doubt that they will conquer the market. All that is left is for manufacturers and producers to expand their consumer base to reach them. Sounds easy enough, right? There is just one problem: of all the available alcoholic beverages on the market, wine might not be the first pick for millennials. It is now up to winemakers to find a way to market their drinks to appeal more to the younger generation. This article delves into how wineries can improve their reach to millennials by analyzing four factors that impact their purchasing decisions. These primary factors are label design, cost, sustainability, and social media advertisements. These factors interact with one another to form a comprehensive and effective marketing strategy necessary to capture the unique market of millennials.

MARKETING AND MILLENNIALS

The wine industry is extremely important in Canada, generating $1.1 billion in revenue from 16.6 million Canadian wine consumers (Government of Canada, 2016). Wine, however, is a difficult product to market (Canada Portraits, 2015). Winemakers are selling a taste, but customers rarely get the chance to taste the product before actually buying it. Instead, consumers must rely on extrinsic cues, such as the origin, brand, label, and cost, to choose their wine (Atkin and Thach, 2012). Market research done at the Liquor Control Board of Ontario (LCBO) shows customers frequently rush into stores, buy their favourite wine and leave immediately, sometimes in less than a minute (Marie Cundari, personal communication, September 18, 2017). But how does a bottle get that elite status of being "your wine"? Wine companies and vineyards must find creative marketing strategies to win over customers right from the start.

One common marketing strategy is to target products towards a specific generation, as people of similar ages tend to share similar life experiences, values, and beliefs (Wiedmann, Behrens, Klarmann and Hennigs, 2014). One such generation of interest is the millennials. Millennials, also known as Generation Y, are defined here as individuals born between 1977 and 2000 (Atkin and Thach, 2012). This represents approximately 35% of the Canadian population and, although some millennials are new to the world of wine, this generation already represents one of the fastest growing wine consumer markets (Population by sex and age group, 2017; Atkin and Thach, 2012). Descriptions of this generation vary but, in general, millennials are considered to be internet proficient, socially and environmentally aware, conscious of diversity, and fun but practical (Thach and Olsen, 2006).

Millennials are a unique generation, and those in the wine industry have recognized that their traditional marketing techniques will not be effective on them. Discovering strategies that appeal to this new market represents a treasure trove of opportunity for wineries to extend their client base, and potentially develop customers who will stick with them for life. It is therefore in a company's best interest to catch the eye of that young shopper, showing them that wine can be fun, casual, and youthful. This is primarily achieved through the use of wine labels, strategic pricing, advertising sustainable practices and reaching out to the market through social media.

WINE PACKAGING

Labels are some of the first things a customer sees walking down the aisle of a liquor store. Companies therefore design their bottles with the explicit purpose of making their target consumer stop and look (Hank Hunse, personal communication, October 2, 2017). From colour to name to overall style, a lot of marketing gets packed into that little rectangle. Millennials often do not want to purchase the wines their parents drink, meaning labels must be fun, exciting, quirky, and socially aware, just like their purchasers (Thach and Olsen, 2006). When asked to design wine packaging for millennials, students at Guelph University were found to favour not only non-traditional names, but those bordering on daring and risqué (Elliot and Barth, 2012). Names like Frisky Stripper, Lady Killer, and 4 Play were all suggested, with varying degrees of success among the students (Elliot and Barth, 2012). But how far is too far? This was one of the questions included in our informal survey. The survey, administered to 89 individuals between the ages of 19-29, asked respondents to rank how likely they were to purchase a certain wine based solely on the name provided. As reported in Figure 1, the majority of millennials surveyed were unlikely to go for brand names that stepped too far away from traditional norms.

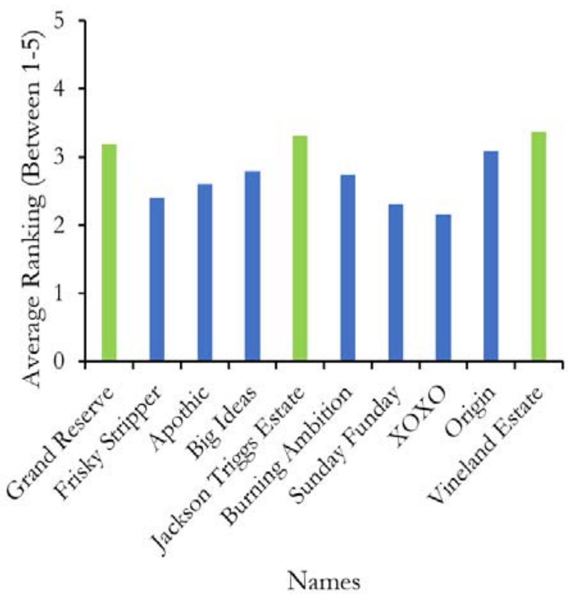

FIGURE 6: A BAR GRAPH OF AVERAGE RANKINGS FOR WINE NAME RATINGS. In an informal survey, individuals between 19 and 29 were asked to rank how likely they would be to buy a wine based solely on the name, where 5 represents very likely and 1 represents not likely at all. More traditional wine names are identified in green, while more modern ones are shown in blue. Average rankings are reported, showing that most of the millennials surveyed shied away from non-traditional and risqué names.

In addition to having names that strike the perfect balance between non-traditional and somewhat mainstream, wines need to have attractive packaging to win over the millennials. Wineries that specifically target millennials, such as Rebel Coast Winery in California and Small Talk Vineyard in Niagara, ON, tend to focus on abstract imagery with words and graphic designs (Figure 2). In e-mail correspondence, the owner of Small Talk winery stated that they specifically target the millennial generation through their youthful approach, bright colours, and fun images. Small Talk has recently seen an increase in sales and plans to continue producing wines with fun and unique packaging (Hank Hunse, personal communication, October 2, 2017).

FIGURE 2: A VARIETY OF WINE LABEL DESIGNS AND PACKAGING STYLES. By choosing different label designs, wineries are able to market their wines to specific demographics. Canned wines from Between the Lines (Left) use geometric designs that have proven successful with the millennial generation. Small Talk (Middle) and Rebel Coast (Right) both focus their designs on words and quirky geometrics to appeal to young buyers. (Modified from Between the Lines Family Estate Winery, 2017; Big Ideas Wine, 2017; and Rebel Coast Winery, 2017).

Packaging is not only about the label; there is ample opportunity to stand out by choosing alternative closures and containers. Between the Lines, another Niagara winery, offers a sparkling white wine in a can, with a unique name and geometric label (Figure 2). Cans may feel cheap and low-class to some, but they represent a new way of viewing wine. Wine is no longer restricted to dinner parties with family, but can now be sold at concert venues and taken on hikes or camping trips. This convenient packaging alternative is aimed at millennials, the majority of whom regularly engage in these sorts of activities (Higgins, Wolf and Wolf, 2016). Between the Lines has found considerable success with their product, specifically among older, female millennials (Between the Lines Winery, personal communication, October 2, 2017), showing that there may be a future for wine in a can.

THE INFLUENCE OF COST

Labels are essential to draw attention to a bottle and create a good first impression; however, one of the biggest factors that affect whether a wine is purchased is its price. When buying wine, consumers assess the perceived value of the wine by considering what they are giving and what they are receiving in exchange (Oh, 2000). The concept of consumer value is extremely important to marketing and is always considered when pricing a product. A product, like a bottle of wine, is considered highly valuable when the quality is perceived to be greater than the financial sacrifice (Oh, 2000). Thus, the price of wine is integral to a consumer's decision of what product to buy.

Millennials typically pay more attention to the perceived value of wine than older generations and look for good quality drinks at a fair price (Thach and Olsen, 2006; Wiedmann, Behrens, Klarmann and Hennigs, 2014). It is very difficult to judge the quality of wine upon purchase because the customer cannot utilize intrinsic cues, such as taste and aroma. Instead, they must rely on extrinsic cues and price is often used as a strong indicator of quality (Atkin and Thach, 2012).

Price influences not only the decision to purchase a wine, but also the perception of the wine's taste. Consumers are aware of the positive correlation between the quality and cost of wine, and this subconsciously influences how the taste of wine is perceived (Plassmann, O'Doherty, Shiv and Rangel, 2008). In one study, participants were told that they were tasting five different types of cabernet sauvignon (Plassmann, O'Doherty, Shiv and Rangel, 2008). In reality, there were only three wines and two types of wine were given to each participant twice, once indicated as a cheaper wine ($5 or $10) and once indicated as a more expensive wine ($45 or $90). When participants rated the pleasantness of the wine, the product was perceived as significantly more pleasant when it was presented as expensive compared to cheap. Using an fMRI scanner the researchers identified that while tasting the more expensive wine, there was increased activity in the medial orbitofrontal cortex, a region in the brain known to influence experienced pleasantness. The increased perception of flavour is a result of a cognitive process, in which one's expectation of taste is integrated with the actual flavour through the medial orbitofrontal cortex (Plassmann, O'Doherty, Shiv and Rangel, 2008). Another study replicated these findings and found that the valuation systems in the brain have varied responses to the wine based on its price. While tasting the expensive wine, there was increased activity in various brain regions that play a role in the brain's valuation system (Schmidt et al., 2017). Additionally, a blind tasting with over five hundred participants found that people enjoyed more expensive wines slightly less when they were not aware of the price. This exemplifies that price may not be a good indicator for quality of wine; nonetheless, most consumers still rely on it (Goldstein et al., 2008).

This results in a balancing act for wineries: if the wine is too cheap then consumers will think it tastes bad, but if it is too expensive they will not purchase it (Atkin and Thach, 2012). Millennials have been found to pay significantly less for wine than the older generations, which is likely due to less disposable income and a strong interest in fair pricing. For the most part, the millennial generation buys wine in the $8-10.99 price range; hence, cheaper wine sells much better with millennials (Atkin and Thach, 2012). Our informal survey found that the price of a bottle of wine is the most important factor that millennials consider when purchasing wine. This factor had an average score of 5.35 on a scale where 7 is the most important factor and 1 is the least (Figure 3). Additionally, 85% of the millennials who drink wine reported that they typically purchase bottles for less than $20.

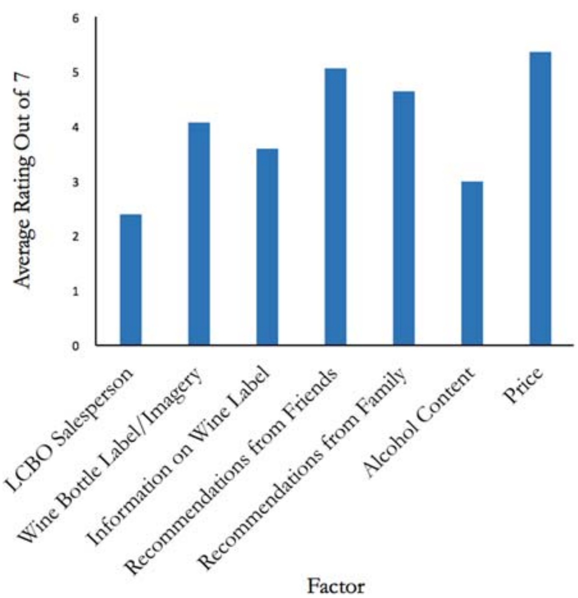

FIGURE 3: MOST INFLUENTIAL FACTORS WHEN PURCHASING WINE. In an informal online survey, people aged 19-29 (millennials) rated the importance of different factors they consider when purchasing a bottle of wine. This graph illustrates the average scores of each factor, where 7 is most important and 1 is least important.

When wineries direct their marketing towards millennials they understand that this generation tends to buy less expensive wine and that the price plays a large role in their decision of which wine to purchase. Hank Hunse, the owner of Small Talk Vineyards, explained that all of the wines they sell are marketed towards the millennial generation and the lower the price of the wine, the more bottles they sell. He acknowledged the effort to balance the value that their fun labels bring to their product with the price of the wine (Hank Hunse, personal communication, October 2, 2017).

SUSTAINABLE WINERIES

Sustainability is another aspect to consider when marketing wines to the younger generation. Having been raised in a world that is saturated with smart devices and the media, millennials are considered to be more socially and environmentally aware than other generations (Thach and Olsen, 2006). In fact, studies have already shown that there is an increased interest for green and eco-friendly labelled wines (Berghoef and Dodds, 2011; Pomarici and Vecchio, 2014). Naturally, there could be a premium associated with going green, but how much is too much for that eco-safe label? Apparently, a sustainable tag falls second to cost. Most millennials are only willing to purchase environmentally friendly wines if there is little to no price increase (Berghoef and Dodds, 2011). As shown in Figure 4, this was supported by our informal survey with most respondents reporting an interest in sustainable wines but with price still being an important consideration.

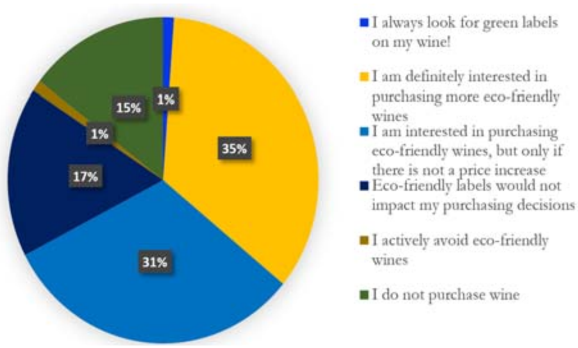

FIGURE 4: A PIE GRAPH OF THOUGHTS ON SUSTAINABLE PRACTICES. The results of our informal survey from millennial respondents aged 19-29 regarding their thoughts and opinions on sustainable/eco-friendly wines. Most millennials indicated that they are interested in sustainable wines; however, many would only buy them if it did not increase the price.

Now for the important question: what does "going green" really mean? Despite a general interest in eco-friendly goods, buyers are often unsure of what a sustainable label means and how it can be applied to the wine industry (Berghoef and Dodds, 2011). The techniques employed by a vineyard can differ vastly from large industrial factories to farms. Nevertheless, the universal consensus to limit the environmental impact at wineries is dependent on several central practices. These include limiting water usage, reducing pesticide application, investing in alternative energy sources, and improving waste disposal (Colman and Päster, 2009; Berghoef and Dodds, 2011).

In the Niagara region specifically, there are a number of wineries that opt for completely organic and eco-friendly farming practices. For example, Featherstone Estate Winery rejects the use of insecticides entirely (Featherstone Estate Winery, 2015). Instead, they use a substance called diatomaceous earth (DE) – a natural product generated from fossilized marine algae – to deter insects, rather than kill them (Chintzoglou, Athanassiou and Arthur, 2008; Featherstone Estate Winery, 2015). Other vineyards in the region recruit animals such as guinea fowl to keep the bugs at bay (Frogpond Farm Organic Winery, 2017).

Wineries are also prone to generating substantial amounts of waste throughout the production process. Once grapes have been cultivated, they need to be properly fermented, juiced, and packaged. One of the concerns associated with the preparation of wine is the chemicals used to clean the fermentation tanks. These are often harsh cleaners that can be released into the environment if they are not handled properly (Gabzdylova, Raffensperger and Castka, 2009). In lieu of using harmful substances, some Niagara-based vineyards, such as Jackson-Triggs and Rosewood Estates, implemented the use of steam cleaners to keep their equipment sanitary and reduce waste output (Will Roman and Allan Jackson, personal communication, September 30, 2017).

Despite this progress, there are many more sustainable practices that could be implemented in the industry. The Niagara region itself is home to a large number of wineries, such as Southbrook Vineyards, Frogpond Farm, and Featherstone Estate Winery, each of which employ organic techniques in hopes of improving the sustainability of their wineries.

Since labelling is a big factor to take into consideration when marketing to millennials, it would be beneficial for these vineyards to publicize their environmentally conscious practices directly on the wine bottles. Specifically, this generation prefers a clean and simply-designed "seal-of-approval" style label (Berghoef and Dodds, 2011). Despite the pride that these vineyards take in being eco-friendly, it is not always advertised directly on their product labels. Instead, they turn to much larger and more diverse social media platforms to communicate their stories and customs.

SOCIAL MEDIA

One of the defining characteristics of the millennial generation is their aptitude for technology, especially the internet and social media. Millennials grew up during a technological revolution and it is estimated that 75% of millennials in the United States have a profile on a social media site and 55% check their profile once or more per day (Pew Research, 2014). This has created a new platform for marketing that is especially effective on millennials, who are constantly accessing social media on their phones, tablets, and other devices. Many wineries in North America are using social media to market their wines, but there are a variety of strategies being used to target different audiences.

A study performed in 2014 found that 98% of wineries had a website and 93% had some form of social media, the most predominant platform being Facebook (Higgins, Wolf, and Wolf, 2016). Wineries use social media to post pictures and videos, promote marketing campaigns, and develop an identity for their winery. One winery that is targeting millennials is Rebel Coast Winery in California. Their social media websites are full of pictures involving wine consumption in fun and non-traditional locations (Figure 5) (Rebel Coast Winery, 2017). Their slogan is "Not your parent's winery", and their marketing highlights the fact that wine is not just for special occasions and family dinners (Rebel Coast Winery, 2017).

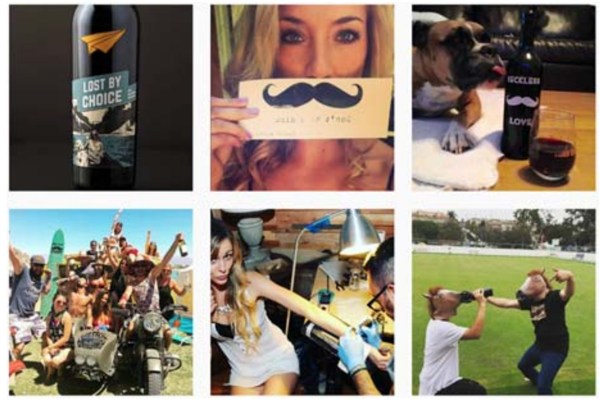

FIGURE 5: HOW WINE IS MARKETED ON SOCIAL MEDIA. Rebel Coast Winery's Instagram page boasts pictures of their wines being consumed in fun locations and non-traditional ways. Rebel Coast Winery uses social media to promote their wines to a younger generation by showing them that wine is best enjoyed while having fun and "ignoring your parents' advice" (Rebel Coast Winery, 2017).

Another winery that is using social media to market towards millennials is Southbrook Vineyards from Niagara-on-the-Lake. Southbrook uses their social media pages to advertise their certified organic and biodynamic wines. Their "About" section references their eco friendly practices and their posts use hashtags such as #organic #biodynamic (Figure 6) (Southbrook Vineyards, 2017). Sustainable wines are desired by millennials and social media provides an effective tool for eco-friendly vineyards like Southbrook to advertise their wines to millennials.

Between the Lines Winery is also using social media as an effective tool to market their wine and special events. This winery uses common social media platforms such as Instagram, Facebook, and Twitter to post

FIGURE 6: INSTAGRAM ADVERTISING OF ORGANIC PRACTICES. Southbrook Vineyards uses their social media sites to advertise their organic and biodynamic practices. Their posts include pictures of sheep and falcons which are used for pest and plant management and articles on the benefits of eco-friendly farming. Their posts usually have the hashtags #organic and #biodynamic (Southbrook Vineyards, 2017).

pictures of their wine and vineyards and inform customers about events they host such as K9s, Vines and Wines. Between the Lines also uses Snapchat, which is less commonly used by wineries, to advertise their events. This is especially effective for millennials because 71% of Snapchat users are under the age of 34, which puts them primarily in the millennial generation (Aslam, 2017). Many of their events are also geared towards millennials by pairing wine tastings with dogs, dancing, or yoga (Between the Lines Family Estate Winery, 2017). This is another example a winery trying to show that wine can be enjoyed outside of special events or family dinners. The use of social media allows Between the Lines to reach a millennial audience and advertise events targeted towards younger age groups.

Social media is a part of many millennials' daily lives, making it extremely effective as a marketing tool. The use of social networking sites has been drastically increasing in the past decade, with a 58% increase in adults from 2005 to 2015 (Pew Research, 2015). Many of these sites are primarily used by millennials, such as Snapchat, which make them excellent for marketing to younger generations (Aslam, 2017). There is concern that as some social media platforms, like Facebook, become more mainstream, they will lose their appeal towards millennials and their marketing success will decrease (Higgins, Wolf, and Wolf, 2016). This may cause younger generations to move towards other social platforms and require wineries to employ new marketing techniques (Higgins, Wolf, and Wolf, 2016). However, for the present time the use of social media is a pivotal part of marketing wine towards millennials, and advertising fun, non-traditional wines to their target audience.

CONCLUSION

Millennials currently represent the largest generation in Canada and the United States, making this younger population an ideal target for marketing campaigns (Atkin and Thach, 2012; Norris 2015). In order to market wine to millennials, misconceptions about wine only being consumed at lavish and uptight events must be broken down. The millennial generation prefers a wine that reflects their identity: fun, impulsive, and non-traditional. Wineries are taking advantage of these traits by incorporating them into their wine labels, names, and social media accounts. Millennials are also a generation that is very conscious of the environment and the impact their actions have on the Earth. Wines created using environmentally friendly practices are more desirable for millennials. which can be used to increase sales. Although, in the end, it always comes down to the cost of the wine bottle, which is important for both affordability and the perceived notion of quality.

Evidently, there are countless factors that need to be taken into consideration when marketing wine. Different wines appeal to different age groups and personalities, but the most successful wines are the ones that target the largest audience. Millennials are currently the largest wine consumer market and many are new to wine drinking, which creates an excellent opportunity for wineries to target these young drinkers. Wine marketing will continue to change and evolve as time goes on and, for the next couple decades, much of it will be driven by the millennial generation.

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Tannins and Barrels and Ultrasound, Oh My!

Noah Houpt, Sonya Martin, Gabriella Wynn, and Jonas Yeung

"With age comes wisdom, but sometimes age comes alone." ~Oscar Wilde

While Oscar Wilde was referring to humans in the above quotation, the same can be said of wines. As some wines age, their sensory qualities evolve and heighten, whereas others spoil. This article will delve into the chemical processes underlying the aging of wines as they relate to the perception of astringency, a dry mouth-feel. The biochemical mechanism by which the agents of astringency in red wines, called tannins, interact with human salivary proteins are explored in detail.

We will also be addressing, the past, present, and future techniques for manipulating the parameters of wine aging. Remarkably, past methods of wine aging, including barrel aging, alter the chemical composition of wines in a way that was unknown to winemakers during their original implementation. Modern techniques, such as micro-oxygenation, are much more fine-tuned and are designed to directly influence certain chemical reactions. The future of wine-aging technologies offers an opportunity to apply more extravagant physical techniques to accelerate the wine aging process. These techniques allow wines to gain Oscar Wilde's proverbial wisdom, without the age.

If you want a sneak peek at the future of wine-making technologies, read on.

WHAT IS ASTRINGENCY

Red wine is a complex beverage, often filled with subtle notes, deep colours, and aromas that co-mingle with human sensory perception. The sensory complexity of red wine results from its intricate and dynamic molecular makeup. The wide-ranging chemical components of red wine interact with human sensory mechanisms leading to the perception of taste, appearance, scent, and mouth-feel. The last sensory trait will be the focus of this article, specifically the sensation of astringency in red wine and the techniques that winemakers can use to manipulate it.

Astringency is a mouth-feel property that is described as a drying and puckering sensation. This feeling can be elicited not only from drinking wine, but also through nuts, tea, and some berries (Lee and Lawless, 1991). The astringent characteristic of grapes is especially apparent in their seeds and skin. It should be noted that astringency is commonly confused with the taste sensation of bitterness. However, bitterness is mediated through taste receptors, while astringency is the sensory perception of an actual texture in the oral cavity (Vidal et al., 2003).

While many chemicals influence the perception of astringency in wines, it is thought that the principle contributors are tannins (Cheynier et al., 2006; Jöbstl et al., 2004; Bennick, 2002; Luck et al., 1994). Tannins in wines refer to a group of structurally diverse polyphenolic compounds that interact with proteins when consumed (Cheynier et al., 2006).

The word polyphenolics simply means chemicals that have many phenolic rings, which are a ubiquitous structural group in organic chemistry. A phenolic ring, pictured below (Figure 1), is made up of a six-carbon aromatic ring with at least one alcohol group (-OH) attached to it. Phenolic rings are moderately acidic due to the available hydrogen and hydrophobic due to the uncharged carbon ring backbone. The word hydrophobic refers to a molecule that is non-polar, and thus repellant of water.

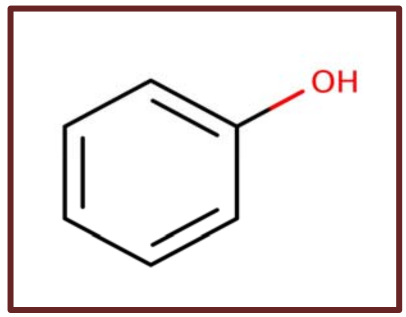

FIGURE 7: PHENOLIC RING. These rings are the principal components in red wine tannins (Cheynier et al, 2006).

CHEMISTRY OF ASTRINGENCY

The consumption of tannins in red wine leads to the perception of astringency by their adherence to a certain class of proteins found in human saliva known as Proline-Rich Proteins (PRPs) (Bennick, 2002). As the name suggests, PRPs are rich in the amino acid subunit proline (shown below, Figure 2A) and they have several unique properties which influence their tendency to associate with tannins. The elongated shape of PRPs and their excess of proline subunits provides hydrophobic "sticky patches" upon them that adhere to tannins when the two come into contact (Jöbstl et al., 2004; Luck et al., 1994). This is because hydrophobic molecules tend to group together with one another when in solution. This is comparable to an oil-and-water mixture where hydrophobic oil molecules group together, sequestering themselves from water, a hydrophilic substance. Another important quality of PRPs that allows them to group together with polyphenols is the tendency of proline to form hydrogen-bonds with alcohol groups, such as the one present on phenolic rings. (Jöbstl et al., 2004). As shown in Figure 2B, the relatively positively charged hydrogen of the phenol group is attracted to the relatively negatively charged nitrogen of the proline, leading to a more stable, tightly held adhesion (Jöbstl et al., 2004).

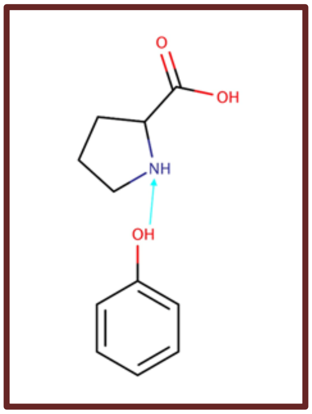

FIGURE 2: PROLINE REACTIONS. Phenolic groups interact with proline units via hydrogen bonding. The hydroxyl group from the phenol "donates" its positively charged hydrogen atom to a free electron pair on the nitrogen of the proline.

The interaction between tannins and PRPs is thought to be responsible for the sensation of astringency in wine because it leads to the aggregation and precipitation of the lubricating proteins of the saliva (Jöbstl et al., 2004; Noble, 1998). Aggregation refers to the grouping together of similar molecules in solution, leading to the formation of larger particles. Precipitation refers to the removal of certain insoluble particles from solution.

The process of aggregation and precipitation can be explained in three steps. First, the PRPs exist as large chains that are in an elongated, unfolded conformation. As explained previously, the polyphenolic subunits in tannins interact with the proline subunits, which make up the PRP, by attraction between the nitrogen and hydrogen. This association leads to the PRP chain twisting itself around the polyphenol, decreasing the large size of the PRP and resulting in a more organized, compact shape (Jöbstl et al., 2004). The process can be visualized as the PRP being a long chain of tangled string which is then wrapped neatly around a ball, the polyphenol (Figure. 3).

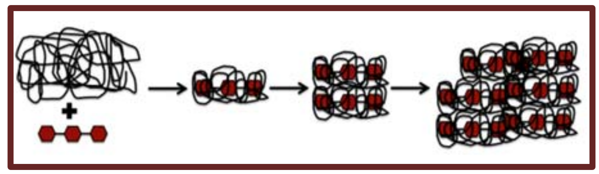

FIGURE 3: PROCESS OF AGGREGATION. Steps involved in the adherence of proline-rich proteins (black lines) to polyphenolic compounds (red chains).

Second, as there are several PRP-phenol groups being created, two of these groups can bind together. When this occurs, the complex becomes so large so that it is no longer soluble in water (Jöbstl et al., 2004). Continuing the analogy, this can be thought of as two or more of the aforementioned balls of string becoming tangled with one another.

The third and final step is the aggregation of the cross-linked PRP-phenol complexes that have precipitated from the saliva (Jöbstl et al., 2004). These precipitated protein aggregates reduce lubrication in the oral cavity, causing the sensation we perceive as astringency (McRae and Kennedy, 2011). When drinking red wine, these chemical reactions occur in the mouth leading to the sensation of astringency.

TANNINS DURING WINE AGING

While generalized interactions between red wine tannins and salivary proteins are well understood, the situation is rendered more complex by the diversity of tannins that occur in wine, each with their own particular properties. The tannins found in grapes are structurally diverse, and differ in the type and the number of subunits that contribute to their larger structure (Bennick, 2002). This diversity in tannin structure gives rise to diversity in their astringent qualities, as different tannins interact with salivary proteins in various ways (Fulcrand et al., 2006; Bennick 2002). The relationship between red wine tannins, salivary proteins, and astringency is further complicated by the evolution of a wine's tannic composition during wine aging (Fulcrand et al., 2006). In general with increased aging comes decreased astringency in red wines.

Although many reactions that occur during wine aging change the structure of tannins, the most important chemical modification is polymerization. Polymerization refers to the linking of subunits together to form a chemical chain, expanding the size of the tannin molecule (Fulcrand et al., 2006). The degree of polymerization, or the length of the chemical chain, directly influences its ability to crosslink PRPs together to form aggregates (Fulcrand et al., 2006; Jöbstl et al., 2004). The length of the polyphenolic chain affects the tannins ability to reach and link together two PRPs, and its flexibility when doing so (Bennick, 2002). In particular, intermediately sized tannins invoke the strongest astringent response because of their blend of length and flexibility, which both help to form crosslinks (Jöbstl et al., 2004). Tannins that are too large have difficulty binding to PRPs and therefore are less astringent. On the other hand, smaller tannins, such as those that come from the grape seeds, tend to bind to bitter taste receptors rather than creating an astringent sensation (McRae and Kennedy, 2011).

The first tannins that are introduced to wine are extracted from the seeds, skin, and stems of grapes (McRae and Kennedy, 2011). These tannins are relatively small and contribute to the astringency and bitterness of young wine (McRae and Kennedy, 2011). More tannins can be added to the wine through contact with oak barrels that have naturally-occurring tannins in their staves, the wooden panels that make up barrels. These tannins are larger and contribute less to astringency than the tannins extracted from the grapes (McRae and Kennedy, 2011). During aging, it is thought that the tannins grow longer through polymerization, changing the astringent character of the wine (Cheynier et al., 2006). It is generally accepted that aging decreases astringency, giving wines a softer taste (Cheynier et al., 2006).

An important reaction involved in the polymerization of tannins is called an aldehyde polycondensation reaction. An aldehyde is a group of organic molecules, for example the well-known formaldehyde, that increase in concentration in wine with exposure to oxygen (Fulcrand et al., 2006). Tannins can polymerize when an aldehyde binds to a polyphenolic subunit. The aldehyde activates the polyphenolic subunit and allows it to bind to another polyphenol, producing water as a byproduct (Figure 4).
This reaction can repeat itself several times and increases the length of the tannin chain. Therefore, as time passes the tannin length changes which will produce a new tannin with different astringent characteristics (Fulcrand et al., 2006).

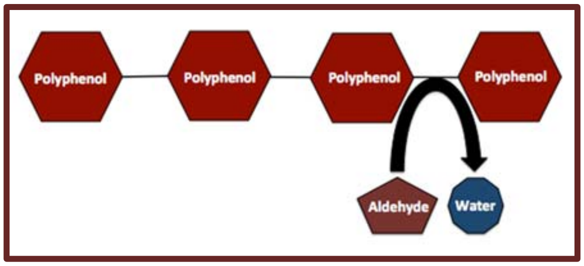

FIGURE 4: ACETYLALDEHYDE MEDIATED POLYCONDENSATION. Polyphenol subunits are added to the chain via the aldehyde condensation reaction, using an aldehyde and producing water as a byproduct. This decreases the astringency in wine.

The aldehyde polycondensation reaction shows that the chemical processes involved in wine aging are directly related to the sensory characteristics and quality of a wine. It is by understanding the chemistry of wine aging that winemakers can begin to manipulate these processes to their benefit and to the benefit of their customers.

OAK AGING TECHNIQUES

FIGURE 5: OAK BARRELS. The traditional aging technique among winemakers.

Long before the chemistry of winemaking was well understood and documented in the literature, winemakers were making decisions that directly influenced the chemical compositions of their products.

Oak barreling (Figure 5) has always been the most common technique used for wine maturation. William Roman, operations manager at Rosewood Estates winery in Niagara, Ontario, has this to say on the topic: "My personal philosophy on this stuff is that sometimes, taking your time and waiting for the wine to age in barrels the appropriate time is a good thing. It creates a product that is more natural, authentic and an honest expression of the vintage and region of origin (William Roman, pers. comm., 2017)." So, what makes oak barrels so beneficial? During barrel aging, aromatic compounds related to astringency are released into the wine from the wood, contributing to the flavour, colour, and mouth-feel of the wine (Bautista-Ortín et al., 2008). In addition, oak barrels are permeable to oxygen. This results in the oxidation of certain compounds, leading to a reduction in astringency (Bozalongo et al., 2007).

However, oak barrel aging is not without disadvantages. First and foremost, it is expensive. Barrels are costly and take up a lot of space - and the aging process can take anywhere from three months to several years (Oberholster et al., 2015). For wine makers, this can result in a longer investment in each batch; for consumers, it can mean more expensive shelf prices. Second, barrels have limited lifespans. As a barrel ages, the abundance of compounds and the permeability to oxygen is decreased (Cerdán and Ancín-Azpilicueta, 2006; Cano-López et al., 2010). Older barrels are also more likely to become contaminated with harmful yeasts, since they are difficult to clean. *Bretanomyces* and *Dekkera* are two common contaminants that can cause unpleasant aromas in the wine, making it undesirable for consumers (Suárez et al., 2007). Finally, wine evaporation occurs during barrel aging, leading to a maximum loss of around 3% of the product per year (Ruiz de Adana et al., 2005). With such factors at play, it is clear to see why new techniques are being introduced to reduce maturation time while maintaining quality – this will benefit both winemakers and consumers. While some modern techniques are currently in practice, some techniques are purely in their experimental stages (Tao, Garcia, and Sun, 2014).

The use of wood is still the preferred method of wine maturation because of the unique phenolic and aromatic compounds, such as soft tannins, it introduces into the wine (Oberholster et al., 2015; William Roman, pers. comm., 2017). As such, the addition of oak alternatives, such as oak chips, to wines has become increasingly used as a method of wine aging, with oak chips placed in stainless steel tanks or used oak barrels being a common alternative. Compared to barrel aging, the extraction rate of beneficial volatile compounds from the oak chips is higher, thus increasing the rate of the aging process (Bautista-Ortín et al., 2008). This increase in the concentration of volatile compounds in the wine increases the astringency of the aged wine. In barrels, only the inner surface of the wine barrels is in contact with the wine. With oak chips, there is more wood-to-wine surface area contact per unit volume of wood, which increases the rate volatiles can absorb into wine (Tao, Garcia, and Sun, 2013). This also increases the extraction of oak-related compounds into the wine, reducing the length of contact time required between the wood and the wine. However, because the rate of extraction of these volatiles is greater in wood fragments, their longevity is shorter than wood barrels. Wood fragments can only be used for about three months before they cease to add compounds to the wine (Bautista-Ortín et al., 2008). Additionally, the sensory characteristics differ slightly between oak barrels and wood chips: chip-treated wines create a more astringent sensation in the mouth and contain less desired flavors (Ortega-Heras, et al., 2010). Furthermore, while wood fragments can reduce the aging time, characteristics may differ from traditional wine. As such, using solely oak chips may not be ideal; although, oak chips can be used to supplement older barrels, stainless steel barrels, or for short-term aging wines such as white wines (Bautista-Ortín et al., 2008). One way to mitigate the differences between oak barrel and oak chip aged wines is to add small amounts of oxygen into the tanks during aging, since stainless steel tanks do not allow oxygen diffusion. This method is known as micro-oxygenation (Tao, Garcia, and Sun, 2013; Oberholster et al., 2015).

MICRO-OXYGENATION

Micro-oxygenation (MOX) is a modern technique that was invented in 1991 in an attempt to mimic oak barreling aging. The technique gives winemakers more control over the timing and amount of oxygen that is introduced to the wine, and possibly lowers the time and production cost (Anli and Cavuldak, 2012). As oxygen is a key ingredient in the aldehyde polycondensation reaction, the addition of oxygen decreases the astringency. The expected benefits of MOX would match oak barrel aging which includes improved mouth-feel qualities, colour stabilization, and removal of unwanted herbaceous odours. The modifications of these characteristics are attributed to the change and structure of phenolic compounds in red wine (Anli and Cavuldak, 2012; Kilmartin, 2010).

There are various MOX systems that are currently used in industry. The most widely used and commercially available MOX technology would be micro-bullage delivery (Kilmartin, 2010). This technique uses a porous diffuser (micro-bullage) that generates microbubbles within the wine. These pores are only a few micrometers and produce bubbles with a diameter of approximately half a millimeter. Oxygen is then carefully delivered into the tank at relatively low amounts over a prolonged period of time. The duration and intensity of MOX is adjusted for the desired final product. For instance, decisions relating to MOX should consider initial tannin and anthocyanin content, and aroma characteristics, along with pH, temperature, and sulphates being controlled factors (Schmidtke, Clark and Scollary, 2011; Kilmartin, 2010). A wine with little phenolic content has lower aging potential and would not be a good candidate for wine aging. Wine makers should also avoid further MOX once the wine has achieved its optimal quality, in which the wine undergoes an "over-oxidation" phase and starts developing unwanted astringency and aromatic properties (Kilmartin, 2010).

The Wine Business 2008 Barrel and Oak Survey Report showed that only 16 percent of respondents indicated the implementation of MOX in their wineries. Therefore, the usage of MOX seem to be quite low. The percentage can be misleading since the vast majority of wineries surveyed in the U.S. are small and don't account for the total volume of wine produced. In fact, more than 80 percent of wine is produced by major wine companies that essentially all use MOX in some of their products (Phillips, 2008). Evidently, MOX is not considered to be a full replacement for barrel aging. Larger wineries are using MOX in conjunction with traditional barrel aging for certain products. It seems that smaller wineries are content with traditional barrel aging for the moment as it is part of their identity and gives them a "competitive niche" in the wine industry (Phillips, 2008).

When Rosewood Estates Winery was in the startup stages, MOX was used to accelerate the rate at which products were brought into the market. However, MOX operations were halted once the winery was in a more comfortable position in the market. The quality of the wine after bottle aging was not satisfactory to the winery's standards and they consequently switched back to traditional oak barrel aging techniques.

ULTRASOUND

Experiments are currently being conducted to develop new techniques that accelerate wine aging. Despite these technologies not being widely used, these methods show great potential to speed up the aging process. One promising technique is ultrasound. Ultrasound is high frequency sound waves that are above the upper audible limit for human hearing. Ultrasound takes advantage of a physical process called cavitation, which is the formation of cavities as liquids partially vaporize. The bubbles are subject under acoustic and hydraulic pressure, then collapse and generate a localized hotspot with extremely high pressures and temperature (Ponomarenko et al., 2014; Ferraretto and Celotti, 2016). A combination of turbulence and extreme conditions can accelerate chemical reactions and create new reaction pathways (Ferraretto and Celotti, 2016). Scientists have exploited this mechanism as a solution to bypass the kinetic limitations of wine aging, which are present in several processes (Ferraretto and Celotti, 2016). These processes include maceration, release of lees, and promotion of tannin polymerisation.

Ultrasonic waves can be applied to speed up the kinetics of extended maceration. Maceration (Figure 6) is a process that involves soaking grapes, seeds, and stems in the wine to extract polyphenolic compounds. A greater concentration of these compounds will help increase the aging potential of certain red wines (Bautista-Ortín et al., 2017). Ultrasonic treatment would use cavitation to promote the release and dissolution of tannins and anthocyanins contained in epidermal tissue. This technique has shown to reduce the required maceration duration by up to 30%; however, this is quite dependent on the type of grape (Ferraretto et al., 2013). The disruption of cell membrane and walls is used to accelerate the release of protective colloids, or sugars, from dead yeast cells (Ferraretto and Celotti, 2016). Moreover, the ultrasound can be used to quicken the polymerization of tannins by modifying important reaction pathways. As with most winemaking technologies, the effectiveness of ultrasound would depend on the type of wine. The frequency and number of treatments would vary for different wines to achieve optimal quality. In some cases, ultrasound may even interfere with other chemical processes that are detrimental to the quality (Chang, 2004; Ferraretto and Celotti, 2016). Therefore, it may be worthwhile to invest in studies to determine the effectiveness of ultrasound for various types of wine.

FIGURE 6: MACERATION. Grapes are mechanically broken down to facilitate extraction of phenolic compounds.

Ultrasound is a powerful technique as it can accelerate different processes involved in producing quality aged wine. The technology is also a relatively low-cost, non-hazardous, and environmentally friendly, which makes it a good candidate for innovative wine aging technology. However, a winemaker should consider the amount of ultrasonic wave exposure and the limitations of this technology to certain wines.

CONCLUSION

The chemistry of wine aging is vital to manipulating the astringency and overall quality of wine and must be taken into consideration by winemakers. The chemical reactions that occur during wine aging affect the phenolic content of the wine resulting in a change in wine quality. Currently, the wine aging process is costly and time consuming. By incorporating modern techniques that manipulate the natural chemical evolution of the wine, higher-quality products can be made in a shorter amount of time, having financial benefits for both winemakers and consumers. While most wineries still use traditional barrel aging techniques, wineries all over the world have began to introduce MOX and oak chips to their wine to save money and increase sustainability (Bautista-Ortín, 2008). Additionally, physical acceleration techniques such as ultrasonic waves are in their experimental primitive development. If more winemakers begin to exploit the benefits in accelerated wine aging techniques, the net benefits for all parties will result in a thriving and sustainable market for years to come.

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The Impact of Temperature Variability with Mitigation Strategies for Niagara Grapes

MONISH AHLUWALIA, RACHAL BOLGER, GRAHAM JOHNSTONE, BRIAN YU, NICOLE ZHANG

Wine is a commodity enjoyed by people all across the globe. There are many different grape varieties involved, flavours to explore, and adventures to be told. However, what might be surprising is that a major factor that affects the quality and taste of wine is almost completely out of the grower's control. This factor is temperature. Grapes are highly sensitive in terms of the temperatures they need. Too hot and the grape ages faster, it's composition changes, and sometimes, proteins denature and photosynthesis stalls. Too cold and the grapes freeze or lay dormant. Here we will delve into how we tailor grapes to certain regions based on their "Growing Degree Days" (GDD) requirement, the potential effects non-ideal temperatures, and strategies growers can take to ensure they maintain the highest quality of crop and obtain the greatest yield.

ABSTRACT

The range of temperatures over the course of a growing season, and between years, is one of many factors viticulturalists must take into account when growing grapes for wine production. Growing Degree Days (GDDs) are a useful metric for analyzing heat tolerance differences between regions and varietals. Hot temperatures result in excessive GDDs, which can cause premature veraison – transition to berry ripening, modified sugar/acid ratios, and even denaturation of proteins. Cold temperatures result in grapes freezing, increased sugar content, deeper skin colouration, but also stress on the plant as demonstrated by increased abscisic acid concentrations. When a grape is not perfectly suited to its environment, farmers can undertake both mechanical and genetic mitigation strategies to increase yield. Overall, determining the suitability of a certain varietal to a given region, and understanding the various adaptation methods that can be used to further improve suitability, can allow viticulturalists to ensure that the highest quantity and quality of grapes is harvested.

INTRODUCTION

The Niagara peninsula viticultural region offers a unique climate that favors the extensive cultivation of a wide range of grape varietals. In fact, a central aspect of Niagara's distinctive sub-tropical growing environment is the high variability in temperature fluctuations, observed both within and between growing seasons. The temperature in any given region can be impacted by many variables, and defined as the quantitative measure of the subjective perceptions of hot and cold calibrated to a temperature scale of a given metric, such as degrees centigrade (ºC). The average and extreme temperatures in a region are important considerations in viticulture, as temperature can impact the varietals that can be grown, maturation rates of the berries, anthocyanin levels, acid-sugar ratio of the grapes, pest management, and overall yield of a vineyard (Coombe, 1987).

Extreme Temperature is defined to be outside of the normal temperature range of the Niagara region and the growth range in plants. Extremely high temperature is defined as **35ºC** for more than 30 min. This is the temperature in which photo-synthesis ceases (Zha et al., 2016). Extremely low temperature is considered to be below **-10ºC**, when the water in grapes risk forming ice crystals.

To fully ripen, grapes need a sufficient amount of heat during the growing season, as many of the vine's metabolic processes will arrest below 10ºC. Similarly, winter temperatures need to be cold enough to encourage the vine to lay dormant, often below 0ºC (Loubere and Unwin, 1992). In the Niagara region, the temperature can fluctuate between below -25ºC in the winter months, to above 30ºC in the peak of summer, with a yearly mean temperature of approximately 9ºC (Shaw, 2005). Given these temperature ranges, over 58% of all vines grown in the Niagara region are of the European *Vitis vinifera* species, with additional species such as *Vitis labrusca, Vitis riparia, Vitis rupestris, Vitis berlandieri, Vitis* *aestivalis*, and *Vitis champinii* (Shaw, 2005). Sometimes other hybrids are used for rootstock and cross-breeding to introduce heat and cold tolerant traits. The overall dominant white varieties include Chardonnay, Riesling, Sauvignon Blanc, Gewürztraminer, Pinot Gris, and Geisenheim clones; while the reds include Cabernet Franc, Cabernet Sauvignon, Merlot, and Pinot Noir (Shaw, 2005).

ANALYSIS OF TEMPERATURE

The first step in analyzing the effects of temperature on Niagara grapes is to choose an appropriate metric such as GDDs. A grapevine will accumulate GDDs over the course of its growing season, and experimental data on the breed can be used to predict when its berries will appear and ripen (Winkler, 1974). In simpler words, GDDs are like a growing currency for plants. When a plant has enough GDDs it will gradually enter another stage of its lifecycle. GDDs for a single day can be calculated by dividing the sum of the maximum and minimum temperatures by 2, and subtracting the lowest temperature that the plant is capable of growing in, known as T_{base},.

$$GDD = \frac{(T_{max} + T_{min})}{2} - T_{base} \quad (1)$$

A T_{base} of 10˚C was used for our GDD calculations to generate Figure 1a and 1b since it is widely accepted for *Vitis vinifera* and *Vitis labrusca* grapevines. However, considering that plant growth is proportional to biological time, it is more accurate to use separate base temperatures for budbreak and leaf appearance. Studies by Moncur et al. (1989) and Oliveira (1998) have confirmed a statistical difference in base temperature throughout a grapevine's lifecycle, but there is no consensus on a single base temperature for each stage.

The total accumulation of GDDs over a growing season can be used to determine where the location lies on the Winkler Index for growing wine. The Winkler Index classifies a wine growing region as one of five types of climate regions (I-V) (Amerine and Winkler, 1944). For each climate region there is a recommended variety of grape to grow in that temperature condition. For example, grapes grown in a Region 1 (with <1389˚C GDD) should be early ripening varieties such as pinot noir, riesling, or chardonnay. A Region 5 on the other hand (with >2222˚C GDD) is suitable for table wine varieties such as primitivo, palomino, and fiano.

Two graphs were produced from the historical weather database from Government of Canada, (see Figure 1a and 1b). We used data from two stations so the result would be more representative for the Niagara region as a whole and to demonstrate the geographical influences on GDD. The location of the stations can be seen in Figure 2, one located near Lake Ontario and the other near Lake Erie. From Figure 1a, it is clear the GDDs increased most rapidly from day 150 to 250, approximately May to September, which is the growing season of grapes. There does not seem to be a drastic difference in GDD peaks between Fort Erie and Vineland, but the accumulative GDDs of Vineland exceeds accumulative GDDs of Fort Erie by almost 500 ˚C. This could be caused by the difference in lake depth between Lake

Ontario and Lake Erie. Lake Ontario is smaller than Lake Erie, but has a much greater depth, resulting in a greater capacity for temperature modulation (Shaw, 2015). The accumulative GDDs of Vineland were calculated to be 1636.65 and 1167.5 for Fort Erie. This makes Fort Erie a Region 1 in

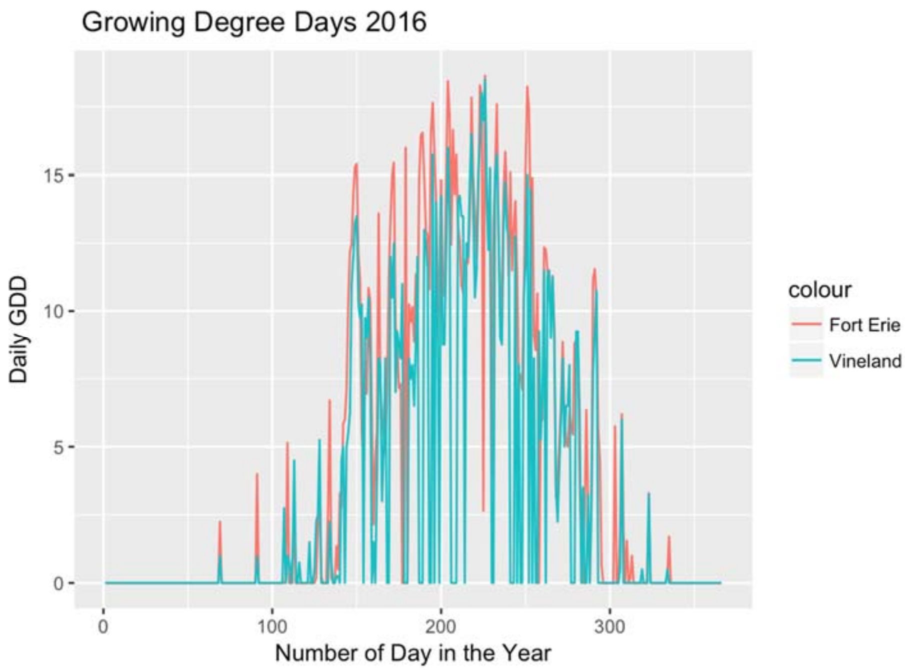

FIGURE 1a: GROWING DEGREE DAYS SHOWN IN DAILY GDD IN 2016 VS NUMBER OF DAYS IN YEAR. A daily
growing degree … was assumed to
be zero. The d… ineland Weather
Station is 43°1… ather Station is
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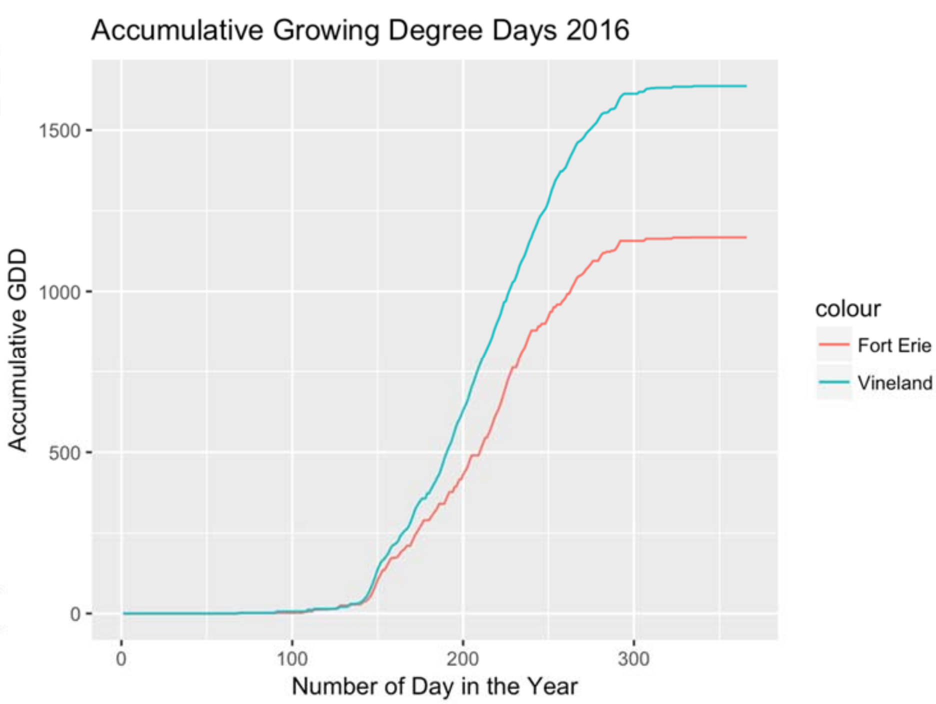

FIGURE 8b: ACCUMU … oduced
calculating GDD using … ro. The
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43°11'00.000" N, 79°24 … 000" N,
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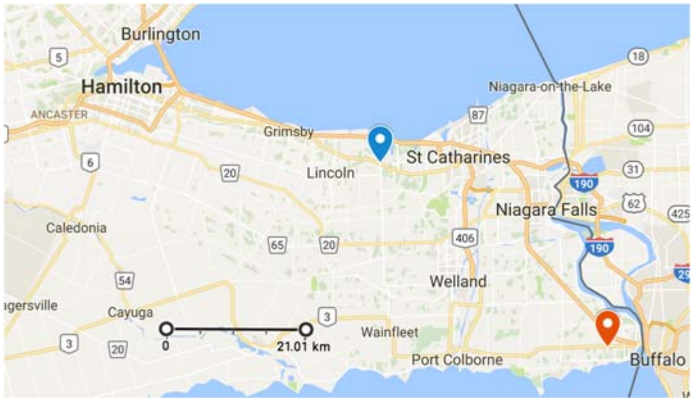

FIGURE 2: MAP SHOWING THE LOCATION OF FORT ERIE AND VINELAND. The orange pin locates Fort Erie and the blue pin locates Vineland (GOOGLE MAPS, 2017). The locations were chosen such that the most Northern region of Niagara (Vineland) and the most Southern region of Niagara (Fort Erie) is included.

Winkler Index and Vineland a Region 2 (Amerine and Winkler, 1944). Nevertheless, this model may fail to provide accurate results when there exists missing temperature data as the accumulative GDDs would be inaccurate. In this case, the reason for Fort Erie to have a GDD

value less than Vineland may be largely due to the missing data, which amounts to 86 days while Vineland only have 12 days of missing temperature.

PHYSIOLOGICAL EFFECTS OF HIGH TEMPERATURE

Temperature is an environmental factor that poses a serious threat to current viticultural practices and future wine quality. Increases in temperature are known to increase the sugar concentration of grapes at harvest (Pastore et al., 2017). Furthermore, high temperatures are known to accelerate the breakdown of malic acid and lower acidity as a result (Pastore et al., 2017). Since acid-sugar balance is a huge consideration in winemaking, the alterations in grapes from high temperatures may drastically change the flavor and chemical profile of current wines. High temperatures are also associated with a reduction in anthocyanin and flavonol concentrations (Pastore et al., 2017). The change in the chemical profile of grapes in response to increased temperature appears to shift in the ripening process of the grapes, rather than large scale transcriptional modification (Pastore et al., 2017). As a result, temperature also acts to shift the onset of véraison in grapes and resultantly the time of harvest. In addition to affecting the chemical composition of grapes and modifying their growth and ripening processes, high temperatures hold the risk of berry shrivel and fruit sunburn (Pastore et al., 2017). Rates of photosynthesis are reduced by high heat as transpiration tends to increase in response to high temperatures (Greer and Weedon, 2013). As a result, high temperatures tend to delay the ripening of grape berries and cause a significant reduction in berry quality (Greer and Weedon, 2013). Furthermore, high temperatures during the flowering stage can result in crop losses (Greer and Weedon, 2013).

MOLECULAR EFFECTS OF EXTREMELY HIGH TEMPERATURE

Through the course of grape production, vines often face climate challenges such as heat stress. This not only influences the physiology and composition of the grapes, but it also has a profound implication on plant health. Photosynthesis is a vital biochemical activity that supports growth, and it is extremely sensitive. Under extreme heat and light conditions, photosynthesis is often reduced or shut down entirely. By cross-breeding vine varieties with different characteristics, it is possible to cultivate a more heat resistant strain. Zha et al. (2015) investigated Vitis vinifera x Vitis labrusca breeds, Kyoho and Jumeigui. Kyoho is a Vitis vinifera x Vitis labrusca breed and Jumeigui is a Kyoho x Vitis Vinifera 4X. They investigated the biochemical composition of the vine leaves under controlled heat stress and temperature control. A few central proteins were found in the cultivars in order to mediate the heat stress: heat shock protein (HSP), heat shock factor (HSF) and small heat shock protein (sHSP). These proteins are expressed to mitigate the damage done by high light intensity and heat intensity. sHSPs, for example, are suggested to act as a chaperone protein to help refold denatured proteins at high temperatures. HSP21 binds to the thylakoid to protect photosystem II (PSII) and the electron transport chain from excess light (Zha et al., 2016). The variety Jumeigui was found to be less resistant to heat stress than Kyoho, as shown by its near collapse of heat response gene expression due to extreme heat. This result highlights the importance in breed and genetic composition of the vine. In another study by Zhang et al. (2008), it was found that Heat Shock Protein of 70 daltons (HSP70) and sHSP17.6 have cold acclimatization as well as heat adaptation in *V. vinifera*, although some HSP70 were found to be only activated in colder conditions (Thomashow, 1999). Similar to other HSPs, HSP70 is a chaperone protein that can mediate cold-induced denaturation of proteins (Thomashow, 1999). High temperature usually causes other cellular dysfunctionality, which can be detrimental to the plants. Though in some circumstances, high temperature stress can cause accumulations of heat shock proteins that is theorized to help with cold acclimatization.

MOLECULAR EFFECTS OF EXTREMELY LOW TEMPERATURE

Grapes, in general, have a certain baseline temperature for growth. Below this, the grapes do not die, but they enter a dormant phase characterized by the cession of growth and the development of terminal buds until warmer temperatures return. This temperature varies by species but it can be generalized to 10˚C (Duchêne et al., 2010). Some grapes have cold tolerance and are able to survive and photosynthesize during decreased photoperiods and lower temperatures, but a colder year would still affect the produce and resulting wine (A. Salzman et al., 1996). Grapes grown in the Niagara region often face colder temperatures later in the growing season due to the region's climate, and thus, breeds that can survive colder temperatures are of great importance.

According to Yamane et al. (2006), colder temperatures result in a greater production of abscisic acid (ABA), a plant hormone involved with plant stress responses, dormancy, and anthocyanin production. The accumulation of anthocyanins determines the colour of grape skins and thus, the colour of the wine. Colder temperatures result in more intense colouration and a bolder wine colour. This of course, is balanced with the resulting stress on the plant (Yamane et al., 2006). In response to this stress, monosaccharide synthesis pathways are stimulated, possibly resulting in increased sugar content in the fruits (Hamman et al., 1996). As described, stressing grapes with colder temperatures may allow farmers to reap the benefits of bold wine colour and higher sugar content, however, this must also be balanced with bud dormancy and plant stress. Niagara farmers may find it beneficial to take advantage of temperatures slightly lower than the optimal growing temperature, assuming the breed can tolerate it.

PHYSIOLOGICAL EFFECTS OF EXTREMELY LOW TEMPERATURE

When planted in regions with highly variable climatic conditions, grapevines can be seriously damaged or killed by extremely cold temperatures in the winter or the highly variable temperatures of early spring. As such, severe winter temperatures can impact grapevine productivity through tissue and organ damage by freeze injury. Extreme cold may also split open the woodier tissue of grapevines, leaving them susceptible to fungal infections. Grapevine crops can begin to experience physiological damage at temperatures as high as 12.5 °C. Direct freeze damage is caused when ice crystals form within the protoplasm of cells (Xin et al., 2013). It is the ice formation, not the cold temperatures, that physically damages grapes. This intercellular ice formation causes a water vapor gradient between the inside and outside of cells, leading to water migration to outside of the cell. However, grapes are also known to be able to resist ice formation through supercooling, which is the freezing point depression through an increase in dissolved solute concentration (Xin et al., 2013). Grapevines are also able to initiate a more physical form of resistance through endodormancy, which is the prevention of new growth in buds during early winter temperature fluctuation (Xin et al., 2013).

MITIGATION STRATEGIES

Since temperature variance is a problem for wine farmers everywhere, farmers have taken mechanical and/or genetic strategies to mitigate these effects. These strategies have various costs, timescales, and applications.

Mechanical mitigation strategies require varying amounts of planning for their implementation. In certain regions of Brazil, wineries set up transparent plastic covers (TPC) when they expect high temperatures and low cloud coverage. This technique is quite laborious for large vineyards, and thus, it is not a method that can be adapted on a day to day basis. A study by de Almeida et al. (2017) compared photosynthetic depression between covered and exposed grapevines under high photosynthetic photon flux. The study found that a 160 µm thick TPC was capable of blocking 43% of incident photons. Without TPC, the grapevines experienced a 50% reduction in net photosynthesis rates under high photon flux. Therefore, TPC could be an effective mitigation strategy for excessively hot summers in the Niagara region.

For Niagara's extreme cases of short-term weather variability, there are reactionary measures which do not require as much labour or planning as TPC. When a cold snap is imminent, it is common for grape growers to spray their crop with water (Anderson, n.d.). It may seem counterintuitive, but since freezing water is an exothermic process, heat is given off to the surroundings. This means that the water on the plant will provide the grapes with just enough heat to prevent them from becoming damaged.

High Stakes at Low Temperatures

The links between wine making and high-stakes gambling might not seem clear at first glance. But when it comes to producing ice wine, wagering on a narrow harvest window and the right temperature conditions, getting the grapes from the vine to the bottle requires plenty of expertise, risk, and a little bit of luck. While cold temperatures are traditionally considered antithetical to producing fine wines, vineyards in Niagara risk it all, leaving their grapes on the vine below freezing temperatures each year attempting to create world-renowned ice wines. To produce this sweet dessert wine, grapes must be naturally frozen on the vine, and cannot be harvested until there are sustained temperatures below -8°C. Even then, the grapes must be harvested quickly; if the temperature rises, the berries will thaw and dilute the concentrate, and if it gets too cold, the crop is lost to vine damage, as the grapes fall to the earth, unusable. In Ontario, there are currently over 60 vineyards that produce ice wine, with Niagara vineyards such as Inniskillin, Jackson Triggs, and Ice House Winery generating some of the more coveted vintages. A highly regulated industry, policies dictate grape varieties, harvest procedures, winemaking and testing before the icewine can be certified authentic by VQA Ontario. There is no doubt that producing icewine is a high-risk, high-stakes endeavour of extreme oenology, but when art and alchemy align, the result is a sure bet.

Too Hot To Handle?

On 2001, August 08, Niagara ON reached an extremely high temperature of 35ºC (Pelmorex Inc., 2017). This temperature, when maintained for more than 30 minutes, would have a damaging effects on the vine. The excessive heat would cause a substantial amount of water loss, which would cause the plant to close its stomata. This results in a drastic decrease in the amount of CO2 that is available for photosynthesis, and thus halts the process. In addition, the proteins that are essential for plant cell survival start to denature under the heat, which causes apoptosis in plant cells. As the sun starts setting and the temperature drops, the heat shock factors activated by the heat initiate the transcription of heat shock proteins, which act as chaperones to restore the denatured plant protein and help the plant to survive the heat.

Blow Away the Bad

In order to keep their grapes warm during the tail ends of the growing season, Niagara wineries such as Jackson-Triggs rely on wind-machines. By generating an air current that replaces cool air with warm air, the grapes can be kept at more comfortable growing temperatures (Fraser, 2015). There are, however, a few drawbacks of wind-machines. While operating, they are exceptionally loud. It costs approximately $100 to operate the wind machines per hour, so they must be on for at least 6 hours to be economical (Jackson, 2017).

Another reactionary method to protect grapes from cold temperatures in the Niagara region is through the use of wind machines. These machines are large, engine-powered turbines that are fixed in place and reverse convection. While spinning, the wind machine replaces the cold air lingering above the grapevines with warmer air from up above (Fraser, 2015) While there are mechanical strategies farmers can employ to adapt to varying temperatures, sometimes changing the grapes themselves is the best solution. Different species of grapes have different baseline growth temperatures and different heat tolerances. This is just one reason why certain grapes are better suited to certain areas.

However, this heat/cold tolerance is based on the variety's molecular characteristics. For example, grapes with genomes that contain transcribable heat shock proteins have greater heat tolerance and those that consist of developed carbohydrate synthesis pathways (raffinose and stachyose specifically) have greater cold tolerance (Hamman et al., 1996; Zha et al., 2016). Grapes that consist of these adaptations can be crossbred with other varieties to create hardier grapes. Duchêne et al. (2010) crossbred Riesling and Gewurztraminer varieties to create 120 different genotypes of progeny, each with different GDD tolerances. This shows that temperature requirements and tolerances are inheritable and affected by genetic factors. Of course, these crosses could result in differently tasting wine since it is a blend of two varieties, which could be good or bad depending on the taste of the consumer. This can be avoided through genetic modification where a heat shock protein gene, for example, could be inserted into the variety of interest so that it is able to adapt to the climate of the region. Genetic modification doesn't end with temperature resistance, it can also be used for disease control, water use efficiency, and overall sustainability of the product, and it is a promising tool for all these purposes (Vivier and Pretorius, 2002). In the future, Niagara viticulturalists might be able to plant whatever variety they would like, no matter the GDD requirement or tolerance.

CONCLUSION

As is seen in other areas of viticulture, moderation of temperature and selection of varietals based on climatic variables are crucial to producing good berries and a reliable final product. Temperature variability in the Niagara region can be determined by various metrics such as the calculation of overall regional GDDs and analysis via the Winkler Index. Similarly, understanding the physiological and molecular effects of both the hot and cold extremes of a given region allows for the adapting of grapes to their environment. Crossbreeding and selection of varietals with adaptations such as heat shock proteins, can be of benefit in the Niagara region. Understanding the fluctuating growing conditions, and the level of resilience of different varietals also allows viticulturists to employ various mechanical mitigation strategies to protect their crops from temperature-related damages such as TPC, air circulation, and the use of water to prevent freezing during the winter season. As temperatures continue to reach increasingly high extremes in the coming decades due to climate change, this information becomes invaluable. An understanding of temperature, response to heat- and cold-related stressors, as well as mechanical and genetic mitigation strategies to respond to these fluctuations will allow viticulturists to maximize overall output and quality of the wines they produce. This consideration of temperature moderation, varietal selection, and local climates will allow the Niagara viticultural region to continue to expand and produce some of the world's best vintages for years to come

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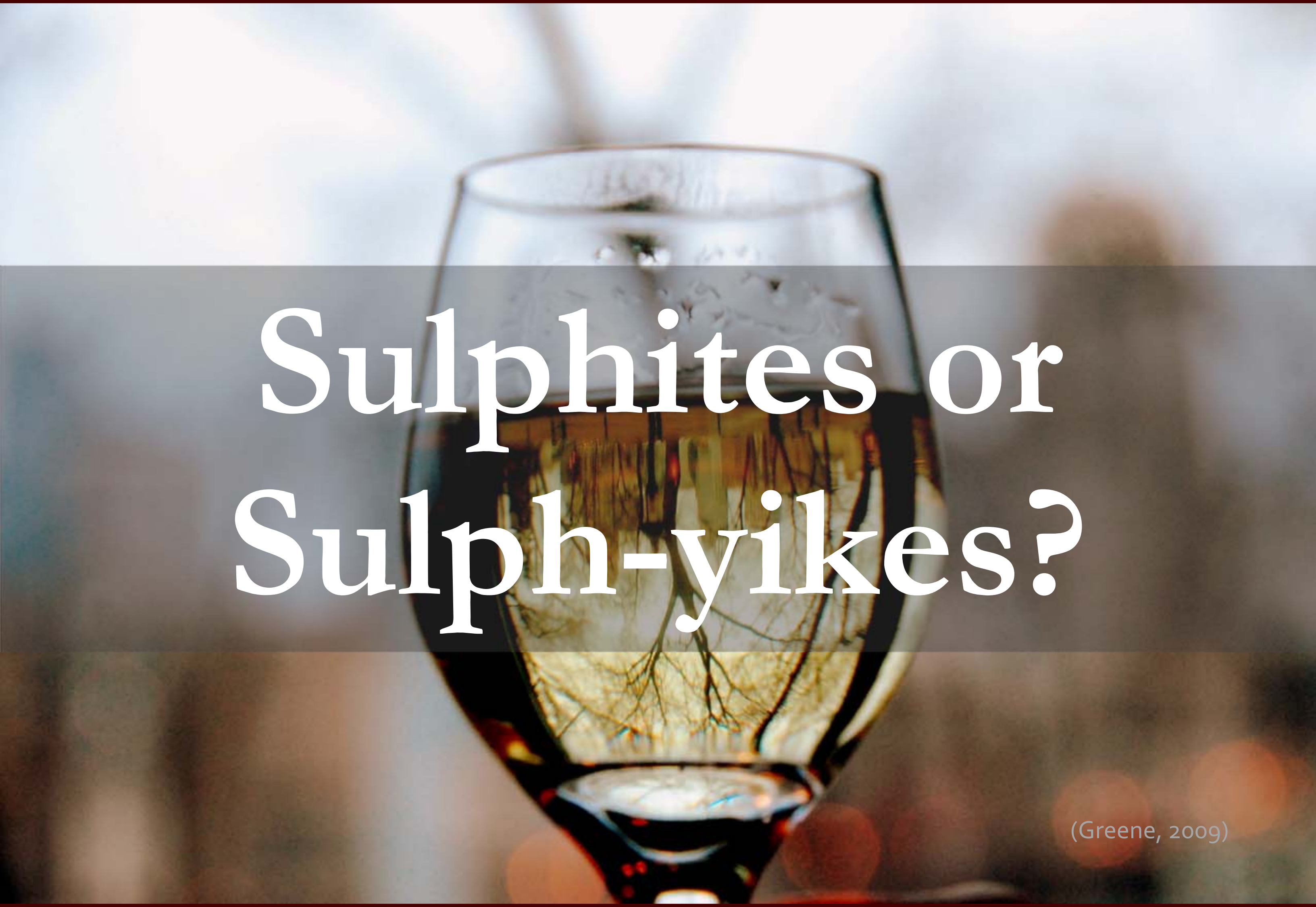
Sulphites or Sulph-yikes?



(Greene, 2009)

Bronwyn Barker, Jacqueline Garnett, Urszula Sitarz, Jack Stewart, Monica Takahashi

With the recent organic food craze, people are becoming more concerned with the additives that their foods may contain. One particular additive that has gained a lot of traction is sulphites in wine. But what are sulphites, exactly, and why are they added to wine? What negative effects, if any, do they have on our bodies once they are ingested? In this article, we will also discuss regulations that have been implemented, both on a local level and on an international level. Finally, we will discuss some alternatives to sulphites that look promising, and hypothesize as to why they are not yet popular in the industry.

WHAT'S THE CONCERN?

With the ease at which news and information spreads, it's no wonder that we find ourselves more and more interested in how the food and beverages we ingest affect our health. Additives in particular have people worried, and one that may be an area of concern for some is sulphites in wines.

Sulphites are a group of compounds that include sulphur dioxide, sodium sulphite, sodium & potassium bisulphite, and sodium and potassium metabisulphite; throughout the 1970s and 1980s, reports surfaced that linked adverse reactions to different food and drink items which contained relatively high levels of sulphites (Vally and Misso, 2012). Although there seemed to be a variety of suspects, wine was often found to be a consistent trigger (Vally and Thompson, 2003). Even more interestingly, a pattern of similar reactions emerged among reports, which consistently described a rapid onset of asthmatic symptoms (Vally and Thompson, 2001). Serious public concern ensued as there were some deaths associated with the consumption of wine and reactions to sulphites. At the time, however, there was no real understanding of what caused such serious reactions (Vally and Misso, 2012).

In the following years, several government and international agencies, such as the United Nations, implemented new regulations, which monitored and restricted the use of sulphite additives in food and beverages (Canadian Food Inspection Agency, 2017). More recently, there has been a growing interest in the production of organic wines to replace wines that use sulphite additives. But do we really need to be concerned? Should we purchase No-Sulphite-Added wines just to be safe? Or is there a public perception of danger that does not align with reality?

SULPHITES AS A PRESERVATIVE IN THE WINE INDUSTRY

Antioxidant Properties of Sulphites

In the winemaking process, additives can be used to keep the wine fresh. Sulphites are sometimes added to wines to act as antioxidants, as they help to maintain the desired sensory characteristics of wine by preventing oxidation (Vally and Thompson, 2003). It would be more accurate to describe sulphites as oxidising controlling agents, as the limit of their antioxidant ability is largely dependent on the amount of sulphites added to the wine. Once added, sulphur dioxide (SO_2) will dissociate into sulphite compounds, the concentrations of which depend on factors, such as pH. Since wine is acidic, most of the sulphites will be present as molecular SO_2 and as the bisulphate ion (HSO_4^-) (Henderson, 2009). The major role of these compounds is to prevent the oxidation of aromatic and phenolic compounds in the wine must, which is composed of the freshly pressed grapes and grape skins (Roullier-Gall, et al., 2017). Aromatics and phenolics are vital for a winemaker because they influence important factors in the wine drinking experience, such as the taste, colour, and mouthfeel. In terms of oenology, which is the study of wine and winemaking, the major reason for the addition of sulphites into wine is that they can act as both an enzymatic and non-enzymatic oxidation prevention methods. Enzymatically, sulphites can act as inhibitors for the polyphenol oxidase enzyme; non-enzymatically, they can prevent the Fenton reaction, which yields highly oxidising hydroxyl radicals (Oliveira, et al., 2011). Since these two mechanisms serve to influence the final product in two very different ways, it is important to understand the role they play throughout the winemaking process.

The major class of oxidising enzymes found in wine are polyphenol oxidases (PPO). They are responsible for the oxidation of monophenols to o-diphenols and can further oxidise these diphenols to o-quinones (Figure 1). These enzymes are predominantly responsible for the darkening of wines (Margalit, 2012). PPOs have copper atoms at their active site, and since metal ions have been shown to non-enzymatically contribute to oxidation, this explains why PPOs are such a critical component of this process (Margalit, 2012). Sulphites allosterically regulate PPOs as the bisulphites (HSO_3^-) formed from the addition of SO_2 causes irreversible structural alteration of the enzymes. The sulphites are thus acting as non-competitive inhibitors, reducing the level of oxidation (Margalit, 2012).

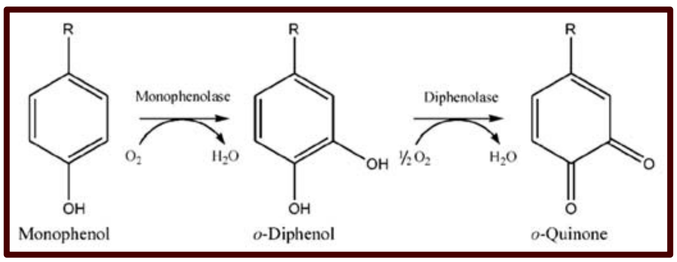


FIGURE 9: POLYPHENOL OXIDASE ACTIVITY. The oxidation of monophenol to o-diphenol and o-quinone by polyphenol oxidases (Molloy, et al., 2013).

Inhibition of the Fenton reaction is one of the major mechanisms through which sulphites help to protect against non-enzymatic oxidation (Reaction 1). In the presence of a transition metal catalyst, the reduction of hydrogen peroxide forms highly reactive hydroxyl radicals. These radicals have high oxidising potential and result in the oxidation of ethanol into acetaldehyde and phenols into quinones (Oliveira, et al., 2011).

$$Fe^{2+} + H_2O_2 \rightleftharpoons Fe^{3+} + HO^{\bullet} + HO^{-} \quad (1)$$

$$Fe^{3+} + H_2O_2 \rightleftharpoons Fe^{2+} + HOO^{\bullet} + H^{+} \quad (2)$$

REACTION 1+2: THE FENTON REACTION. The Fenton Reaction showing the regeneration of Fe(ii) catalyst (Oliveria, et al., 2011).

The SO_2 exerts a protective function in the Fenton reaction by effectively 'scavenging' the H_2O_2, which oxidises the free SO_2 into sulphate. Therefore, the rate at which the Fenton reaction is carried out in the wine is determined by the competition between the H_2O_2-Fe(II) and H_2O_2-SO_2 interaction. After several redox reactions, the bound sulphate will effectively regenerate the lost SO_2 molecule (Elias and Waterhouse, 2010). Controlling this process is vital because the rate of oxidation is related to the ageing of the wine, both in terms of its taste and the level of browning (Li, Gao and Wang, 2008).

Sulphites have many roles in the wine industry. Although important in controlling the chemical components of the wine itself, sulphites are also commonly used to control external agents that may affect the quality and value of the final product.

Sulphites as a Method of Reducing Microbial Growth

Winemakers have been using sulphites as an additive in their wine for decades because they are an effective method of reducing microbial growth throughout the winemaking process. Microbial ecosystems can reduce wine acidity and contribute to aroma and flavour. Conversely, some microbes contribute to wine spoilage, which reduces the quality and value of the wine (Bartowsky, 2009).

Vinification is the process of turning must into wine through fermentation. Sulphites can be added to wine before or after vinification in the form of either SO_2 gas or as $K_2S_2O_5$ which is a salt that is dissolved in water. In general, once the sulphite is mixed with the wine it will reach a pH-dependent equilibrium of bound SO_2 and free SO_2 (Wibowo, 1985). This free SO_2 inhibits the growth of select microorganisms, especially lactic acid bacteria (LAB) and acetic acid bacteria (AAB) (Bokulich, et al., 2015; Takahashi, et al., 2014).

LAB are commonly found in all stages of the winemaking process (Muñoz, Moreno-Arribas and Rivas, 2011). They are responsible for malolactic fermentation (MLF) in wine which, depending on the type of wine, can either be beneficial or detrimental to the final product (Muñoz, Moreno-Arribas and Rivas, 2011). The conversion of malic acid to lactic acid is not considered a true fermentation since no ethanol is produced (Wibowo, 1985). Rather, it is an enzymatic reaction conducted by bacterial cells after they have grown (Wibowo, 1985). During the process of MLF, LAB can decarboxylate amino acids (Lonvaud - Funel, 2001). This often results in the production of biogenic amines, which are amines produced by a living organism (Lonvaud - Funel, 2001). High concentrations of biogenic amines have been shown to have negative health effects, such as headaches, respiratory distress, and heart palpitations (Santos, 1996). Winemakers can minimize biogenic amines by adding sulphites to their wine, which will reduce the LAB populations (Bokulich, et al., 2015).

Unlike LAB, AAB are solely linked to wine spoilage (Guillamón and Mas, 2011). AAB are well adapted to ethanol and sugar rich environments, so they thrive in wine must (Guillamón and Mas, 2011). The metabolism of AAB results in the production of undesirable organic acids due to the incomplete oxidation of sugar and ethanol (Guillamón and Mas, 2011). Most notably, the AAB will convert ethanol into acetic acid, which essentially converts the wine into vinegar. The addition of sulphites has been shown to inhibit the growth of AAB; however, limiting oxygen reduces AAB levels more effectively because AAB need oxygen to complete all of their metabolic processes (Guillamón and Mas, 2011; Bokulich, et al., 2015). Although SO_2 inhibits AAB growth directly to a certain extent, it also serves to indirectly downsize their population through limiting oxygen levels in the wine.

The important role that sulphites play in the winemaking process, as well as the potential adverse health effects associated with sulphites have led to several government regulations ensuring the safety and quality of our wine. But do our wines actually cause a health concern for the general public? According to the Canadian Government, wines that are produced using sulphite additives are completely safe and do not affect the health of the population at large (Health Canada, 2010).

POLICY AND PRACTICE

Due to the potentially extreme reaction of sensitive asthmatic individuals, sulphites are listed as a priority allergen on Health Canada's website despite not actually being allergens. In order to be classified as an allergen, the body would need to respond to the substance with antibodies and antigens as part of an immune response (Health Canada, 2017b). Sulphites affect other bodily systems such as digestion and respiration, and therefore do not fall under this category. As seen in Figure 2, if sulphites are added to the wine in more than 10 ppm, the threshold level for reactions, then the wine label must advise the consumer that there are sulphites present in the wine, though not necessarily through an explicit "Contains" statement (Health Canada, 2012). This is part of the Government of Canada's acknowledgement that they do not believe sulphites present in wine in concentrations under legal limits, of 350 ppm in the combined state and 70 ppm in the free state, pose any risk to the majority of Canadians (Health Canada, 2017a; 2010). These regulations apply only to added sulphites; any naturally occurring sulphites in wine do not have to be measured nor labelled, as they equate to be far less than the 10 ppm limit (Health Canada, 2012). The Canadian Food Inspection Agency (CFIA) is the organization responsible for enforcing the regulations established by the government, which includes monitoring labels, recalls, inspections, and fertilizers used. The CFIA works in accordance with the United Nations' rules set out in the Hazard Analysis Critical Control Point (HACCP) to confirm research and conduct risk assessment and surveillance to ensure the safety of food and drinks sold in Canada (Canadian Food Inspection Agency, 2017; 2012). The CFIA is also the agency responsible for conducting research into the limits imposed on Canada's food and ingredients. The maintenance of these high standards should set our minds at ease in terms of the safety of our wine.

FIGURE 2: WINE THAT CONTAINS SULPHITES. This is an example of how winemakers display sulphite contents in their wine. This bottle contains more than 10 ppm and thus the label must advice the consumer that there are sulphites in the wine (Wine Bottle, 2014).

It is also apparent that the winemakers themselves care deeply about the quality of their wine. When asked about their approach to making wine and the use of sulphites, William Roman, the operations manager at Rosewood Estates Winery, explained how he likes to focus on making the best wine possible in order for the consumer to have the best experience, as opposed to only focusing on restrictions and the general public. Roman's reasoning for this mindset is that it's more direct to think about the health of the wine, and the health of the people will follow (Roman, 2017). For these reasons, Rosewood Estates Winery do add sulphites to their wines. It should be noted, however, that this is only the opinion of one winemaker. Different winemakers will have different opinions regarding whether or not they choose to add sulphites to their wine. But what is it that causes people to react differently?

THE METABOLISM OF SULPHITE SENSITIVITY

The majority of the global population is not affected by the sulphite additives. However, there is a portion of people that do exhibit sensitivities, which generally refers to the triggering of adverse symptoms upon exposure to or ingestion of sulphites (Vally, et al., 2009; Vally and Misso, 2012). People with asthma are most vulnerable to sensitivities, and it is estimated that anywhere from 5-10% of asthmatic patients exhibit this sensitivity (Vally and Thompson, 2003). The risk of having a reaction is often heightened in acidic solutions; lower pH levels release higher concentrations of free sulphites, which are more unstable and can continue to react with other compounds in the body (Vally, et al., 2009).

It is important to note that the cause behind sulphite sensitivity relating to wine consumption is complicated, and is most likely attributed to the combination of many metabolic and environmental factors (Stevenson and Simon, 1984). Responses are unique to each individual and reactions range from mild disturbances to severe or even life-threatening reactions. In addition to asthmatic and anaphylactic reactions, symptoms often include dermatitis, urticaria, flushing, hypotension, and abdominal pain (Vally and Misso, 2012).

Why does this portion of the population experience such diverse and severe reactions? The answer may lie in one very important element: molybdenum. Patients with sulphite sensitivities were found to have almost no detectable molybdenum in their blood (Papaioannou and Pfeiffer, 1984). Molybdenum is the trace element contained within the enzyme sulphite oxidase, which is responsible for catalyzing the oxidation reaction that processes sulphites in the body (Gunnison, et al. 1987; Papaioannou and Pfeiffer, 1984). In an article written by Stevenson and Simon (1984), all sulphite sensitive patients exhibited a sulphite oxidase deficiency. The absence of this enzyme results in an inability to detoxify the sulphites that enter the body (Gunnison, et al., 1987). Consequently, adverse reactions occur from the inability to rapidly process and eliminate accumulated sulphite loads (Gunnison, et al., 1987). Airways that lead to the lungs to consequently constrict, which makes it much harder for sensitive patients to breathe (Vally and Misso, 2012).

POTENTIAL ALTERNATIVES

Approximately 15-30 million people worldwide may be sensitive to sulphites, therefore there seems to be a large enough demand for sulphite-free wines such that winemakers could profit from producing wines that cater to this market (Masoli, et al., 2004). This holds great value, particularly if this characteristic allows a wine to stand out as a unique product that can accommodate this portion of the population. A recent study by Costanigro, et al., (2014) highlighted public interest on this subject, and indicated that consumers may be encouraged to buy wines with no added sulphites, provided that the quality of the wine is not compromised. Ultimately, the winemaking industry could have a lot to gain by both accommodating the sulphite sensitive consumers and capitalizing on public interest. Sulphite-free wine may remain as an option for specialty wines that, if marketed properly, can enter the industry in a way that has never been seen before.

The question must be asked: are there alternatives to sulphites? The problem, or some might argue the beauty, of wine is the artistic aspect of its production. The wine produced without added sulphites must have the flavour, aroma, colour, and overall quality of the wine produced with sulphites. This must be considered in the search for sulphite alternatives. As it happens, there are a number of potential alternatives currently being researched.

A recent study published in the Australian Journal of Grape and Wine Research used ozone as a preservative rather than sulphites (Bellincontro, et al., 2017). The experiment involved the fumigation of Petit Verdot grapes using ozone instead of SO_2 (Bellincontro, et al., 2017). The rest of the winemaking process was standard and the wine was aged for four months in barrels (Bellincontro, et al., 2017). From a chemical perspective, the wine met the standards of any wine treated with sulphites. The ozone is also cost effective as decreased vinification time can reduce costs. However, the art and culture that surround wine are not the simple result of chemistry. In quality experiments on aroma, taste, and colour - which will ultimately decide if ozone is a feasible replacement for added sulphites - the wine treated with ozone was quite successful (Bellincontro, et al., 2017). The treated wine was rated high for aroma, particularly, with emphasis placed on small red fruits, blackberries, cherry liqueur, spices, and an overall fruity olfactory sensation. The panellists noted the rich red and purple tints in the treated wine and the fruity taste of the wine. Overall, the positive reception of the wine from the panel and the economic feasibility of this method demonstrate that ozone has great potential as a sulphite alternative (Bellincontro, et al., 2017).

In another study, researchers in Spain tested the addition of antimicrobial plant extracts as an alternative to sulphites in wine (García-Ruiz, et al., 2013). Phenolic compounds, including polyphenols, have been cited as potential alternatives to sulphites (García-Ruiz, et al., 2013). This suggests that polyphenol-rich plant extracts could be used to control MLF in winemaking (García-Ruiz, et al., 2013). Two plant extracts were compared in this study, an extract derived from almond skin and one from eucalyptus (García-Ruiz, et al., 2013). It was found that both extracts are successful alternatives to sulphites, as they perform the same antimicrobial activity without significantly changing the colour or aroma of the wine. Unfortunately, this study did not include a taste component; however, based on the chemical composition of the resulting wines, it was hypothesized that the plant extracts may cause an increase of the astringent sensation of the wine. Similarly, this paper did not comment on the cost efficacy of using plant extracts as an alternative to sulfites (García-Ruiz, et al., 2013).

Dimethyl dicarbonate (DMDC) and lysozyme are two preservatives currently used in wine and food (Ancín-Azpilicueta, et al., 2016). A 2016 study hoped to analyze the effects of these preservatives individually, mixed, and mixed with sulphites.

Interestingly, DMDC and lysozyme have antimicrobial, but not antioxidant, properties (Ancín-Azpilicueta, et al., 2016). It was found that a mixture of lysozyme and sulphur dioxide was the best alternative to just sulphur dioxide addition (Ancín-Azpilicueta, et al., 2016). This combination resulted in an overall reduction of total sulphites in the final product (Ancín-Azpilicueta, et al., 2016). Unfortunately, like the plant extract experiment, there were no proper cost, taste, aroma, or colour studies. Despite the lack of flavour studies, the lysozyme and sulfur dioxide mix has clear potential as a sulphite alternative (Ancín-Azpilicueta, et al., 2016).

As the concern regarding sulphites has increased in recent years, as noted in each of the studies highlighted above, researchers have taken this concern to the laboratory. There are several proposed alternatives, all of which have been successful in sulphite reduction; however, there is still much more research to be done. What is wine without its aroma, colour, taste? Aside from the chemical benefits of any of these potential alternatives, none will become common practice unless the wine can be made at the same, if not higher, quality.

Sulphites are currently inherent to the wine industry. They are important in the prevention of enzymatic and non-enzymatic oxidation reactions in wine, which is crucial throughout the winemaking process. This is also affected by the antimicrobial properties of sulphites, which reduce the risk of wine spoilage while maintaining the quality that microbes can add. Their reliable nature has made them a staple in the wine industry; however, since sulphites can have negative effects in some populations, it is important that we understand the purpose of the regulations on sulphites as additives. It is also important that we trust these regulations, especially with regards to the general public. As more and more alternatives to these additives are developed, we may see an increase in the number of sulphite-free wines which cater to the whole population. Thus far, there are no replacements at the same price and relative quality; however, drinking wine with added sulphites will not pose a risk to your health if you do not have a sensitivity. If you are unsure if you have a sensitivity to sulphites, you may want to consult a doctor prior to consuming wine. Lastly, if you know you have a reaction to sulphites and are sensitive, there are alternatives! The selection of wines available to you may just be, at least for now, more limited.

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Modern Technology in the Winemaking Process

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For thousands of years, wine has been a staple in many different cultures and societies. As technology has progressed, the winemaking process has improved by becoming more efficient and precise. Recent technology has shaped wine-making at every major step in the process from vineyard management to wine storage. These technologies are being used locally in the Niagara region of Ontario, Canada, with potential room for growth with these innovations.

INTRODUCTION

Technologies and equipment used in the winemaking process have a significant impact on the quality of the resulting wine (Catania, et al., 2016). From crushing grapes by foot to automated sorting, technology has evolved dramatically in the 9,000 years that humans have been producing and consuming wine (Borrel, 2009). The winemaking process is constantly evolving as new technologies are developed to produce better wine in terms of taste, cost, and efficiency.

Annually, Canadians enjoy over 1.2 billion glasses of Canadian-produced wine (Frank, 2017). In 2015, the Ontario wine industry contributed $4.36 billion to the Canadian economy, with 90% of Ontario's grape production coming from the Niagara region (Frank, 2017). The Niagara region extends from Niagara-on-the-Lake in the East to Grimsby in the West. There are almost 60 wineries in the Niagara Region that cover 14,000 acres of land (Ryerson, et al., 2008). As such, this region is very important to the advancement of Canada's wine industry. Impactful technological advancements affect Niagara's wine industry and Canada's economy as a whole.

Technological advances have been made in all aspects of the winemaking process, as outlined in Figure 1. Beginning with vineyard management, remote sensing technology has allowed viticulturists to evaluate grape quality, nutrient status, and pest infestations. Mechanical harvesting has increased the efficiency of collecting grapes ready for harvest. Grape destemmers improve the quality and taste of the final wine by removing the stem. The precision in sorting grapes has also increased since the introduction of optical sorters. Crushers and pressers have replaced the practice of stomping on grapes. Finally, once the grape juice is prepared, the final wine is often fermented and stored in large stainless-steel barrels. Technological innovations from all aspects of the winemaking process improve the efficiency, precision, and economics in the industry.

REMOTE SENSING

While the farming of conventional food crops, such as corn and wheat, involves maximizing only growth, the management of vineyards encompasses a multitude of factors (Ryerson, et al., 2008). These crop growth factors include evaluating canopy density, identifying grape quality in different areas, and monitoring issues with nutrient status and pest occupation (Johnson, et al., 2003; Lewin, 2002). However, from the ground level, it is difficult and time-consuming to collect enough accurate data to evaluate the health of entire fields. Thus, many wineries in areas such as California's

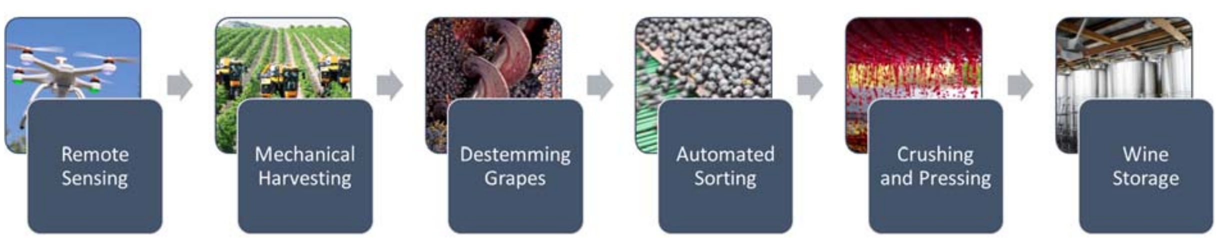

FIGURE 1: STEPS IN THE WINEMAKING PROCESS. Technology has significantly improved the efficiency, precision, and economics related to several steps in the winemaking process.

Napa Valley utilize remote sensing technologies to monitor and manage their fields (Ryerson, et al., 2008; Johnson, et al., 2003). Technologies, such as satellite and aerial imagery, the Global Positioning System (GPS), and geographic information systems (GIS), provide fast and efficient means of collecting data and mapping out various features of the vineyard. This information allows precision viticulture techniques to be implemented. For instance, grapes are harvested individually at their peak quality rather than by whole blocks of vines at once (Comba, et al., 2015; Marciniak, et al., 2015).

Remote sensing is comprised of two main steps: image collection and image processing. Multispectral images of vineyards are taken either via satellite, aircraft, or unmanned aerial vehicles (drones) (Comba, et al., 2015; Johnson, et al., 2003). These images are then processed using specific algorithms that calculate a normalized difference vegetation index (NDVI) for each pixel, which assesses whether or not an observed target contains live green vegetation as seen in Figure 2 (Johnson, et al., 2003). In some cases, this requires an additional preprocessing step where data are collected from a few select calibration sites, along with their GPS coordinates, to provide the algorithms with a reference.

One of the biggest challenges to effectively implement remote sensing to evaluate vineyard health has been developing the complex algorithms needed to distinguish vine rows from each other and from other vineyard features with minimal user input (Johnson, et al., 2003; Comba, et al., 2015). However, in the past decade researchers

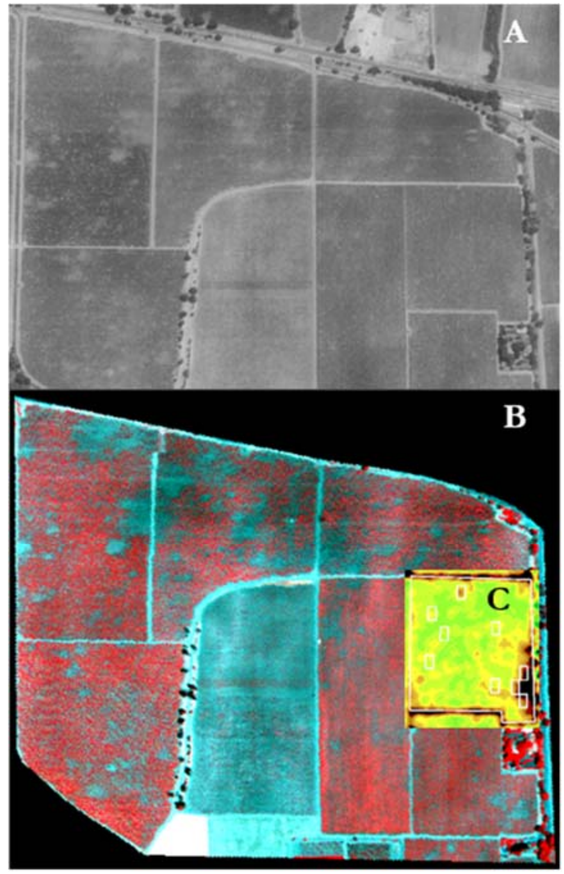

FIGURE 2: IMAGE PROCESSING. (A) Images from work by the NASA Ames Research Center to using remote sensing in a California vineyard in 1993. (B) Infrared images were taken of the study area and processed to create an NDVI image where green indicates dense vegetation and black is no vegetation (Johnson, 1993; Google Earth, 2006).

have developed many new algorithms proven to overcome these issues with high accuracy while remaining autonomous (Comba, et al., 2015; Johnson, et al., 2003). Other issues of cost, computation time, and availability are becoming negligible as the required technologies become cheaper, more efficient, and readily available to the general public (Lewin, 2002).

Most companies that offer remote sensing service charge $8-10 per acre with a 20-40 acre minimum cost (Ryerson, et al., 2008). For large wineries in the Napa Valley area, this means an investment of $400 leads to an additional income of upwards of

$100,000 (Ryerson, et al., 2008). However, Niagara vineyards are much smaller in size so most wineries use simpler GIS systems and collect data manually (Marciniak, et al., 2015; Ryerson, et al., 2008). Despite its current commercial absence in the region, recent studies have demonstrated the viability of remote sensing in Niagara vineyards, particularly for identifying areas prone to frost damage in the spring, winter vine damage, and ideal placement of wind machines (Ryerson, et al., 2008).

The use of remote sensing greatly improves the speed and accuracy of collecting vineyard data while requiring far less labour. Modern imaging systems accurately identify distinct vineyard features and are very effective at showing change over time. Throughout the year, this information is extremely valuable for assessing the quality and health of individual vines and the vineyard as a whole.

FIGURE 3: HARVESTING GRAPES. This self-propelled harvester moves over and around the grapevines, shaking them when underneath to collect the grapes as they fall. The spacing between vine rows has to be large enough to accommodate the harvesters.

MECHANICAL HARVESTING

Traditionally, grapes have been hand-picked from their vines. Although this ensures selective picking and gentle transport of the grapes, this method is labour-intensive, time-consuming, and expensive (Domingues and del Aguila, 2016). To introduce a more efficient method of harvesting, experimentation with mechanical harvesters first began in California in 1953 (Hendrickson, et al., 2016). While many wineries around the world still employ hand-picking, the majority of wineries in the Niagara region have adopted this mechanical approach.

Harvesters remove grapes from the vine by shaking a segment of the grapevine so that the grapes detach from their stems (Hendrickson, et al., 2016). There are two main types of harvesters: trunk shakers and pivotal strikers. (Hendrickson, et al., 2016). Trunk shakers have two parallel rails that vibrate the upper trunk by oscillating perpendicular to the direction of the vine row. Alternatively, pivotal strikers shake the foliage instead with two banks of rubber rods arranged parallel and on either side of the grapevines (Jackson, 2014). Compared to pivotal strikers, trunk shakers remove fewer leaves and material other than grapes (MOG) from the vines (Jackson, 2014). Additionally, striker-shaker combinations use both trunk shaker rails and pivotal striker rods in tandem. They reduce potential damage to the vines, trellis, and grapes, and prevent the release of MOG by oscillating with less force and at a lower frequency (Jackson, 2014).

As for collecting the grapes, there are three harvester configurations used: dedicated self-propelled harvesters, multi-functional self-propelled harvesters, and tow-behind harvesters (Goldammer, 2015). The harvester either collects the grapes into on-board bins and offloads them when full or the harvesters have a conveyor belt which collects the grapes to offload them to processing. As seen in Figure 3, self-propelled harvesters straddle the vine rows and typically use pivotal strikers to remove grapes from the vines (Hendrickson, et al., 2016). Alternatively, tow-behind harvesters operate similarly to tractors. The difference between the dedicated and multi-functional self-propelled harvesters is that the former only removes and collects grapes, while the latter also performs other functions such as pesticide spraying (Goldammer, 2015).

One of the major advantages of utilizing these harvesters is their ability to reduce harvesting time. There is a short period of time to cultivate ripe grapes; hand-picking puts the grapes at risk of over-ripening or spoiling, whereas machine harvesting requires a very short amount of time (Domingues and del Aguila, 2016). Furthermore, hand-picking requires more workers than those required to operate a mechanical harvester. After an initial investment in the machines, their operation significantly reduces labour costs and they are relatively inexpensive to maintain (Jackson, 2014; Hendrickson, et al., 2016).

An unexpected benefit of utilizing machine harvesters is the ability to do harvesting at night. Grapes and vines are more turgid at night; therefore, less force is required to remove the grapes from the vines and transportation in cooler temperatures lowers the risk of spoilage due to oxidation (Jackson, 2014). Due to poor visibility, manual night harvesting typically results in much lower grape yield (Hendrickson, et al., 2016). The Niagara region is renowned worldwide for their ice wines (Fraser, 2016). Vintners Quality Alliance (VQA) icewine must be made with grapes harvested at -8°C (Fraser, 2016). Mechanical harvesting is required because icewine grapes are usually harvested at night when temperatures are sufficiently low (Fraser, 2016). In Niagara-on-the-Lake, Pillitteri Estates Winery, the world's largest estate producer of icewine, uses mechanical harvesters to collect their grapes (Fraser, 2016).

The taste and sensory differences between manually and mechanically harvested grapes have been observed in wines (Jackson, 2014). This difference is attributed to the increased oxidation of the grape juice during mechanical harvesting which is a result of increased grape rupturing, as well as the inclusion of different quality grapes in the harvest (Hendrickson, et al., 2016). When collecting the grapes, sulphites are often added to the collecting bins to reduce this oxidation (Jackson, 2014). All sensory characteristics vary depending on the grape varietal and the quality of the wine is never detrimentally impacted from mechanical harvesting. Therefore, mechanical harvesting overall is an effective and efficient alternative to hand-picking.

DESTEMMING GRAPES

Automation has also changed the way in which grapes are destemmed. The destemming process mechanically separates grape berries from the stalks and other vegetable matter. Ideally, the machine removes and separates all of the berries from the stem. However, in practice, some stems make it through with the berries and some berries exit with the stems (Coetzee and Lombard, 2013). Wineries in the Niagara region predominantly use destemmer-crusher machines in their operation, differing only in their processing rates (Bock and Cyr, 2014). Currently, most commercial wineries use horizontal rotating destemmers. These have two main components: the beater shaft and rotating drum seen in Figure 4 (Coetzee and Lombard, 2013).

Grapes are fed into the hopper and then fall into the rotating drum (Coetzee and Lombard, 2013). The beater shaft lies in the centre of the rotating drum and has pins arranged in a spiral around it (Coetzee and Lombard, 2013). The beater shaft serves two purposes; it feeds bunches of grapes into and through the rotating drum and its pins beat the berries from the stems (Coetzee and Lombard, 2013). The rotating drum is perforated to allow the destemmed

FIGURE 4: INSIDE A DESTEMMER. The destemmer consists of two components a rotating drum and the beater shaft (Colas, 2015).

FIGURE 5: PILE OF BERRY STEMS. After being removed from the grapes the piles of leftover stems are collected in separate containers (Mingo Hagen, 2008).

grape berries to pass through and keeps the stems in the drum to be discharged at the other end, as seen in Figure 5 (Coetzee and Lombard, 2013).

Removing the stems before crushing reduces phenol uptake from vine parts, which have a more astringent and bitter taste than phenols from grape skins and seeds (Catania, et al., 2016). Catania, et al. (2016) also found that a destemmer equipped with partially coated rubber beaters produced Chardonnay wines of overall higher quality than a destemmer equipped with steel beaters. After destemming, the grapes still need to be sorted to remove smaller material such as trellis clips, staples, snails, or insects.

AUTOMATED SORTING

Grapes must be sorted to ensure the highest calibre of grape juice for fermenting into wine. The heterogeneous nature of wine grapes means that substandard berries (raisins, rotten berries, and sunburnt berries), material other than grapes (stems, leaves, and petioles) and grapes in perfect condition are all brought in from the vineyard together (Falconer, Liebich and Hart, 2006). Sorting grapes by berry size or

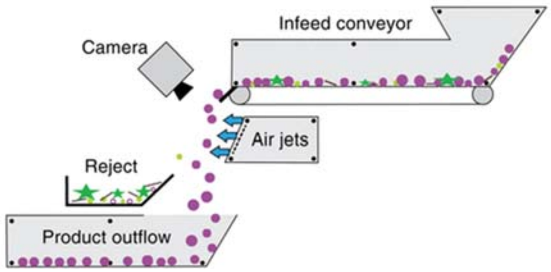

FIGURE 6: OPTICAL SORTER. Schematics of mechanism as grapes are put through system (Hendrickson and Oberholster, 2017).

colour has been found to create a wine with significant differences in aroma and acidity (Friedel, et al., 2016). Traditionally, bunches of grapes pass along a moving belt where people sort the grapes manually (Bird, 2011). However, in recent years, the importance of automated grape sorting has gained momentum and optical evaluation technologies have improved the quality of the final product (Lafontaine, et al., 2013). Relative to hand sorting, optical sorting is a very consistent and efficient method to employ since it inspects every berry individually (Hendrickson and Oberholster, 2017). Grapes were first "light-sorted" in the late 1970s but the technology only allowed for a sorting rate of 64 berries/min (Carroll, et al., 1978; Hendrickson and Oberholster, 2017). As the technology has developed, optical sorting machines have become faster and more efficient, and are now in operation in several wineries globally (Hendrickson and Oberholster, 2017). In 2014, Vineland Estates Winery in the Niagara region became the first winery in Canada to use an optical sorter in their winemaking process (Grape Growers of Ontario, 2017).

After destemming, grapes are fed into a conveyer belt that spreads them out evenly where a high-speed camera captures high-resolution images of the fruit, as seen in Figure 6 (Hendrickson and Oberholster, 2017). A computer then systematically selects and sorts specific grapes based specified colour, texture, and shape parameters (Lafontaine, et al., 2013; Falconer, Liebich and Hart, 2006). When a product does not meet specific conditions, the system uses high-pressure blasts of air to divert the material to a waste bin (Hendrickson and Oberholster, 2017). Modern optical berry sorters process between 3 and 10 tons of berries per hour (Hendrickson and Oberholster, 2017). Within 40 years, optical sorters have become exponentially more efficient and effective, sorting with a degree of precision not possible by hand sorting.

A study by Falconer, Liebich and Hart (2006) found that automated sorting of hand-picked Chardonnay wine grapes had a significant effect on both chemical and sensory characteristics of the final wine. The wine produced from optically sorted grapes had higher total phenolics, pH, and residual sugar relative to the wine made from unsorted grapes (Falconer, Liebich and Hart, 2006). It was also perceived to be sweeter, have a lower acidity, and have a higher tropical aroma; these are considered to be better positive characteristics in wine (Falconer, Liebich and Hart, 2006). Additionally, a study by Hendrickson, et al. (2016) found that when mechanical harvesting and optical berry sorting are used in tandem, they had a synergistic effect on Pinot noir grapes. The differences in the berries as a result of being harvested mechanically instead of by hand were successfully diminished or eliminated by the use of optical sorting (Hendrickson, et al., 2016). By combining both technologies at different stages in the winemaking process, the quality of the wine produced is the same

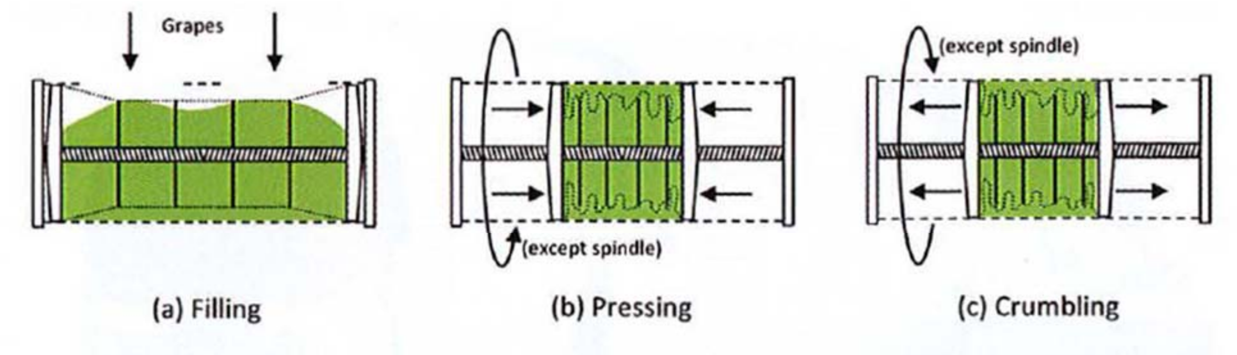

FIGURE 7: HORIZONTAL PRESSER. The mechanism by which grapes are pressed including (a) filling, (b) pressing, and (c) tumbling (Nordestgaard, 2015).

as that produced from hand picked and hand sorted grapes, but is produced at a more efficient rate.

CRUSHING AND PRESSING

After destemming and sorting, the berries are crushed and pressed (Bird, 2011). Crushing the grapes breaks the skin apart for the juice to be released and collected. The crusher has mechanized the ancient process of stomping on the grapes by instead passing them through a set of rollers. Pressing is necessary to release the juice stored in tougher cells within the inner layer of the grape skin (Bird, 2011). Destemming and crushing before pressing has been shown to improve juice yield and protein and phenolic extraction into the juice (Tian, et al., 2013).

There are three main types of pressers: horizontal, vertical and pneumatic. Vertical basket pressers consist of a pile of wooden blocks stacked between the mass of grape material (cake) and the press nut (Nordestgaard 2015). Due to the elastic nature of the wood, as the juice flows from the grapes the wood springs back and continues to press the cake (Nordestgaard 2015). These pressers are incredibly labour-intensive, as the cake and press need to be managed constantly. Horizontal plate pressers, seen in Figure 7, involve putting pressers on their side, where the cylinder rotates, crumbling the cake on its own.

Alternatively, pneumatic presses use an inflatable diaphragm or bladder to press grapes, as seen in Figure 8. As the diaphragm expands, a thin even layer of cake is distributed around the entire drum. This allows it to be pressed very quickly, improving the efficiency of the process. Modern horizontal pneumatic pressers include internal drainage ducts to protect the wine from oxidation, further improving the quality of the wine. The pneumatic horizontal press has largely replaced all other traditional pressers, as it is more efficient, takes up less space, and is easier to

FIGURE 8: PNEUMATIC PRESSER. The diaphragm in a pneumatic presser expands to crush the grapes, allowing the liquid to be collected, without the seeds being broken (Burgundy Wine Board, 2017).

load and unload (Jackson, 2014). Many wineries in the Niagara region, such as Rosewood wineries, prefer this pressing technique (Roman, 2017).

WINE STORAGE

The use of stainless steel tanks versus wooden barrels has been an ongoing point of contention for winemakers. Various studies have found significant chemical and sensory differences between wines aged in steel tanks and oak barrels, warranting different markets for each. Small-scale wineries such as those found in the Niagara Region choose their storage option depending on the desired taste of the final wine and the advantages that each storage method offers.

Fermentation of wine is carried out in various containers, including plastic or glass demijohns, stainless steel tanks, or oak barrels. The usage of each varies across wineries depending on the desired characteristics of the final wine product. Because wood is a porous material, it readily releases compounds into the wine during fermentation. Conversely, stainless steel tanks do not chemically interact with the wine (González-Marco, Jiménez-Moreno and Ancín-Azpilicueta, 2007). The compounds released by the oak affect the colour, aromatic, and tasteful properties of the wine often described as a toasty or spicy taste (Ibern-Gomez, et al., 2001). Thus, winemakers using stainless steel tanks often sacrifice this added woody taste in wine. This has huge applications in marketing since wine that was aged in oak barrels is often seen by consumers as 'vintage' and high quality (Moulton and Lapsley, 2001). As an alternative to barrels, adding oak chips to stainless steel tanks gives wine the same

FIGURE 9: FERMENTATION ROOM. Several temperature-controlled stainless-steel tanks, some of capacities up to 25,000 L in Jackson-Triggs Winery in Niagara-on-the-Lake, Ontario (Eriksson, 2006).

taste obtained from ageing in barrels with the added advantage of the new technology in the steel tanks (Wilker and Gallander, 1988).

The use of stainless steel tanks for wine storage and fermentation has increased dramatically in the past few decades. This increase is largely attributed to the fact that the fermentation of wine is very temperature-sensitive, and the tank units are capable of controlling temperature with low energy costs (Torija, et al., 2001). Moreover, cleaning stainless steel tanks is a simpler task as they have large removable lids accessible for spraying with hot water and cleaners. In contrast, barrels are much harder to clean since their only access point is through the small cork hole. This gives steel tanks the advantage of sterility which prevents spoilage and faults in the wine (Roman, 2017).

Manufacturing steel tanks is also much more controlled since they are built on a large scale in factories. Conversely, barrels are hand-crafted, taking longer to build. The difference in price points drives the cost of wine production in tanks down to a lower price per litre than their barrel counterpart. Further, steel tanks have a much longer commercial lifespan. Wooden wine barrels need to be replaced every 1-3 years, whereas steel tanks last for many more. However, the net return on product value varies in this situation as despite costing more to produce barrel-aged wine sells at a higher price than stainless steel tank aged wine.

As such, wineries often have a combination of barrels and steel tanks, the latter being for bulk production and fermentation, and the former for the smaller batches with 'vintage value'. Some wineries even limit their barrel ageing. For instance, Jackson Triggs Winery in Niagara-on-the-Lake only uses barrels to age red wine (Jackson, 2017). Ultimately, it is up to the winery to assess the quantity of wine they want to age in barrels. However, the value a more controlled and cost-effective storage method is apparent as wine fermentation across the Niagara region occurs mostly in stainless steel tanks.

SUMMARY

Throughout history, winemakers have been implementing new technology in the winemaking process in an attempt to improve its efficiency and the quality of the wine produced. The improvements rendered by these technological advancements have affected the winemaking process at every stage, and have thus been implemented in wineries across the world. As a result, winemakers have fine-tuned the quality and characteristics of their products. Additionally, further advancements can be applied to winemaking technology in the future, producing high calibre wine tailored to specific tastes. New technologies will hopefully continue to improve the efficiency and effectiveness of the winemaking process, increasing competition and production quality in the wine industry.

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FIGURE LIST

Figure 1: Steps in the winemaking process.

Figure 2A: Google Earth V 7.3.0.3832 . (July 9, 1993). Robert Mondavi Winery, Kalon Vineyard, Oakville, CA, USA. 30° 25' 30.76"S, 122° 23' 51.01"W, Eye alt 1.63 km. US Geological Survey. http://www.earth.google.com [October 15, 2017].

Figure 2B: 2m pixel resolution infrared image of Robert Mondavi Winery, Oakville, CA. NASA Ames Research Center, Johnson, Lee F., 1993.

Figure 3: Harvesting Grapes. Pixabay, HardyS, 2012.

Figure 4: Inside a Destemmer. Wikimedia Commons, Olivier Colas, 2015.

Figure 5: Pile of Berry Stems. Wikimedia Commons, Mingo Hagen, 2008.

Figure 6: Schematics of Optical Sorter. Hendrickson and Oberholster, 2017.

Figure 7: Horizontal Pressers. Nordestgaard, S., 2015.

Figure 8: Pneumatic Presser. Burgundytoday.com., 2017.

Figure 9: Fermentation Room. Wikimedia Commons, Tomas Eriksson, 2006.

RED WINE: IS IT AS HEALTHY AS *COSMO* CLAIMS?

AILEEN LIU, SABRINA MACKLAI, CONNOR MACLEAN, POOJA SREERANGAN, JOSH YACHOUH

Many magazines, websites, and health fanatics claim that to live a healthy life, consuming a glass of red wine should be a daily routine. The source of this health kick is said to come from a compound found in red wine called “resveratrol”. This naturally-occurring compound is claimed to treat many diseases including coronary heart disease, diabetes, obesity, and cancer. But, are these claims substantiated? And if so, is it possible to reap these benefits through consuming red wine? This article will explore how resveratrol may improve the aforementioned conditions and provide some recommended “doses” of both resveratrol and red wine. For any self-proclaimed “wine moms” that avidly follow the red wine claims of magazines like *Cosmopolitan*, be prepared to have your perspectives changed.

INTRODUCTION

A glass of wine a day keeps the doctor away - or does it? From *Cosmopolitan* magazine to countless articles plastered across Facebook walls, the idea that wine not only tastes good but can be good for your health is quickly becoming popularized. Yet, this idea of using wine for gaining health benefits is far from new and in fact, is found throughout antiquity. Ancient Egyptians thought wine could be used to combat asthma and epilepsy (Fehér, Lengyel, and Lugasi, 2007). As well, Romans applied wine as a disinfectant in treating wounds and wine was prefered over drinking water that contained contaminants (Fehér, Lengyel, and Lugasi, 2007). Today, centuries later, wine is not directly marketed as a medical treatment, but the question remains if it should be.

In 2015, almost 2.5 million litres of wine were consumed globally, and this figure is estimated to increase annually (The Wine Institute, 2015). The top consumers of wine were the United States (13.43%), France (11.01%), Italy (8.30%), and Germany (8.30%). At the same time, there have been increased global and Canadian incidence rates of prominent diseases and conditions such as coronary heart disease (CHD), diabetes, obesity, and cancer (Statistics Canada, 2016; Government of Canada, 2011; Navaneelan and Janz, 2014; Canadian Cancer Statistics Advisory Committee, 2017). Could wine possibly treat these modern diseases, as it was thought to treat diseases in antiquity?

The French Paradox was a term coined by Dr. Serge Renaud and his colleagues in their 1992 paper. They described the paradoxical inverse relationship between the high saturated fat diet of the French people and their surprisingly low mortality rate from CHD. Renaud and his colleagues hypothesized that the cause of this inverse relationship was a high red wine consumption, shown through epidemiological evidence (Renaud, 1992). It was their belief that wine offers protection against cardiovascular conditions that are likely to arise in individuals with high fat diets. After this paper was published, interest in wine for therapeutic purposes skyrocketed and led to renewed research into the compound resveratrol (Weiskirchen and Weiskirchen, 2016).

Resveratrol is a naturally-occurring compound that is often credited for giving wine its health effects. This compound can be derived from multiple sources including grapes, blueberries, apples, and even peanuts (Weiskirchen and Weiskirchen, 2016). However, the highest concentrations of resveratrol are found in red wines, which contain an average of 1.9 +/- 1.7 mg of resveratrol per litre of red wine (Weiskirchen and Weiskirchen, 2016).

Due to the popularity of the French Paradox and the idea of resveratrol as some magic bullet, many studies have been conducted in animal models to determine the therapeutic capacity of resveratrol (Weiskirchen and Weiskirchen, 2016). While resveratrol has been found in animal studies to impact many organs ranging from the liver to the brain, the interest lies in how effective it is at treating diseases. There still exists much controversy – is the resveratrol hype justified? If so, how much wine must someone drink to reap its benefits?

RESVERATROL AND DISEASE

The simplicity of resveratrol's structure allows it to mobilize in many different molecular pathways and mechanisms and in a wide range of organs (Weiskirchen and Weiskirchen, 2016). This allows the compound to potentially exert therapeutic effects, such as improving the conditions of those affected by numerous diseases including coronary heart disease, diabetes, obesity, and cancer (Figure 1).

CORONARY HEART DISEASE

Since the announcement of the French Paradox, wine has been consistently lauded for its benefits in preventing cardiovascular disease since the announcement of the French Paradox. A study conducted by St. Leger and Cochrane in 1979 was the first to evaluate the relationship between saturated fat intake and incidence of mortality due to coronary heart disease. They examined multiple factors among residents across eighteen developed countries and their epidemiological findings demonstrated that wine consumption somehow offered protective benefits against heart disease related deaths (St. Leger and Cochrane, 1979). This phenomenon was later termed the French Paradox by Renaud as France showed low mortality incidences of cardiovascular diseases despite their high-fat diets and plentiful consumption of wine during meals (Vidavalur et al., 2006).

Additionally, the Copenhagen Heart Study of 2001 showed similar conclusions where there was a decrease in morbidity and mortality of coronary heart disease in wine drinkers, but not in consumers of beer or spirits (Gronbaek et al., 1995). Since these studies were published, many in the general public are convinced that wine is a preventative measure and possible cure for CHD.

Coronary heart disease is a class of cardiovascular disease in which 40% of Canadian adults ages 20-79 are at high risk for mortality (Statistics Canada, 2016). The disease is developed due to an increased accumulation of low-density lipoprotein (LDL), which is responsible for

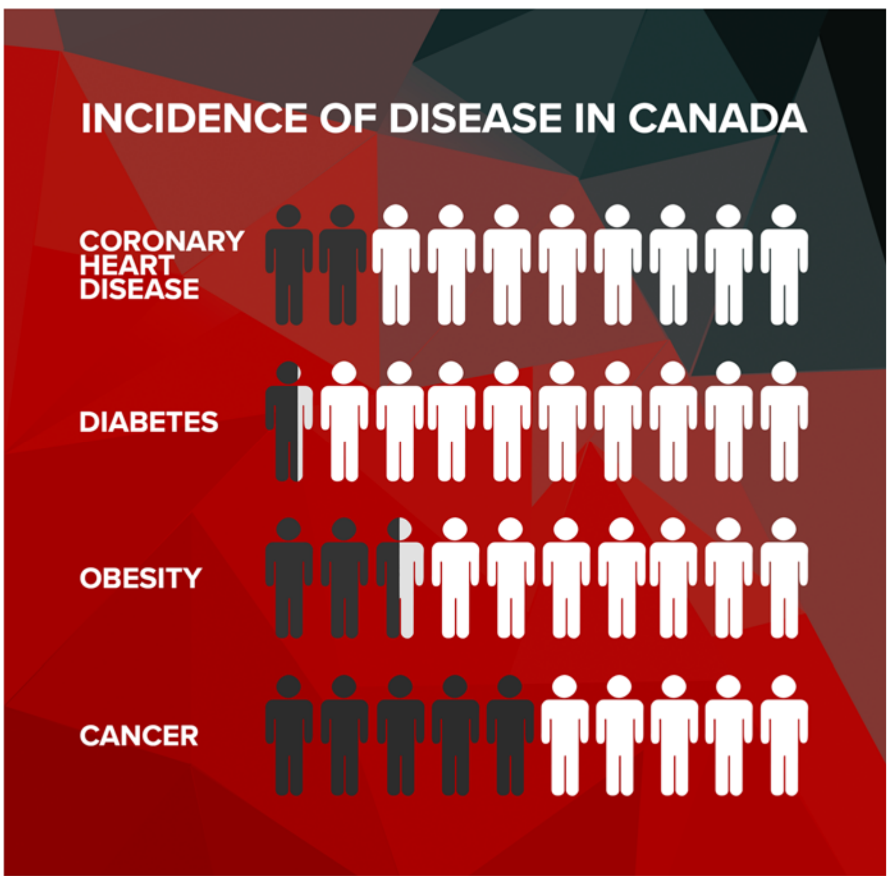

FIGURE 10: INCIDENCE OF DISEASE IN CANADA. Incidence of four prevalent diseases in Canada. Shaded individuals represent those affected by the disease. (Statistics Canada, 2016; Government of Canada, 2011; Navaneelan and Janz, 2014; Canadian Cancer Statistics Advisory Committee, 2017)

gathering cholesterol and lipids (Vidavalur et al., 2006). This buildup results in the hardening and narrowing of arteries which lead to the development of plaques in the arteries (Zordoky et al., 2015. This condition ultimately restricts blood flow to the heart which may result in heart attack and stroke (Zordoky et al., 2015).

Resveratrol plays a role in minimizing the amount of LDL accumulating in the body while promoting the amount of high-density lipoprotein (HDL) (Pace-Asciak et al., 1995). Wine drinkers have been shown to have higher levels of HDL which serve as a protective agent against CHD (Pace-Asciak et al,, 1995). It is proposed that moderate alcohol consumption decreases the degradation of HDL while upregulating the metabolism of LDL to be excreted by the kidneys (Vidavalur et al., 2006). Excretion of LDL is effective in preventing the collection of lipids and cholesterol and thereby inhibiting plaque buildup, known as atherosclerosis (Pace-Asciak et al., 1995).

Furthermore, platelet aggregation is another contributor to the development of CHD. The aggregation of platelets form blood clots which blocks blood vessels (Mukherjee et al., 2010). Resveratrol acts to inhibit platelet activation from aggregating and reducing the formation of occlusions in blood vessels that will restrict blood flow. Furthermore, resveratrol exhibits antioxidant and anti-inflammatory properties which impede the progression of atherosclerosis (Zordoky et al., 2015). These properties play a role in stopping the oxidation of LDL and permit blood vessels to perform their regular functions (Zordoky et al., 2015).

A 2005 study conducted by Das et al. examined the dosage of resveratrol in rats to determine the ideal administered dose of resveratrol to alleviate the symptoms of CHD. They concluded that the ideal daily dose is approximately 2.5 mg/kg body weight (Mukherjee et al., 2010). Altogether, resveratrol appears to offer benefits in mitigating the effects and development of CHD; however, further research regarding the effects of resveratrol on human systems must be investigated before any solid conclusions can be drawn.

DIABETES

Diabetes is a metabolic disorder causing high blood sugar levels over prolonged periods, and affecting more than 2.4 million Canadians (Government of Canada, 2011). Diabetes can cause severe long-term complications including damage to the vascular system, kidneys, peripheral nerves, and skin (Maritim, Sanders and Watkins, 2003). Specifically, type 2 diabetes, which is characterized by defects in insulin secretion and action, represents 90% of all diabetes cases (Wright, Scism-Bacon, and Glass, 2006). The management of balanced glucose levels is crucial in diabetic patients to prevent these long-term complications, although the prolonged administration of some treatments may induce unfavourable side-effects. Recent research on resveratrol has found that the compound improves insulin sensitivity and reduces oxidative stress in type 2 diabetic patients (Szkudelski and Szkudelska, 2011).

There are numerous mechanisms through which scientists believe resveratrol exerts its beneficial effects. One of the predominant mechanisms is believed to be resveratrol's antioxidant abilities (Szkudelski and Szkudelska, 2011). Beta cells, cells used to store and release insulin in the pancreas, are highly susceptible to free radical damage due to their weak antioxidant defence, which is further compromised in type 2 diabetic patients. Resveratrol has the potential to scavenge oxygen free radicals and increase the activity of enzymes participating in antioxidant defense (Szkudelski and Szkudelska, 2011). Resveratrol is also believed to improve the activities of two intracellular regulators, which have weakened expression in type 2 diabetic patients, SIRT1 and AMPK (Szkudelski and Szkudelska, 2015). SIRT1 is an important regulator for inflammation, apoptosis (cell death), and stress resistance processes, which resveratrol activates through the increase of the NAD+/NADH ratio. NAD+ and NADH are important cofactors for biological oxidation-reduction enzymatic reactions. AMPK regulates fuel metabolism and insulin secretion, which is activated by resveratrol through the phosphorylation of the protein AMPKα (Szkudelski and Szkudelska, 2015).

Numerous animal studies produced results that were consistent with the mechanisms of resveratrol determined *in-vitro*. In one study, rats that were fed high cholesterol-fructose diets and experimentally induced with insulin resistance were shown to have improved insulin action with resveratrol consumption (Szkudelski and Szkudelska, 2011). Long-term resveratrol consumption was also shown to improve insulin sensitivity, through a study conducted on obese rhesus monkeys who were fed 80 mg/day of resveratrol the first year and 480 mg/day of resveratrol the second year (Szkudelski and Szkudelska, 2011).

The promising results of resveratrol treatments has prompted researchers to conduct studies on human patients. One study determined that a dose of 1g a day of resveratrol in type 2 diabetic patients saw a marked drop in glucose levels and a reduction in blood pressure due to improvements in insulin resistance and glucose homeostasis (Movahed et al., 2013). Doses at 1 g a day did not cause any toxic effects; however, doses at 2.5 g and higher caused gastrointestinal symptoms. Further research is required, but it appears resveratrol may be taken as a supplement in combination with diabetic medications to control glucose levels (Movahed et al., 2013).

OBESITY

Obesity is a growing problem with approximately 1 in 4 adults being classified as overweight in Canada (Navaneelan and Janz, 2014). This condition is defined as the excessive accumulation of body fat tissue that results in detrimental health effects, including an increased risk for type 2 diabetes and coronary heart disease (Navaneelan and Janz, 2014). It has been proposed that ingestion of resveratrol may provide anti-obesity effects, as these effects have been found in animal models (Timmers, Auwerx, and Schrauwen, 2012). Additionally, epidemiological evidence from France shows that in spite of their high saturated-fat diet, they have an extremely low obese population in comparison to other countries (World Health Organization, 2017). As mentioned previously, the French drink large quantities of red wine which suggests that resveratrol may be an effective anti-obesity compound.

The exact mechanism of *how* resveratrol reduces obesity in humans is not entirely understood. On a cellular level, resveratrol binds to several receptors and signaling molecules that affect a multitude of metabolic pathways (Scapagnini et al., 2014). The key to resveratrol's anti-obesity effects is therefore not a singular mode of action but the union of many mechanisms. For one, resveratrol stops the process of adipogenesis, the formation of adipocytes (fat tissue cells), through the inhibition of early regulatory factor C/EBPβ (Aguirre et al., 2014). This regulatory factor activates the C/EBPα pathway which leads to the eventual differentiation of adipocytes from other cells. Reducing the expression of this pathway also prevents the preadipocytes' ability to change into the characteristic spherical shape of adipocytes (Aguirre et al., 2014). Moreover, resveratrol inhibits lipogenesis, the synthesis of fatty acids from acetyl-CoA, through the reduction of enzymatic activity (Aguirre et al., 2014; Scapagnini et al., 2014). Lipolysis, the breakdown of lipids, is also increased by resveratrol (Aguirre et al., 2014). Finally, fatty acid oxidation is increased, which means that fatty acids are broken down to be used in the Krebs Cycle, an important part of cellular respiration (Scapagnini et al., 2014).

Mice trials have been conducted to observe resveratrol's effects *in vivo*. They have shown that upon ingestion of resveratrol, anti-obesity effects and increased survival are observed in obese mice with high-calorie diets (Baur et al., 2006). This anti-obesity effect appears to be biphasic in terms of doses though; high doses reducing body weight while lower doses increasing body weight (Timmers, Auwerx, and Schrauwen, 2012). However, the decreased body weight observed may be due to an increase in energy expenditure leading to indirect weight loss (Timmers, Auwerx, and Schrauwen, 2012). Additionally, the decreased body weight is oftentimes non-significant (Baur et al., 2006). Therefore, it is questionable if resveratrol is truly an effective and long-term anti-obesity compound *in vivo*.

In humans, these results are not as easily replicable. Variations in humans have shown that a daily dose of resveratrol between 150 and 500 g for four weeks produces no significant changes in adipose tissue or lipid content (Poulsen et al., 2013; Timmers et al., 2011). One study did find that the longevity gene activated by resveratrol, SIRT1, is responsible for upregulating glucose metabolism in the mitochondria, insinuating that resveratrol should have an anti-obesity effect in humans (Timmers et al., 2011). Unfortunately, resveratrol has little to no effect on reducing obesity, implying that resveratrol may only be useful under metabolic-stress conditions or on a longer time scale.

The ideal dosage for resveratrol to have potential anti-obesity properties would be a 2 g daily dose, extrapolated from a mice study by Macarulla et al (2009). However, further research is required to assess the effectiveness of resveratrol in humans.

CANCER

In Canada, 1 in 2 individuals will develop cancer in their lifetime (Figure 1), with 1 in 4 of them dying from the disease (Canadian Cancer Statistics, 2017). There is an increasing demand for innovative treatment methods as cancers are becoming resistant to common therapeutic techniques. Popular therapeutic techniques often revolve around chemotherapy, surgery, and radiotherapy, but in the realm of novel treatment exists resveratrol. Although several studies have explored and seen the anticancer effects of resveratrol, the methods and mechanisms by which it works are not well understood (Gescher and Steward, 2003). Due to the lack of understanding behind the mode of action, resveratrol has yet to be manipulated in a manner such that it may serve as a widespread and effective cancer treatment. Human clinical trials have been conducted to determine optimal dosages and efficacy; however, each study is specific to a certain cancer, and small sample sizes are often used (Brown et al., 2010). Thus, there is still a lack of understanding of the effectiveness of treating unique cases of cancer with resveratrol.

Several mechanisms induced by resveratrol are thought to play a role in preventing the proliferation of cancer cells. Interestingly, while resveratrol is understood to maintain health and longevity in normal cells, at varying concentrations in cancerous cells resveratrol actually induces apoptotic activity (Gescher and Steward, 2003; Wang et al., 2012). In prostate cancer cells, for example, resveratrol plays a role in upregulating the sensitivity to apoptotic mechanisms and proteins, and downregulates the activity of proteins such as Bcl-2 which are anti-apoptotic (Varoni et al., 2016). Resveratrol also decreases cancer proliferation by reducing inflammation through suppression of cyclooxygenase-2, an enzyme that dictates prostaglandins to promote angiogenesis and cell survival in tumor cells (Zha et al., 2004).

The effective dose for resveratrol as a cancer suppressor is incredibly variable given the plethora of models and studies reporting daily dosages from as low as 200 μg/kg body weight to 2 mg/kg and higher exhibiting chemo-preventative effects among *in vivo* rat models (Gescher and Steward, 2003). When scaling studies up to human clinical trials, it becomes a challenge to find nontoxic doses which show similar efficacy (Gescher and Steward, 2003). In terms of cancer chemoprevention, healthy individuals may be able to modulate levels of IGF-1, a growth hormone whose overexpression is linked to causing malignancies with daily dosages of resveratrol (Brown et al., 2010). While this seems exciting, those who saw the largest decrease in IGF-1 at 2.5 g resveratrol/day also saw the most adverse side-effects of the drug, suggesting that higher dosages of resveratrol may be difficult for healthy individuals to tolerate and more beneficial for those with more serious health concerns (Brown et al., 2010).

Interestingly, in order to achieve anticancer results, concentrations of resveratrol accomplished *in vivo* are far lower in contrast to the concentrations used *in vitro* for inhibition of cancer cell growth (Gescher and Steward, 2003; Nguyen et al., 2009). This suggests that other bioactive components found *in vivo* play roles that do not exist *in vitro* which contribute to enhancing the anticancer effects. This is also why understanding resveratrol and its efficacy as a cancer treatment becomes difficult when extrapolating results in studies from cells to animals. Resveratrol remains attractive as an anticancer compound due to its ability to reduce risks of multidrug resistance and its relative safety but it requires further research and development through human clinical trial studies before a recommended dose can be made (Varoni et al., 2016).

DOSAGES

While resveratrol provides many health benefits to people, the question still stands whether these health benefits are obtainable through the consumption of red wine. Many magazines and the popular press claim that drinking red wine daily can provide the therapeutic benefits outlined in Resveratrol and Disease. A litre of red wine contains on average 1.9 mg of resveratrol (this amount varies between types of red wines) (Weiskirchen and Weiskirchen, 2016). The amount of resveratrol that some of these studies focused on were anywhere from 150 mg to 5 g being administered to animals and humans. We can extrapolate animal data to apply it to humans for clinical trial testing. However, this is not a simple process as resveratrol has a very low bioavailability (Zordoky et al., 2015). This means that the amount of resveratrol consumed is not the same as the amount of resveratrol absorbed by tissues and organs as it is metabolized quickly in the body. Therefore, the bioavailability of resveratrol complicates matters for scientists trying to determine an ideal administered dosage. Assuming we can scale the doses administered to animals up to a 63.5 kg (140 lbs) human and ignoring bioavailability changes in humans, we can accurately estimate how much wine is needed to be "healthy". Figure 2 visually depicts the amount of red wine necessary to consume the levels of resveratrol that induced positive health benefits in clinical trials. The amount of red wine required to

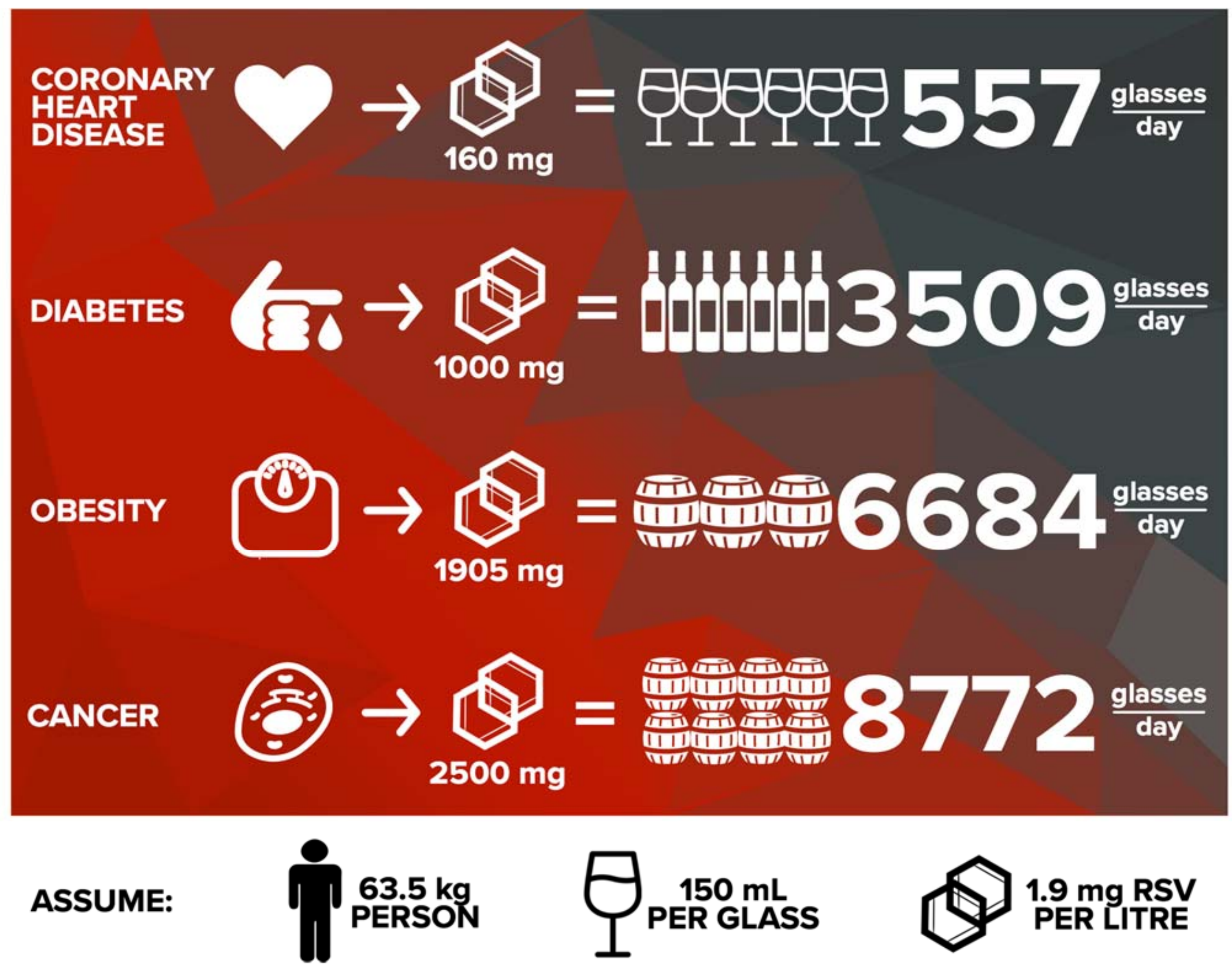

FIGURE 2: Ideal dosages and red wine intake for health benefits from resveratrol.

reduce the impacts of coronary heart disease is 557 glasses of wine per day, which is approximately one third of a barrel of wine. In order to produce anti-obesity effects, one would need to consume over 6600 glasses of red wine each day, which is slightly more than the required amount for diabetes prevention at 3500 glasses per day. With each "glass" representing a standard drink of red wine at 150 mL and 12% alcohol content (13.5 g of alcohol), anyone attempting to receive health benefits of resveratrol would quickly receive alcohol poisoning instead (MADD, 2014).

MISCONCEPTIONS

Resveratrol may indeed have therapeutic potential but it is evident that one cannot reap these benefits solely through drinking red wine. It is true that long-term consumption of red wine has been correlated with lower incidence of metabolic and cardiovascular diseases, but correlation is not the same as causation. Although the French are among the highest global consumers of red wine, it would be menacingly impossible to consume the amount of resveratrol necessary to have any substantial effect on reducing CHD (Figure 2). While the French Paradox study shows compelling epidemiological data, there are some factors that were not taken into consideration that further compromises the study's validity. The study failed to account for the pattern of drinking by the population, nor did they examine the age or health status of their participants (Vidavalur et al., 2006). Due to this, some argue that the French Paradox does not demonstrate a well-rounded representation of the general population, and therefore assumptions cannot be made about the role of wine in treatment of diseases. Thus, justifying the health of the French population through wine consumption is insufficient and research should be done to explore alternate explanations such as drinking patterns, portion sizes, or other aspects of the French diet and lifestyle (Vidavalur et al., 2006).

Moreover, the antioxidant potential of resveratrol has been under constant scrutiny. An editorial by Goldberg in 1995 sparked interest in investigating resveratrol's antioxidant properties. Since then, other scientists and the media have exaggerated resveratrol's antioxidant potential to the public, which is extremely harmful for individuals making decisions about their health (Goldberg, 1996). Today, these same media outlets exaggerate the benefits of consuming antioxidants, with claims of prolonged youth and wrinkle-free skin (Spencer, 2014). The original author of the 1995 editorial even wrote a response renouncing resveratrol as an excellent antioxidant source, however, the damage had already been done (Goldberg, 1996). Though there are many other polyphenols present in wine that may account for some of wine's health benefits, they are often overlooked and under-researched due to the media's glorification of resveratrol (Goldberg, 1996).

Regardless of the uncertainty surrounding resveratrol's therapeutic potential, magazines like Cosmopolitan and Glamour still publish headlines pronouncing "Wine is basically as good as going to the gym" and "Great news for red wine fans - it keeps us looking young" (Harvey-Jenner, 2015; Spencer, 2014). These articles tend to take the results of singular studies, often done in mice or even *in-vitro*, and use these results as evidence for their outlandish claims. The target audience for these articles are most likely the "wine mom" demographic, a culture of women whose aim is to normalize their drinking habits as a healthy indulgence (Stampler, 2011). It is important to identify these harmful misconceptions and educate the vulnerable demographics involved, in order to promote more meaningful wine science research.

SUMMARY

In this article, the various roles that resveratrol play as a therapeutic agent have been outlined, with focus on coronary heart disease, diabetes, obesity, and cancer. The recommended daily doses of resveratrol through the consumption of red wine are also calculated and shown to illustrate the impossibility of obtaining appreciable amounts of resveratrol through red wine. The main take-away from this article is that while resveratrol may be good for you in specific dosages and for specific conditions, as determined from scientific studies, beneficial amounts cannot be consumed through red wine. The amount of red wine one must drink to achieve some of the benefits would result in death before one even comes close to their "ideal" dose. Additionally, more research is required to determine whether resveratrol delivers the same benefits to humans as it does to animal models. As it stands, individuals should not drink red wine for the sole purpose to be healthier. While there may be few measurable health benefits, red wine should be consumed in moderation. And for all you wine moms out there, keep drinking wine but be wary the next time you read some fantastical "science-based" article in *Cosmopolitan*.

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The Future of Viticulture in the Niagara Appellations

Amory Conant, Leeor Greenblat, Cory Kawamoto, Jacob Saunders, and Adam Tweedle

Ontario's southeasternmost quadrant is studded with spectacular sights: the rugged Niagara Falls, the impressive industrial skyline of Hamilton, and the pristine and ordered rows of Niagara's world-renowned vineyards. The latter of these gems, as with many other agricultural operations, is presently at risk due to the impending changes climate change will pose. In anticipation of these changes, we have gathered various greenhouse gas forecasts, climate models, and other computational methods to assess how, and by how much, viticulturally important variables will change over the next 80 years. The news is bittersweet: frost levels and precipitation will remain relatively constant, while the frequency of days with temperatures surpassing 35 ℃ will increase quite substantially. In response to these findings, we suggested what techniques, if any, should be adopted by Niagara viticulturists.

Introduction

The wine industry of Ontario, as of 2014, is a $395 million industry, with the Niagara region alone providing 55% of Ontario VQA (Vintners Quality Alliance) wineries (Vintners Quality Alliance Ontario, 2016). In Niagara, 13,600 acres of land are dedicated to grape production, producing approximately 11.4 million litres of wine annually (Vintners Quality Alliance Ontario, 2016).

One of the reasons that the Niagara region is able to support a large wine industry is due to its milder temperatures in comparison to the surrounding regions. This atypically mild pocket of temperature is known as the Niagara microclimate. The microclimate is created by the northerly winds that bring warm winters and cool summers as they travel over Lake Ontario. Due to Lake Ontario's great depth, it has a high heat capacity, and can therefore retain thermal energy for long periods of time (Shaw, 2011). This helps to moderate the climate of the region, resulting in mild temperatures year-round, and extending the grape growing season for the region (Shaw, 2011). The presence of the lake also helps to create a cyclic air current by perpetually cooling air that has been heated when it was over land (Shaw, 2011). This circulation slows the ripening of the grapes via decreased temperatures and lowers the humidity of the vineyard, helping to prevent disease and fungal growth occurring in grape bunches (Shaw, 2011). This microclimate combined with the sandy soils of the former Lake Iroquois helps to create ideal conditions for grape production.

With the industry playing a large role in the economic stability of the Niagara region, one major factor to be considered for the longevity of the industry is climate change.

Climate change is primarily caused by the accumulation of greenhouse gases within the atmosphere, altering the composition of the atmosphere (Karl, 2003). These alterations can cause variations in temperature, which affect the growing degree-days (GDD), precipitation, or the number of days with extreme weather (Shaw, 2011).

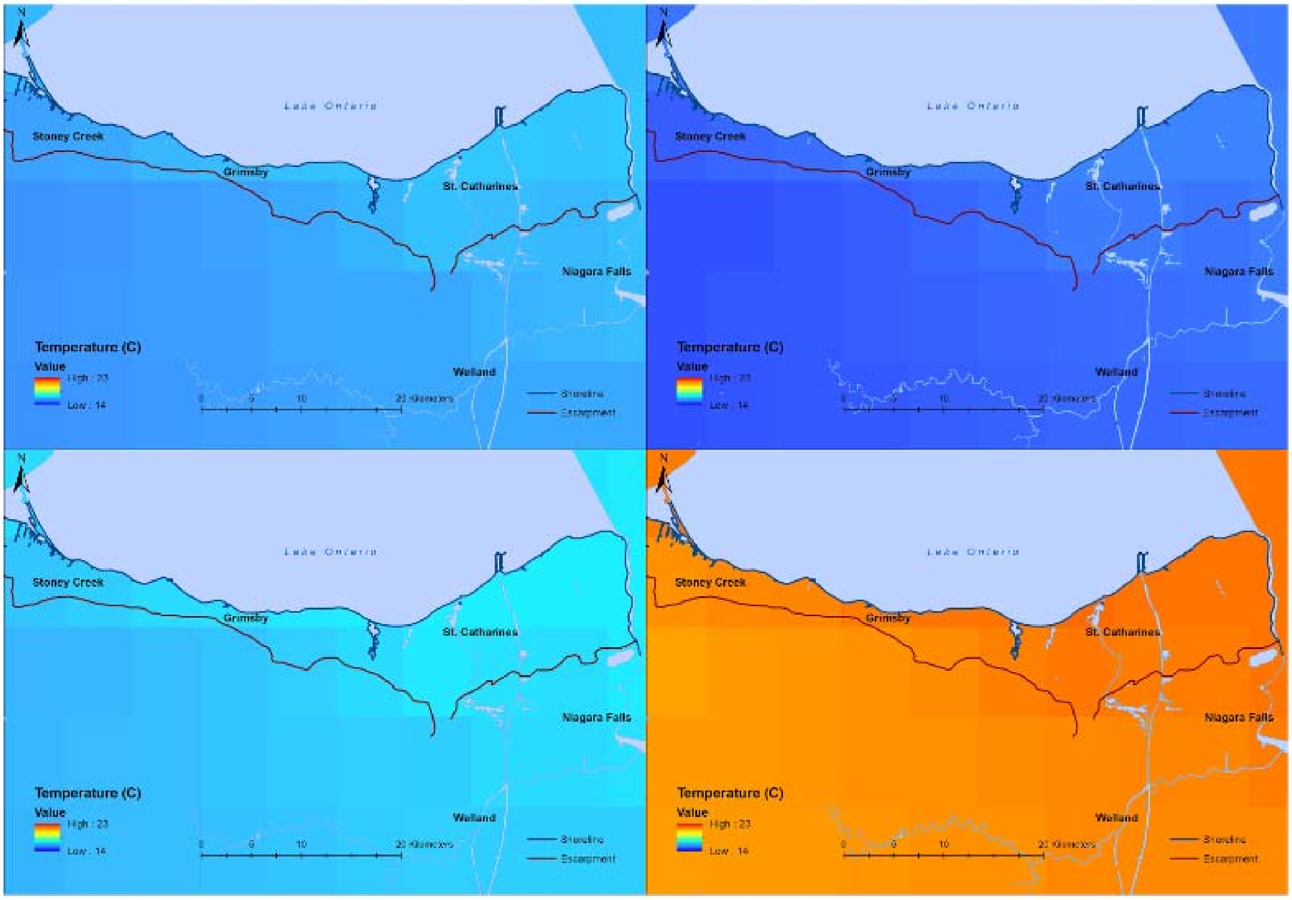
Another key topographical feature of the Niagara region is the Niagara Escarpment. This landform acts as a wind barrier for southerly winds, creating a protected region close to the base of the Escarpment with lower wind speeds and moderate temperatures (Shaw, 2011).

These factors have serious implications for viticulture in the Niagara region, and this article will explore and discuss these factors in further detail.

Climate Change Models

The science of climate change modeling is a complicated and broad discipline, with thousands of publications on the subject. Each publication incorporates a different combination of background data, variables, future greenhouse gas concentrations, and computations. In order to create a simple and representative study, the objective of this paper in regard to the forecast of the Niagara microclimate is threefold:

1. To identify climatic variables relevant to the wine industry.



2. To identify and utilize a singular climate change model relevant to the Niagara Region.
3. To identify what actions should be performed by viticulturists in response to the predictions of this model.

Two principal climatic variables are investigated; temperature and precipitation. Both variables are nearly universally forecasted in climate change models, and thus the variable data are easy to obtain. Secondly, both variables are critical to the concept of soil terroir, as extreme values for either variable can have a significant effect on grape viability and quality.

A critical component of climate change analysis is predictive analysis of climate forcings, the factors affecting the Earth's climate. For this study, two Representative Concentration Pathways (RCPs) were selected to determine forcing boundaries. The RCPs were commissioned by the International Panel on Climate Change (IPCC) (Moss, et al., 2008), and were subsequently adopted by the IPCC for its fifth assessment report (AR5) in 2014. Each RCP was developed by a separate team that created their own predictions of greenhouse gas emissions and concentrations, and land-use trajectories for the next century (van Vuuren et al., 2011). Each RCP is

FIGURE 1: Using the described model, the average temperature of the growing season for the Niagara Region was determined for the following scenarios, clockwise from top left: 2050 for RCP 2.6, 2100 for RCP 2.6, 2100 for RCP 8.5, 2050 for RCP 8.5.

"pathway" in that it is not a fully realized scenario, but instead an internally consistent projection of climate forcings (van Vuuren et al., 2011).

The two RCPs selected were RCP 2.6 and RCP 8.5. The number indicates the target radiative forcing (RF) level in 2100, which is the difference in energy absorbed by the Earth and the energy radiated outwards by the atmosphere, measured in watts per square meter (van Vuuren, et al., 2011). RCP 2.6 is a best-case scenario which assumes the rapid investment in mitigation technologies and the development and deployment of negative emissions technologies later in this century, which results in a decreasing RF value by 2100 (Moss, et al., 2008). In contrast, RCP 8.5 projects a steady rise in RF throughout the 21st century (van Vuuren, et al., 2011).

The model chosen to create predictions from these data was the Canadian Earth System Model (CanESM2). An accepted model by the IPCC, CanESM2 was chosen as it uses Canadian climate data to accurately explain the changes in Arctic temperature over the last century, which helps support the probability of accurate forecasts (Chylek, et al., 2011). As with most models, CanESM2 initially predicts climate change at a resolution too coarse to allow for detailed analysis at the scale of the Niagara Peninsula. In order to obtain a better resolution, the output was downscaled to a resolution of approximately 10 km, based on Global Climate Model (GCM) predictions and historical gridded data of the region. This was done with the use of the Pacific Climate Impacts Consortium downscaling engine, which downscaled the CanESM2 model, while accounting for biases, to obtain temperature and precipitation data based on RCP 2.6 and 8.5 forcings (Pacific Climate Impacts Consortium, 2014).

Figure 1 displays some of the potential analyses that can be conducted with these models, showing average temperature for 2050 and 2100 based on RCP 2.6 and 8.5 forcings.

Growing Degree Days (GDD)

While average temperature values are important in many situations, they do not tell us enough about crop viability. Combining crop viability with a temporal factor, however, allows a much more appropriate comparison. This concept of thermal time is embodied in several metrics, with an incredibly simple and effective metric being growing degree-days (GDD). GDD units are a synthesis of temperature values above a particular threshold and the amount of time spent there. There are several ways to calculate GDD, resulting in different values and interpretations (McMaster and Wilhelm, 1997). GDD is typically calculated by finding the difference between the average daily temperature and some temperature threshold referred to as the base temperature. In this case the base temperature describes the temperature below which the plant exhibits no growth or development. GDD is described using the equation (Nielsen and Hinkle, 1996):

$$GDD = \frac{T_{max} - T_{min}}{2} - T_{base}$$

Usually it is the cumulative GDD that is discussed, which is simply the sum of the GDD values over a given number of days. When performing the calculation, it must be decided whether to set the value to zero when the average daily temperature is less than the base temperature or when the minimum daily temperature is less than the base temperature. These two methods give different results and it is important to indicate which was used in the methodology (McMaster and Wilhelm, 1997). With respect to *Vitis vinifera*, the base temperature is typically taken as 10°C, although it is more accurate for it to change according to the phenological stage (Oliveira, 1998; Winkler, et al., 1974; Yang, Logan and Coffey, 1995). Furthermore, while higher temperatures are desired, prolonged exposure

predict the phenological timing of crops to assess viability and agricultural decisions (Miller, et al., 2001). Winkler regions are an application of GDD calculations that assign grape varietal viability to regions with a particular cumulative GDD (Amerine and Winkler, 1944). There are five climatic regions that range from 950 to 2900 GDD and it is thought that the best quality wine is produced from regions with 1400 to 2000 GDD (Jones 2003; Winkler, et al., 1974). Niagara, with its approximately 1600 GDD, is considered to be between Region Ib and Region II and produces varieties such as chardonnay, pinot

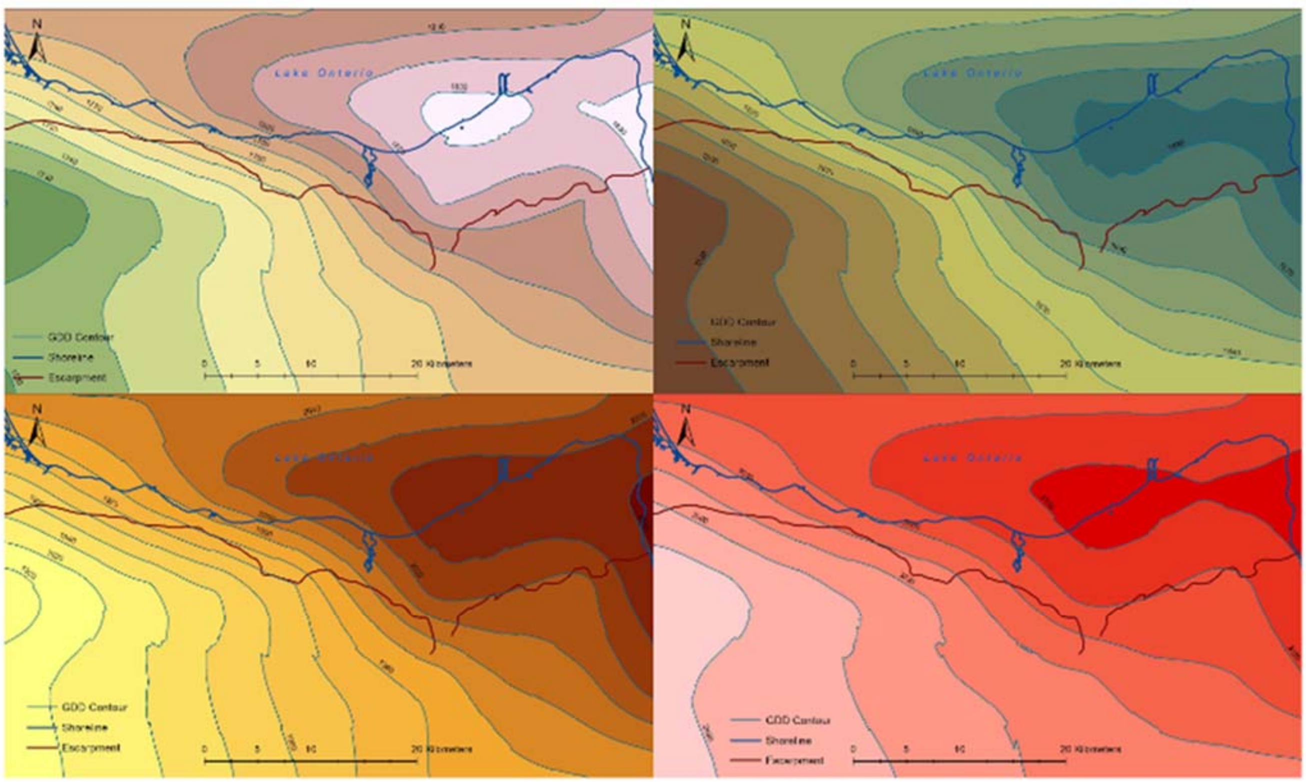


FIGURE 2: Clockwise from top left; GDD values will increase but remain in the ideal range in 2050 under RCP 2.6. Continuing to 2100, RCP 2.6 projects a decrease in GDD from 2050, but still greater than present values. 2100 under RCP 8.5 projects GDD at the limit of grape growth viability. This limit is nearly approached by 2050.

to extreme temperatures can damage ripening grapes (Mullins, Bouquet and Williams, 1992). Grape quality is considered at risk if temperature surpasses 35°C (Keller, 2010).

The GDD unit has a lengthy historical background and has primarily been used to

noir, cabernet sauvignon, and merlot (Jones, 2003; Vintners Quality Alliance Ontario, 2016).

Since growing degree-days are dependent on temperature, climate change will greatly impact them. As the climate warms, it follows that GDD values will also increase accordingly, pushing the region into higher Winkler ranges with different varietals.

Having constructed a map of the Niagara regions and having obtained the projected temperature data, the GDD formula was applied to assess how viticultural viability might change for the predictions proposed by RCP 2.6 and RCP 8.5 at 2050 and 2100 (Figure 2). All of our GDD calculations are done according to the equation above, using degrees centigrade and a base temperature of 10C, setting the value to zero when the average daily temperature is below the base temperature, and without a heat stress factor (an avenue for further investigation). With respect to RCP 2.6, the 2050 GDD projection indicates values above 1700. This is about 200 greater than those values found by the Vintners Quality Alliance in 2017, likely improving the viticultural viability of cold-sensitive varieties such as grenache, though their methods for calculating GDD may be different (Vintners Quality Alliance Ontario, 2017). The subsequent snapshot at 2100 shows that the GDD values then decrease in accordance with the temperature which is caused by a reduction in the atmospheric carbon concentration. Under this projection, viticulture in Niagara seems largely unaffected. RCP 8.5 shows a more concerning upward trend in temperatures where the regions reach the upper range for the production of quality wine by 2050. The GDD values continue to soar through the defined Winkler regions towards the limit of wine viability between 2800 and 2900 GDD in Region V by 2100. This range is only viable for early season table wines such as Primitivo, Muscat, and Thompson Seedless (Winkler, et al., 1974). Niagara's globally renowned ice wines, which required prolonged periods of temperatures below -8 ℃, would become increasingly more difficult to produce and by the end of the century, impossible in the Niagara region (Vintners Quality Alliance Ontario, 2017). As regions further north warm up, we expect the wine industry to expand into these areas. However, if the climate warms at such a high rate, wine makers will be forced to change their varietals relatively frequently, ultimately being forced to move north or leave the business altogether.

Extremes of Temperature

Climate change brings about not only increases in the average temperature, but also increases in the frequency with which extreme weather events occur. One might therefore ask how vineyards might suffer as a result of these extremes. Before addressing this question, we shall define extreme to be any temperature less than 2 ℃ or greater than 35℃. Naturally, temperatures at either end of this spectrum pose different challenges to viticulturists. At the lower end, frost can render entire crops worthless via several mechanisms. Frost threatens to solidify ground water, thereby removing the solvent that dissolves nutrients essential to plant metabolism. Frost also exerts its effects on vines by killing plant tissues, specifically those responsible for reproduction (Keller, 2010). At the other end of the continuum, another suite of challenges plagues viticulturists. In the soil, accelerated rates of evaporation threaten to increase salt levels in soil, and by extension, within the plant. As a result, osmotic pressures are altered to levels unfavourable to vine productivity. Furthermore, increases above 35℃ depress mitotic activity, decreasing the fruit set at the season's end (Keller, 2010). Extreme temperatures threaten not only the quantity of fruit, but their quality as well. Given that the anthocyanin profile influences the final character of wine, and that anthocyanin production slows at temperatures greater than 35 ℃, extreme heat may interfere with these important oenological compounds (Keller, 2010).

Due to the anticipated increases in weather extremes, climate predictions for the Niagara peninsula have been generated by the IPCC.

According to RCP 8.5 data, climate change will bring with it increases in the frequency with which excessively hot days occur (Figure 3).

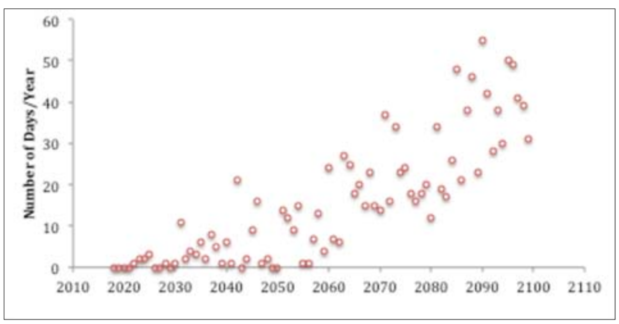


FIGURE 3: NUMBER OF DAYS PER YEAR 35 CENTIGRADE IN THE NIAGARA REGION. The expected number of days above 35 ℃ over the next 90 years in the Niagara growing region. These data were derived from RCP 8.5. Produced using excel version 14.4.3.

As Figure 3 above indicates, the frequency with which excessively hot days occur as a result of climate change poses a serious threat to viticulturists in southern Ontario. By the end of the century average daily maximum temperatures in the summer could approach the extreme threshold.

The other major threat associated with extreme temperature is frost. However, according to RCP 8.5 data, frost occurrences throughout the growing season are expected to remain relatively stable over the next 80 years (Figure 4).

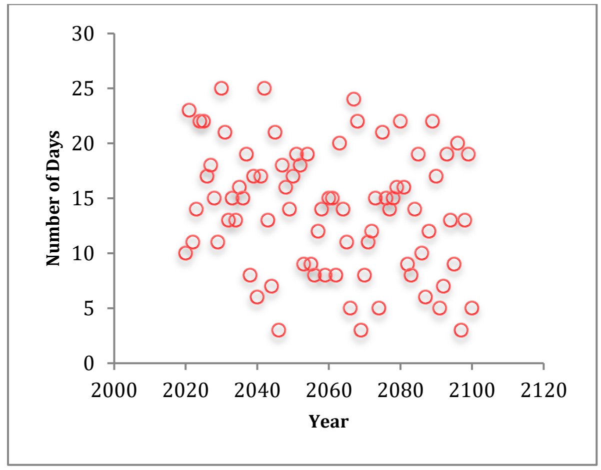


FIGURE 4: NUMBER OF DAYS (BETWEEN MARCH AND OCTOBER) WITH TEMPERATURE BELOW -2 CENTIGRADE Graph indicating the number of days with temperatures below -2 in the growing season expected over the next 80 years. No upward trend is present. Therefore, Niagara viticulturists need not worry about increases in frost levels as a result of climate change. Data derived from PCIC, 2017. Produced using excel version 14.4.3.

Because frost levels will not increase considerably within the near future, current methods will likely prove sufficient in maintaining the yield of vineyards. However, the pronounced increase in the occurrence of extreme high temperatures will necessitate the adoption of new growing techniques to manage elevated heat.

Although several solutions are available to viticulturists, not all will be discussed in this text. Two strategies at their disposal, however, involve increasing canopy cover and switching to varietals with greater heat tolerance.

The first of these solutions allows for increased shading of berries, preventing grapes from assuming temperatures that are unfavourable to protein synthesis and anthocyanin production. This solution is not without its disadvantages. One issue with increasing canopy cover is that it entices increases in insect populations.

Another solution to increased temperatures is to grow varietals more tolerant of warm climates. At present, the predominant crops of the Niagara region include Riesling, Cabernet Franc, Chardonnay, Merlot, and Cabernet Sauvignon (VQA Ontario, 2017). The projected temperature increase, however, may necessitate the adoption of varietals that are currently found at lower latitudes. Such varietals include Zinfandel, Dobrièiæ, and Plavac mali (Maletiæ, et al., 2004).

Precipitation

Viticulture in the Niagara region has been successful over the past decade, with the region producing consistent yields of high quality grapes. The Niagara region received 546 mm of precipitation during the 2016 growing season (VQA Ontario, 2017). Present precipitation values support the local viticulture, and looking forward, winemakers need not worry about drastic changes in precipitation levels.

According to our model predictions, it appears that monthly precipitation levels are most variable during the spring and summer. This could mean variability in the frequency of vineyard irrigation scheduling, the timing of grape phenological events, and the spread of disease within the vineyard (Jones and Davis, 2000). Figures 5 and 6 display the predicted changes in precipitation, based on the best and worst case RCP forcings.

Excessive levels of precipitation may cause soil erosion, which disperses essential plant nutrients away from the roots (Cook and Wolkovich, 2016). Additionally, rainstorms could have a warming effect on the air if the rain is caused by a warm front. This will cause the air to become humid and decrease the amount of evaporation, which promotes the invasion and spread of pathogens within the vineyard (Cook and Wolkovich, 2016).

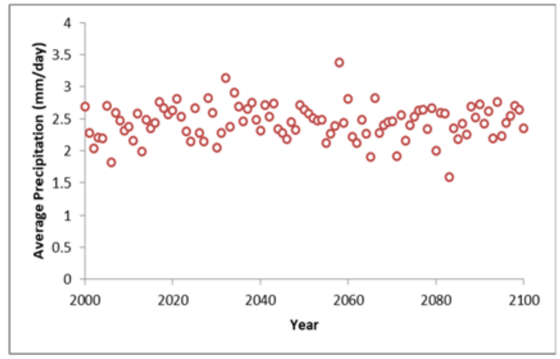


FIGURE 5: PREDICTED PRECIPITATION (RCP 2.6) With RCP 2.6 forcings applied, the average daily precipitation will vary over time, but is generally centered around a value of 2.5 mm/day, similar to current values. Data derived from PCIC, 2017.

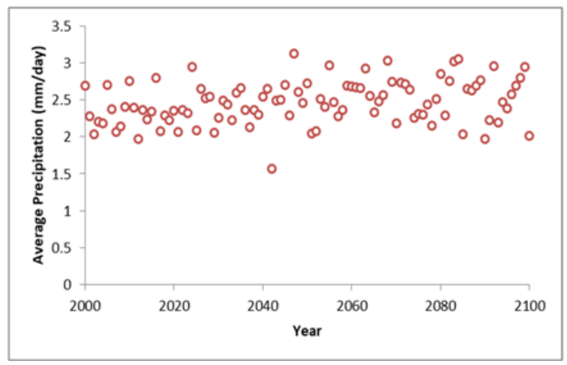


FIGURE 6: PREDICTED PRECIPITATION (RCP 8.5). Projections incorporating RCP 8.5 forcings are very similar to those incorporating RCP 2.6 forcings, with average daily precipitation for each year usually falling between 2 and 3 mm/day. Data derived from PCIC, 2017.

Conversely rainstorms could have a cooling effect if the rain is caused by a cool front. Heavy rainstorms can inflict water damage on root systems, resulting in the vines becoming stressed (Bramley, et al., 2011). If the months of April to May receive more precipitation, the grape vines transition from producing flowers to producing fruit will be negatively affected as too much water during this transition stage can result in poor fruit set and aborted fruit, which can lead to yield reductions (Jones et. al., 2011). On the other hand, intermittent drought conditions will force the vines to face temporary water deficit, thus affecting the yield (Bramley, et. al., 2011). Vines are highly sensitive to water quantities during particular stages of development (Jones, 2011). Water deficit during these critical stages adversely affects a bud's ability to produce fruit, which in turn may impact yields in the following season. It can also reduce berry size and cause berry dehydration, resulting in higher sugar concentrations in the berries (Jones, et. al., 2011).

Conclusion

In the art of winemaking, the concept of managing terroir is vital in the production of high quality wines. The current Niagara microclimate supports a burgeoning wine industry, but the effects of global climate change threaten to change this terroir over the next century. Both climate change scenarios explored in this paper suggest elevated temperatures that continue to rise well into this century, which could drive up total GDD for the region and create a longer, hotter season. A worst-case scenario of climate change suggests the entire wine industry could be at risk at the end of the 21st century. Higher predicted levels of greenhouse gas concentrations could result in greater frequencies of high, damaging temperatures (>35 ℃). It could thus be of benefit to Niagara viticulturists to adopt heat resistant varietals and techniques such as canopy covering in the upcoming decades to account for the encroaching difficulties.

In both scenarios, there is no noticeable trend in the volume of average daily precipitation, and frost days should continue to remain relatively stable. As such, Niagara viticulturists can likely continue the current practices utilized to mitigate the effects of variable climatic factors. While volumetric precipitation should show no major changes, it is still highly variable and is likely subject to a greater proportion of precipitation arriving as rain, in conjunction with higher temperatures. Irrigation practices should be carefully managed in order to accommodate for rainfall fluctuations.

Lastly, the climatic variables investigated in this paper compose just a fraction of the concept of terroir. The projections and suggestions posited by this paper should be taken into consideration as a mere part of a framework, whereby viticulturists also consider factors such as soil type and quality, as well as economic motivations into their decisions on vineyard development moving forward.

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Creating Sustainable Vineyards in Niagara

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Sustainability – a vague term with many connotations, associations, and assumptions. What does this term mean and how is it relevant to viticulture? More and more, we are seeing viticulturists in the Niagara Peninsula shift toward sustainable management practices. However, this shift is complex, with a potential for higher costs and more time invested, as well as a lack of knowledge presenting barriers for viticulturists. In this article, we will delve into the whys and hows of shifting toward sustainable viticulture, highlighting individual wineries that practice sustainability in tangible and creative ways. After reading this review, you will have a better understanding of how to approach sustainable viticulture from the joint perspectives of the lithosphere, hydrosphere, and biosphere.

INTRODUCTION

What is sustainability in the context of vineyards? First, we must define sustainable viticulture.

> ***Our definition:***
>
> *Sustainable viticulture involves practices that promote resilience for present and future generations in terms of economic and environmental perspectives.*

Sustainable viticulture is important because winemakers must implement practices that reduce long-term costs, increase vineyard health, and minimize negative environmental impacts in order to maintain a healthy and productive vineyard. In order for viticulturists to maintain a lasting practice, they must focus on important aspects of the lithosphere, hydrosphere, and biosphere, as they are all interconnected. As the overall quality of grapes is highly dependent on the interactions between the vines and the soil, as well as native plants and organisms, safe strategies must be taken into account. In the Niagara region, viticulture continues to grow as an industry, and understanding vineyard management is key. By working to recycle waste products, conserve water, and reduce chemical insecticide, fungicide, and herbicide applications, viticulturists in Niagara can build more sustainable vineyards for generations to come.

LITHOSPHERE

Why does the lithosphere matter for viticulture?

Sustainable vineyards are rooted in the foundation of the earth. The lithosphere is the outer rock layer of the Earth, including the soil that supports grapevines (Keller and Botkin, 2008). Apart from wine quality, viticulturists should care for soils because healthy soils maintain healthy ecosystems. In a vineyard, imbalances in the lithosphere harm the biosphere and hydrosphere as well. For example, harsh chemical fertilizers used in vineyards can leach into surrounding bodies of water and cause damage to plants and animals. In the long run, an unhealthy ecosystem will not only impact the health of grapevines, but also contribute to global environmental problems, such as climate change and the lack of fresh water.

Vineyards play a role in mitigating greenhouse gas (GHG) emissions via carbon sequestration, whereby carbon sinks absorb and store CO_2 from the atmosphere. Several studies demonstrate that vineyards are able to store a net amount of carbon in biomass and soil (Longbottom and Petrie, 2015; Brunori, Farina and Biasi, 2016; Sirca et al., 2013). However vineyards are also carbon sources (Sirca et al., 2013). It is necessary to nurture vineyards as carbon sinks more than carbon sources to work towards creating more sustainable vineyards that mitigate climate change. We know that promoting healthy soils and carbon storage are important, but how can viticulturists practice sustainability in their vineyard?

Productive waste

One sustainable technique viticulturists can implement to nurture healthier soils is to use biowaste as a fertilizer to provide essential nutrients to plants. Biowaste is decomposable, leftover material from living organisms. In viticulture, biowaste can come from the excess vegetation of grapevines.

Studies of organic fertilizers, including biochar and compost, have demonstrated environmental benefits, such as improving plant nutrient availability and increasing organic carbon and water in soils (Agegnehu, et al., 2015). Using biowaste can also reduce the flux of GHGs, such as CO_2 and N_2O (Agegnehu, et al., 2015). Physical improvements of soil include an increase in porosity, which is important for soil-water-plant relationships (Marinari, et al., 2000). Organic treatments also stimulate soil biological activity, measured in CO_2 production and enzymatic activity (Marinari, et al., 2000). Additionally, using manure as an alternative to synthetic fertilizers promotes biodiversity (Mariani and Vastola, 2015).

A drawback of using compost as a fertilizer is the nitrogen released in the soil. This could contribute to leaching and denitrification, polluting the water and air (Nendel and Reuter, 2007). Using manure is also associated with a higher release of N_2O, NH_3, and NO, thereby increasing GHG emissions (Nendel and Reuter, 2007).

Nevertheless, research shows that the benefits of using organic fertilizers outweigh the drawbacks. A comprehensive cost-benefit analysis of the environmental, economic, and human health factors of composting in the Niagara region revealed that using organic materials instead of landfill or energy from waste produces a net economic benefit of 1.4 to 5.8 million dollars per year (CM Consulting, 2007). Biowaste also results in the least pollution. Overall, biowaste as an organic fertilizer is sustainable from an economic and environmental perspective.

To till, or not to till

Another technique that is employed in vineyards, but can be unsustainable in certain contexts, is tillage. Tillage is a traditional technique involving the preparation of soil by mechanical agitation (The 3 Types of Soil Tillage, n.d.). It is an alternative to herbicide use for the grape berry moth, a major pest in the vineyards of eastern North America. Tillage buries these moths' overwintering pupae on the vineyard floor, and interferes with adult emergence

VITICULTURIST SHOWCASE: JACKSON-TRIGGS NIAGARA ESTATE

FIGURE 1: A JACKSON-TRIGGS VINEYARD. Vines are planted in perfectly parallel, equally spaced rows (Kim, 2017).

There is more to the Jackson-Triggs Niagara Estate than their award-winning fine wines. Beside their perfectly parallel rows of vines (Figure 1), are several large bins. Here, they store biowaste to use as both fertilizer and biofuel. As for tillage, they don't till every year; it is highly dependent on the season. After particularly harsh winters, they need to remove the dead vines and till the soil. For the most part, however, they don't till because they do not replant their vines regularly and the soil is fertile in the area. Jackson-Triggs values sustainability because all their practices affect the quality of what they grow, and the quality of wine begins with the quality of the grapes. They want to be proud of the wines they create.

(Matlock, Isaacs and Grieshop, 2016). Additionally, tillage can be beneficial because it improves soil aeration and water infiltration, eliminates weeds, incorporates organic matter into the soil, and stimulates decomposition (Pertot, et al., 2016).

However, no-till practices also have benefits. Tillage mainly affects the physical properties of soil by altering its structure, porosity, and size distribution. Several studies show that no-till plots provide the ideal pore distribution for root growth (Pagliai, et al., 1984; Raducu, et al., 2002). Other benefits of no-till practices include allowing earthworms to survive and increase organic matter in soil, as well as increasing carbon sequestration (Corbeels et al., 2016).

Bringing it all together in the lithosphere

It is worthwhile to consider the effect of biowaste and tillage when applied together (Andrenelli et al., 2010). Tillage increases availability of water and nitrogen for the grapevine (Pertot et al., 2017). However, in the Niagara region, soil water availability is rarely an issue, and nitrogen availability can be supplemented through the use of biowaste. Although there may be benefits and drawbacks to tillage frequency and use of biowaste, viticulturists on the Niagara Peninsula can shift toward sustainability by using more biowaste and tilling less frequently. In turn, they can preserve the quality of their grapes and the Earth in the future.

HYDROSPHERE

The hydrosphere allows for transport of nutrients and potential contaminants between the spheres, so maintaining its health is crucial when looking at sustainability. The hydrosphere consists of all liquid water on Earth, covering approximately 70 percent of the planet's surface. Of this 70 percent, only 2.5 percent is freshwater, the only usable source of water in agriculture (Mariani and Vastola, 2015). Water is essential in viticulture; regions require varied amounts of additional water depending on the climate and precipitation patterns in the area.

FIGURE 2: NIAGARA REGION IN RELATION TO GREAT LAKES. (Niagara Peninsula Locator, 2006).

How is the Niagara Region unique?

The Great Lakes make the Niagara region's (Figure 2) climate unique because a mild mesoclimate forms through the cycling of air between Lake Ontario and the Niagara escarpment. The escarpment acts as a barrier, influencing both wind and temperature (Shaw, 2005).

The presence of tropical and polar air masses, along with high and low pressures, also helps determine these unique weather patterns (Cyr, Kusy and Shaw, 2010). This highly variable climate involves differing amounts of rainfall during the year. Studies have shown that precipitation below 700-800mm is thought to produce the best quality of wine, though the more significant contributing factor is the timing of precipitation (Cyr, Kusy and Shaw, 2010). This is important to take into account, as excessive rainfall throughout the region in September and October, the major harvest months, may be detrimental to grape health (Cyr, Kusy and Shaw, 2010). Further understanding the hydrosphere and climatic conditions can facilitate the implementation of sustainable practices in vineyard water management.

Managing water in vineyards

Up to 70 percent of water used in vineyards becomes wastewater; thus, it is important to understand the trajectory and minimization strategies of wastewater (Mariani and Vastola, 2015). This starts with understanding where the water comes from and how it may be managed. The Wine Council of Ontario stated that 94 percent of Ontario wineries believe that water management is vital to a productive vineyard (2016). Winemakers must also consider how their water use impacts neighbouring wineries, as the use of the same aquifer means that the depletion or risk of contamination will affect everyone involved. Currently, Niagara viticulturists are implementing several different water-saving strategies, including collecting runoff rainwater to reuse, adopting more efficient cleaning practices, and using on-site water treatment technology (WCO, 2016).

Several strategies for sustaining water use have been discovered over the years. A common water conservation method is deficit irrigation; a strategic procedure that applies less water than what is required by the crop to increase grape quality (Costa et al., 2015; Medrano et al., 2015). There are two types of deficit irrigation: regulated deficit irrigation (RDI) and partial root drying (PRD) (Chaves et al., 2007; Medrano et al., 2015). RDI involves reducing or ceasing the amount of water used based on the sensitivity of plants to water throughout the crop cycle (Chaves et al., 2007; Medrano et al., 2015). This can be challenging because it requires significant control over water

VITICULTURIST SHOWCASE: CAVE SPRING CELLARS

Cave Spring Cellars is a leading Niagara winery in terms of water conservation and management. In 2015, they installed BioGill, an on-site wastewater treatment system (BLOOM, 2015). Wastewater contains a high amount of organic materials from alcohol and sugars, leading to a high biological oxygen demand (BOD) (Hirzel, 2017). Cave Spring Cellars disposes of their wastewater through their drainage system. However, wastewater with high BOD is not legally permitted to be returned to the environment. Consequently, when the water reaches the municipal treatment system, wineries have to pay a fee if the BOD exceeds a certain threshold (Mitham, 2015). BioGill has 'gills' that contain microorganisms that consume the organic material in the water (EcoEthic, 2017). This reduces the BOD meaning that the water needs minimal treatment, reducing the cost for the winery and the burden on municipal systems (EcoEthic, 2017; Mitham, 2015). The water can then be safely sent to Lake Ontario to be reused (Cave Spring Cellars, 2015).

application so that soil and plant water levels remain in a narrow range (Chaves et al., 2007; Medrano et al., 2015). However, RDI produces smaller berries with greater sugar and colour (Santesteban and Royo, 2011). PRD is an alternating process whereby approximately half of the root system is irrigated while the other half is left to dry. This allows the plant to have an adequate water supply while also reducing stomatal conductance (Chaves et al., 2007; Medrano et al., 2015). While PRD can be difficult to implement due to high costs and the complex system of irrigation lines and valves required, it greatly improves water use efficiency and berry quality (Costa et al., 2015; Medrano et al., 2015). Another method that could be implemented to improve water use efficiency is the planting of cover crops. A cover crop is a secondary crop planted within the primary crop to take up excess water and nutrients (Medrano et al., 2015). Cover crops typically use a variety of grass-type plants, such as barley and ryegrass. They are able to reduce water runoff, consequently improving water infiltration (Celette, Gaudin, and Gary, 2008). For cover crops to be successful, they require significant management to avoid excessive water consumption during dry periods, which would ultimately increase water stress and reduce crop yield (Medrano et al., 2015). These practices will increase the health of grapes, and maintain water use in vineyards year-round.

What happens to Niagara's water?

Wineries constantly produce wastewater as a result of grape processing and sanitation procedures (Hirzel et al., 2017). However, this water is often lost, preventing viticulturists from reusing it. Viticulturists can conserve this essential resource by collecting it for use in watering crops (Costa et al., 2015). This seems like a simple solution, so why don't all vineyards employ this conservation tactic? Apart from a lack of general knowledge on water management practices, the amount of wastewater available and its composition depends on the time of year, winery size, and variety of wines produced (Hirzel et al., 2017). As a result, there may not always be a consistent and sufficient source of wastewater available for irrigating crops (Mosse et al., 2013). In August 2016, the Niagara Region suffered from severe drought conditions (ECCC, 2016). Such conditions can significantly reduce yield, produce berries that are small and unflavourful, and have the potential to affect the growth of vines for years afterward (Jackson, 2008). Furthermore, because the wastewater is produced from cleaning operations, the presence of contaminants, such as sodium and potassium salts, could negatively impact grapevines and soils, and needs to be carefully monitored (Hirzel et al., 2017, Mosse et al., 2013). The impacts of poor water management can have huge negative effects not only on the hydrosphere, but the lithosphere and biosphere as well. By learning to monitor water consumption, viticulturists may be able to reduce the impact of drought, maximize their water use, and develop a more sustainable vineyard.

BIOSPHERE

Why does the biosphere matter for viticulture?

The lithosphere and hydrosphere sustain the biosphere, which consists of all living organisms on Earth, including grapevines and their pests (Thompson, Thompson and

Gates, 2016). Creating sustainable vineyards requires achieving balance between promoting resilient grapevines and managing pests in the biosphere. Grapevine health depends on organisms in the soil that help facilitate nutrient cycling, but vine health is threatened by pests and diseases that attack grapes (Kuen et al., 1994). Viticulturists can fight these pests using time- and cost-efficient pesticides and fungicides, but these chemicals harm essential microorganisms, as well as surrounding ecosystems. If winemakers want to ensure that their crop remains viable in the future, they must employ practices that balance cost- and time-efficiency with environmental impacts.

DOWNY MILDEW
Plasmopara viticola

Under what conditions does the disease develop?

- Primary infections require 10 mm of rain
- Develops quickly at temperatures of 20°C-25°C
- Found in areas on the vineyard that remain wet, areas with dense foliage, low spots

What are its effects?

- Fruit matures unevenly and remains hard
- Fruit loss, reduced sugar content, reduced vine vigour

How is it treated?

- Chemically with fungicides
- Pruning, training, and leaf-removal

POWDERY MILDEW
Erysiphe necator

Under what conditions does the disease develop?

- Cloudy conditions, high humidity, many rainy periods
- Found in areas on the vineyard that remain wet, areas with dense foliage, low spots

What are its effects?

- Reduces sugar accumulation in fruit during veraison
- Causes desiccation of shoots and buds

How is it treated?

- Chemically with sulfur-containing fungicides applied before infection
- Pruning, training, and leaf-removal

PHOMOPSIS
Phomopsis viticola

Under what conditions does the disease develop?

- Most severe with cool, wet springs
- Fruit infections require extended periods of rain and wetness

What are its effects?

- Can damage petioles, rachises, shoots, and fruit
- Rachis infection cuts off water and nutrient movement to developing berries

How is it treated?

- Chemically with fungicides
- Removing infected clusters and shoots
- Removing pruning debris from vineyard

FIGURE 3: THREE MAJOR FUNGAL DISEASES IN ONTARIO. Downy Mildew, Powdery Mildew, and Phomopsis develop in humid conditions, making them a large threat to vineyards in the Niagara region. (Information obtained from Walker, 2006 and Ministry of Agriculture; Food and Rural Affairs, 2009; images obtained from © Queen's Printer for Ontario, 2009).

We enjoy grapes… but so do fungi

Niagara's moderate climate allows for the production of high quality wines, but also provides the ideal growing condition for fungal diseases. In Ontario, there are three major fungal diseases with widespread yearly occurrence and high pest pressure: powdery mildew, downy mildew, and phomopsis (Figure 3) (Walker, 2006). All three diseases thrive in wet conditions, posing a large threat to the Niagara region (Ministry of Agriculture, Food and Rural Affairs, 2009). These diseases can attack several parts of the grapevine, resulting in decreased vine vigour and fewer healthy grapes for harvest. This in turn can impact wine flavour and production, both of which are factors that greatly affect winery revenue.

Currently, the majority of vineyards use inorganic copper- and sulfur-based fungicides to manage grapevine diseases due to their high efficacy (Wightwick et al., 2010). The problem with this isn't immediately apparent – until we remember how interconnected the lithosphere, hydrosphere, and biosphere are. When sprayed, a fungicide may bind strongly to the soil, directly affecting organisms and posing a risk to long-term soil fertility (Wightwick et al., 2010). The chemicals can also leach through the soil or be transported away from the vineyard by surface-runoff, adversely impacting nearby terrestrial and aquatic ecosystems. In the Niagara Peninsula, the regions with poorly-drained silt and clay soils cause fungicides to persist in the soil (Shaw, 2005). Conversely, other areas with well-drained sandy loams allow for chemical leaching, which can lead to groundwater contamination (Shaw, 2005). If no action is taken, these chemicals may continue killing soil organisms, impacting vineyard health and viability in the long term, affecting food chains, and contaminating important watersheds.

Steps toward sustainability

It is unlikely that chemical fungicides can be replaced altogether, as they are more effective and less costly than alternatives, such as fungicides that use microorganisms as active ingredients (Pertot et al., 2016). However, they can be used in a more environmentally-friendly manner and in conjunction with techniques that reduce likelihood of infection. Instead of spraying vines to prevent fungal disease, viticulturists can apply fungicides within 72 hours after the start of an infection (Allen and Johnson, n.d.). This strategy can reduce the amount of chemicals released into the environment, but requires good knowledge of the disease and its life cycle in addition to frequent vineyard scouting. There are also several canopy management techniques that can reduce the occurrence of fungal diseases. Since many fungal diseases develop under wet or humid conditions, practices that improve airflow and lower wetness decrease the likelihood of infection (Provost and Pedneault, 2016). These practices include

VITICULTURIST SHOWCASE: FEATHERSTONE ESTATE WINERY

At Featherstone Estate Winery, winemakers believe that "respect for the land is at the heart of making wine that is true to its soil and its site" (Featherstone Estate Winery, 2016). Their viticulturalists try to use farming practices that nurture the soil and harm the environment as little as possible. For example, they use a recycle sprayer for spraying fungicides that captures and re-uses spray that does not adhere to the vine, preventing chemicals from drifting into the environment. They are also very proud of their innovative use of sheep for pruning vines (Figure 4), which not only reduces the risk of fungal disease, but provides a source of organic fertilizer (Featherstone Estate Winery, 2016).

FIGURE 4: SHEEP GRAZING IN A VINEYARD. Sheep can be used to reduce susceptibility of vines to fungal disease (Palma, 2016).

the use of a vine training system, pruning, and leaf thinning to increase wind speed around grape clusters and to lower relative humidity (Provost and Pedneault, 2016).

In order to ensure the fertility of the soils for future generations and to minimize harmful impacts to Niagara's diverse ecosystems, viticulturists should employ fungicide use strategies in addition to cultural control techniques. Knowledge of the diseases, the crop, and management practices is crucial when deciding upon the best course of action.

Debugging vineyards and attitudes

A grapevine's battle doesn't end with fungus… vines have to deal with a multitude of other pests that infiltrate the vineyard (Figure 5). Grapevines contribute to a billion dollar industry that must be managed, as one insect infestation could destroy a whole crop (Dr C Harvey, 2017, pers.comm., 21 Sept.) Pest management comes down to cost, time, and convenience, so viticulturists usually spray strong pesticides, which are inexpensive, fast, and efficient at warding off arthropods – instigating a continuous battle between pesticide strength and insects' abilities to adapt to resist pesticides (Dr C Harvey, 2017, pers.comm., 21 Sept.) So why do some viticulturists put so much effort into avoiding pesticides? First, pesticides leave residues that are harmful to surrounding ecosystems. In the Niagara region, these

LEAFHOPPERS

Leafhoppers are small, jumping insects that suck plant resources, and love grape leaves. Leafhoppers destroy vines directly by feeding on xylem, phloem and mesophyll cells; and indirectly by acting as transporters of pathogens, including phytoplasma diseases.

ASIAN MULTICOLOURED LADY BEETLE

Lady beetles have been an invasive species in Canada since 1916 when they were brought over from Asia as a biocontrol agent against aphids. During harvest, these beetles live in grape clusters, eating carbohydrates from grapes with ruptured skins.

EUROPEAN STARLING

This starling is a medium-sized mimicry bird. In 1890, Eugene Schieffelin tried to recreate a Shakespeare play and so, released 60 Starlings in New York City's Central Park. As a result, this invasive bird spread to vineyards across the continent.

FIGURE 5: THREE ARTHROPOD AND BIRD PESTS ON THE NIAGARA PENINSULA. (Information obtained from Olivier, 2012; Saguez et al., 2015; Dr C Harvey, 2017, pers.comm., 21 Sept.; Reynolds, 2010; Pickering et al., 2011; Galvan, 2007; images obtained from Wikimedia Commons).

residues leach through the sandy, loamy soils and into the groundwater (Pickering et al., 2011; Flury, 1996). Also, though insecticides are used to kill one type of pest, outbreaks of non-target pests often occur as a side effect (Saguez et al., 2015; Olivier, 2012). Pesticides also disorientate and sometimes kill pollinators, including endangered bee species (Brittain et al., 2010).

There is an alternative path to pesticides, using methods already occurring in nature to prevent pests from destroying vineyards. Integrated Pest Management (IPM) systems use a variety of control practices to reduce impacts of crop pests (Olivier, 2012). IPM systems combine cultural practices with biological control, employing only organic, timed applications of pesticides when pests cannot be controlled by other methods and put the whole crop at risk (Olivier, 2012). Employing cultural and biological practices are the first steps to shifting toward sustainable pest management.

Cultural practices involve changing ground cover, pruning, and irrigation practices. Increasing ground cover often favours beneficial insects (Saguez et al., 2015). However, in some scenarios it is better to remove all ground cover through pruning to avoid increasing the number of host plants available to insect pests (Olivier, 2012). The spacing between vines is also essential to consider, as it is important to create a balance between grapevine foliage density, soil, and other plant species (Saguez et al.,

VITICULTURIST SHOWCASE: ROSEWOOD ESTATES WINERY

FIGURE 6: ROSEWOOD ESTATES VINEYARD. (Kim, 2017).

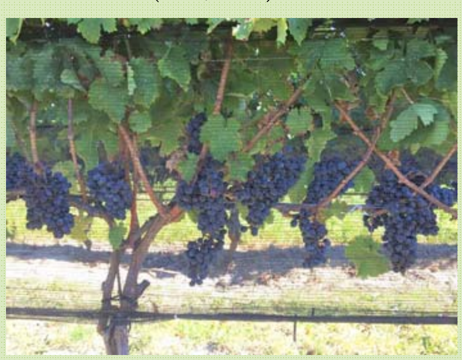

FIGURE 7: NETS AROUND ROSWEOOD VINES. Nets are set up around vines to protect grapes from pests. (Kim, 2017).

Rosewood Estates Winery is an environmentally and socially conscious wine company located on the Niagara Peninsula in Beamsville, Ontario. Rosewood implements various Integrated Pest Management strategies to ward off their greatest grapevine pests: leafhoppers, Asian multicoloured ladybeetles and European starlings. Rosewood strives to avoid pesticide use, but when necessary, uses non-systemic, organic pesticides that are copper- and sulfur-based. Every few minutes, a startling bang goes off at Rosewood. Visitors may jump a few feet, glancing around nervously; but Rosewood staff know this is the sound of a bird banger scaring away a starling, sparrow or robin from decimating the crop. However, not all birds at Rosewood are enemies. A blue jay's favourite meal is insect grapevine pests. Rosewood also has pheromone disruptors to confuse insect males, preventing them from mating with females. Finally, Rosewood workers tie bounty sheets over the vineyard to ward off deer. Rosewood strives to act as a role model for other vineyards to learn more about how they can shift to implementing sustainable viticultural practices (Mr W Roman 2017, pers.comm., 30 Sept.).

2015). Finally, reducing irrigation lowers pest density, as altered leaf structures and canopies change pest feeding and egg laying behaviours (Olivier, 2012; Saguez et al., 2015). Each vineyard is different, as each environment changes, so viticulturists must experiment with which cultural practice work best the grapevines.

Biological control methods include introducing or increasing the natural enemies of insect pests (Olivier, 2012). Though bio-control agents are less effective than insecticides, when combined with other IPM practices, this strategy becomes more efficient (Olivier, 2012). Related to biological control is the push-pull strategy, which changes the distribution of pests by using non-toxic stimuli to deter pests from vines and attract them toward areas free of vines (Pickering et al., 2011; Cook, Khan and Pickett, 2007). To employ this strategy in vineyards, a viticulturist must have an in depth understanding of a pest's biology and ecology (Cook, Khan and Pickett, 2007). The biosphere is a complex battlefield, but with an interdisciplinary approach to pest management, viticulturists can shift to more sustainable practices.

MOVING FORWARD

As the Niagara winemaking industry grows, viticulturists should shift toward sustainable practices to promote resilience for present and future generations. The lithosphere, hydrosphere, and biosphere are interconnected, and practices that harm one sphere negatively impact all spheres. Many Niagara wineries still rely heavily on chemical fertilizers, herbicides, pesticides, and fungicides, due to their relatively low cost and high efficient. With this in mind, it is important for viticulturists to understand the environmental and long-term economic effects of employing unsustainable practices.

Although at times costly or labour intensive, implementing sustainable practices can bring about long-term economic benefits, improve efficiency and crop quality, and reduce environmental impacts. Such practices include using biowaste as an organic fertilizer, reducing tillage, using deficit irrigation strategies, and adopting cultural and biological control methods to fight pests. Armed with these techniques, viticulturists in the Niagara region can continue shifting toward a future of sustainable viticulture, inspiring future generations for years to come. "Wine takes you back in time" (Mr W Roman 2017, pers.comm., 30 Sept.). The flavours of the past tell a story about the conditions of the environment and organisms existing at that time. What story will the wines of our generation tell?

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Drink Wine, Get Dirty

Leena AlShenaiber, Liz Balint, Pascale Bider,
Tanya Daniel, and Isobel Sharpe

When enjoying a glass of fine wine, it is easy to forget that winemaking is a process that begins in the dirt. Soils actually play a crucial role in grapevine and grape growth. Due to its unique geologic history, the Niagara Peninsula is a fascinating location to study the impact of soils on the process of growing grapes for wine. Glaciers and glacial lakes have left the Niagara region with highly diverse soils. Overall, the winemaking area is mostly composed of silts and clays with interspersed sands. In particular, soil moisture is a key factor that impacts grape growth. For the grapevine, a little stress can go a long way as water deficit has been correlated with increased grape quality. To grow the best possible product, viticulturalists must develop strategies to control the amount of moisture in their fields. Combining expert knowledge of soils with careful management as well as a passion for viticulture allows for remarkable diversity in Niagara grapes and wine.

THE NIAGARA PENINSULA

Wine production in Ontario is a lucrative field. Last year, Canada produced 2.6 million litres of wine, increasing 27% from the year prior (VQA Ontario, 2017a). Currently, almost 70% of Canadian wines are produced in the Niagara Peninsula, a region of southern Ontario located between Lake Ontario and the eastern edge of Lake Erie (Figure 1) (VQA Ontario, 2017a).

FIGURE 11 (TOP): MAP OF SOUTHERN ONTARIO. The green area indicates the Niagara region, located between Lake Ontario (north of Niagara) and Lake Erie (south of Niagara) (NordNordWest, 2009).

The region is often divided into different sub-appellations, mainly the Lake Iroquois Plain, Lakeshore Plain, Niagara Escarpment, Lake Iroquois Bench, and Haldimand Clay Plain (Figure 2) (Shaw, 2005; Cliff, Reynolds and King, 2005). The climate, topography, and soil of the Niagara Peninsula are the main factors that promote the growth of grapes for wine. The region experiences a mild climate due to the moderating effects of the Great Lakes. The lakes store heat and reduce the diurnal and seasonal temperature ranges through production of air currents (Cliff, Reynolds and King, 2005). In addition, the shielding effect of the Niagara Escarpment influences temperatures in this region. The Escarpment, located 30-50 m above the Lake Iroquois Plain, acts as a shelter from southwest winds, protecting the Lake Iroquois Bench, and some areas of the Lake Iroquois Plain (Shaw, 2005). As a result,

FIGURE 2 (BOTTOM): MAP OF THE NIAGARA REGION VQA SUBAPPELATIONS. The Lake Iroquois Plain encompasses the Lincoln Lakeshore and Creek Shores. The Lakeshore Plain includes the Niagara Lakeshore, Four Mile Creek, and Niagara River regions. The Beamsville Bench, Twenty Mile Bench, Short Hills Bench, and St. David's Bench compose Lake Iroquois Bench sub-appellation. Finally, the Vinemount Ridge is part of the Haldimand Clay Plain (VQA, 2017b).

these areas experience low wind speeds and moderate temperatures. These factors make the Niagara Peninsula a suitable region for wine grape growing.

GLACIAL HISTORY OF NIAGARA

The soil in Niagara, derived from Late Pleistocene (about 130 000 years ago) to Early Holocene subglacial and proglacial sediments, also significantly influences grape growth in the region (Haynes, 2000). A series of continental glaciations during the Quaternary shaped the bedrock in the area, and the advance and retreat of the ice sheets deposited glacial till (Haynes, 2000). As the ice front retreated, lakes formed beneath the Escarpment and deposited clays and silt above the till. About 12 000 years ago, the ice front retreated past the Toronto area and formed Lake Iroquois. This lake eroded previous sediments and formed a shore bluff, with deposits of sand, silt, and clay below (Haynes, 2000). The Lake Iroquois Bench terraces are located above this shore bluff, where the bedrock is covered by till and other Quaternary glacial sediments. Ultimately, this complex geological history has led to a heterogeneity in soils in the Niagara Peninsula. The soils now include clay, silt, and sand, with higher amounts of sand closer to Lake Ontario (Haynes, 2000). However, a significant portion of the soil in the Niagara Peninsula is clay and clay loam, which has various implications for grape growing. Additionally, Niagara soils have an appropriate pH range for grape growth, between 5.5 and 10, due to the presence of calcium carbonate in the parent material as well as the high cation exchange in clay soils (Ripmeester, Mackintosh and Fullerton, 2013; Burns, 2011). Besides the pH of the soil, two other crucial factors affecting grape growth are soil texture and soil moisture. Overall, the geological history of Niagara produced a variety of soils with qualities that allow for high quality grape and wine production.

NIAGARA REGION SOIL TEXTURE

Soil is an important factor in grape production; it acts as a reservoir for water and provides the majority of the essential nutrients for successful grape growth (Burns, 2011). Subsequently, there are many soil characteristics that affect grapes, notably the texture (Burns, 2011). Soil texture is related to the amount of sand, silt, and clay present in the soil as characterized by the soil texture triangle (Figure 3) (Burns, 2011).

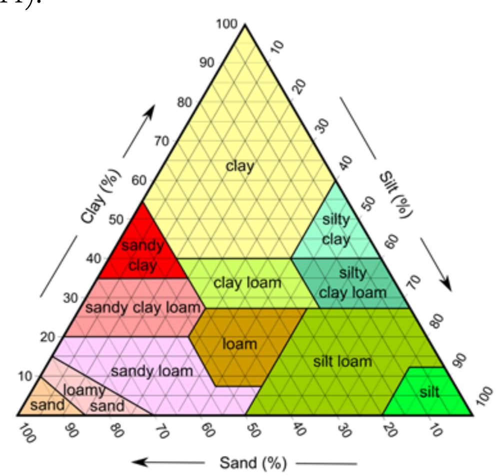

FIGURE 3: SOIL TEXTURE TRIANGLE. Soil texture is an important soil characteristic that relates to wine growth. Soil texture is determined based on the unique percentages of sand, silt, and clay in the soil (Mikenorton, 2011).

Specifically, soil texture influences water and nutrient holding capacities and drainage (Table 1). Some of the most common soil elements in wine growing regions are granite, chalk, limestone, marl, loam, gravel, clay, sand, and slate (Grainger and Tattersall, 2008). Clay is characterized by poor

TABLE 1: SOIL TEXTURES. Soil texture types and corresponding characteristics (Modified from: Osman, 2013).

Soil type	Drainage	Water and nutrient retention
Clay	Poor	Good
Sand	Good	Poor
Loam	Medium	Medium
Silt	Medium	Medium

drainage and good water retention (Grainger and Tattersall, 2008). In comparison, sand soils are loose, making it difficult to store water and nutrients (Grainger and Tattersall, 2008). However, sand soil prevents infestation by phylloxera, a lethal pest that feeds on grapevines and devastates grape growth. Silt soil has moderate water retention and drainage, and is more fertile than sand (Osman, 2013). Finally, loam soil is a combination of silt, clay and sand particles (Whiting, Wilson, and Card, 2005).

NIAGARA REGION SOIL TRENDS

Due to the variety of soils in the Niagara region, a simplified map was created in order to better understand the soils of the Niagara region (Figure 4). We used ArcMap to reclassify existing Soil Survey Complex data (2003) from Scholar's Portal, allowing us to create a simplified soil classification map. In the Soil Survey Complex data, there are areas of similar soil texture based on the soil texture triangle (Figure 3), which we decided to combine in our map. For example, we used separate categories for the coarse and fine sands, as the fine sands (yellow) are found along the shoreline of Lake Ontario

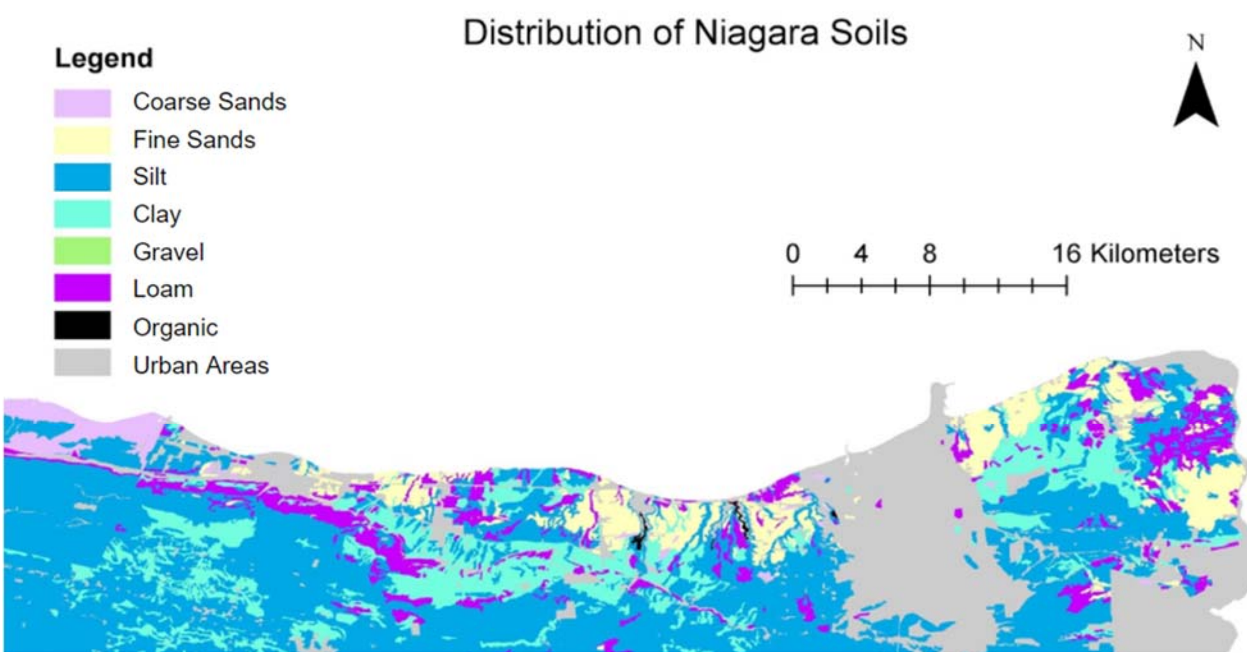

FIGURE 4: MAP OF THE SOIL DISTRIBUTION ACROSS THE NIAGARA REGION. The following legend labels represent groups of soil types: Coarse sands: loamy sand, gravelly sandy loam, gravelly loamy sand, gravelly sand, sand, sandy loam, coarse sandy loam, loamy coarse sand; Fine sands: fine sand, fine sandy loam, loamy fine sand, loamy very fine sand, very fine sandy loam; Silt: silty loam, silty clay, silty clay loam; Clay: clay, clay loam; Gravel: gravel, gravelly loam. Created using ArcMap and Soil Survey Complex data (2003) from Scholar's Portal.

where some wineries are located, whereas the coarse sands (light purple) are located beyond the winery region. Also, silt soils (dark blue) are the most predominate soil type in the Niagara region, but clay soils (light blue) dominate in the winery region. The Niagara area is rich in fine-grained soils, specifically clay and loam. These soils facilitate the effective growth of Riesling, Cabernet Franc, Chardonnay, Merlot, and Cabernet Sauvignon grapes (VQA, 2017b).

NIAGARA REGION SOIL MOISTURE

Soil moisture, the amount of water present in the soil, is another important soil characteristic that influences grape growth (Cornelis et al., 2001; Western and Greyson, 1998). Soil moisture impacts vine physiology and yield by influencing the transport of water, solute, heat, and mass near the soil's surface (Cornelis et al., 2001; Sivilloti et al., 2005). The physical properties of the soil dictate soil moisture and water movement throughout the soil (Cosby et al., 1984). In 1984, Cosby et al. studied nearly 1,500 soil samples and determined that variability in soil texture was most closely related to variability in soil moisture properties.

In the context of the Niagara region, we can begin to understand soil moisture properties using our classification map (Figure 4) and the soil moisture retention curve (Figure 5). The soil moisture retention curve is a graph that displays one of the main properties of soil moisture, expressing the relationship between the matric potential and the water content of the soil (Cornellis et al., 2001). Matric potential is the energy of the attraction and tension between the soil particles and water, and is made up of capillary and adsorptive forces (Cornelis et al., 2001; Hillel, 1980). Capillary forces are the surface tension of the water, while adsorptive forces are the attraction between polar water molecules and the charged soil particles (Hillel, 1980). Each soil texture type has a different curve, based on its unique physical and chemical properties (Cornelis et al., 2001). As previously mentioned, soil texture is the primary influencer of soil moisture (Cosby et al., 1984). Our classification map, based on soil texture, can therefore determine where soil

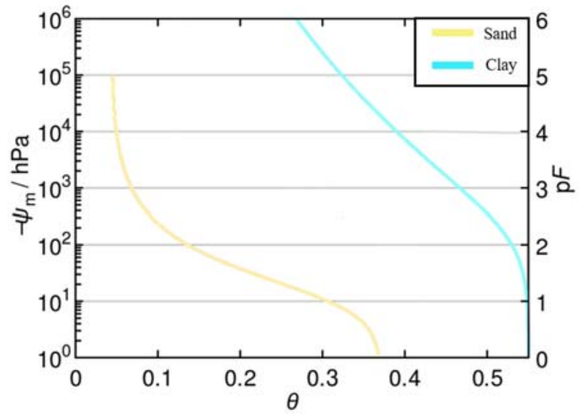

FIGURE 5: SOIL MOISTURE CURVES. A soil moisture retention curve for sand and clay. A soil moisture curve expresses the relationship between matric potential (ψm) and water content (θ) of the soil. Each soil has a different soil moisture curve, based on its unique chemical and physical properties. Soils with more moisture are on the right, while soils with less moisture are on the left. This curve corresponds to our classification map, showing the soil moisture for sand and clay soils in the Niagara region (Modified from: FMoeckel and DufterKunde, 2015).

EFFECT OF SOIL MOISTURE ON GRAPE GROWTH

Variations in soil moisture affect grape growth, ultimately the concentrations of various compounds in the grapes. The yellow areas of the classification map have the least soil moisture (Figure 4), corresponding to the sand line on the soil moisture curve (Figure 5). Areas with sand soils will not hold water due to their drainage qualities, putting grapevines at risk of dehydration. Grapevines experiencing severe soil moisture deficit display signs of necrosis through leaf yellowing and leaf loss (Keller et al., 2016). If grapevines continuously do not receive enough water, the crop will grow extremely small berries in small clusters (Keller et al., 2016). In excess, this is not economically feasible for the vineyard. However, if the grapevines are able to survive moderate drought-like conditions, the relatively smaller berries provide several potentially beneficial phenological changes. Foremost, Fernandes et al. (2015) observed that the grape skins were tougher, which is likely a result of the increased cellulose and lignin content, and that berry anthocyanin content increased. Both of these properties are associated with a richer colour often found in high quality wines (Gil et al., 2015). Furthermore, there were major decreases in total acidity and increases in total soluble sugars at the mature stage of the berry (Fernandes et al., 2015). Control over acidity levels is crucial in manipulating factors that influence taste and perception of the wine (Fontoin et al., 2008). Additionally, sugars including glucose and fructose are essential in the fermentation process by yeast, which will affect the final alcoholic content. In many grape varieties, a lack of water results in similar phenological impacts that decrease the overall berry weight, must volume, and demonstrate changes in specific compound content (Mirás-Avalos and Intrigliolo, 2017; Keller et al., 2016; Fernandes et al., 2015; Shellie, 2014; Romero et al., 2013).

Niagara soils are rich in clay, as seen in the light blue areas on the classification map (Figure 4), indicating a fairly compact soil structure. This means Niagara clays have poor drainage as well as high water and nutrient holding capacities (Ripmeester, Mackintosh and Fullerton, 2013). These areas also have the most soil moisture, corresponding to the clay line on the soil moisture curve, and have the highest water content at all levels of matric potential (Figure 5). Therefore, the soil surrounding the grapevine roots can become oversaturated with water. The compact nature of clay soils prevents vine root from penetrating to depths with essential nutrients and water. Further, the already limited pore space in clay soils is filled with the excess water, causing the roots to respire ineffectively (Soane and van Ouwerkerk, 2013). As a result, the roots are unable to grow and absorb necessary nutrients, resulting in wilting or even death. Thus, the grapevine has a higher probability of drowning, or experiencing "wet feet" (Will Roman, pers. comm., 30 September 2017). Since research is limited regarding the impacts of excess water on grape growth, we can infer that clay soils will be less likely to experience moderate water deficit and less likely to produce the desired smaller, higher quality grapes. Grapes that do not experience water stress would have increased total acidic content with decreased total soluble sugars and anthocyanin levels. Overall, variations in the soil moisture influences the quality of grapes, as well as the grape growing process.

SOIL MOISTURE MANAGEMENT

It is crucial for farmers in the Niagara region to develop efficient soil moisture management systems to maximize crop yield and minimize water waste. For this to be accomplished, it is necessary to determine the existing soil moisture levels. Many tools, such as tensiometers, electrical resistance blocks, and time domain reflectometry sensors can be employed for this purpose (Shortt, Verhallen, and Fisher, 2011). When inserted into the soil at the desired depth, the tensiometer detects the water tension in the soil. Higher tension values indicate a drier soil (Shortt, Verhallen, and Fisher, 2011). Electrical resistance blocks determine soil water tension by measuring the electrical resistance between two electrodes buried in the ground (Shortt, Verhallen, and Fisher, 2011). Alternatively, time domain reflectometry sensors (TDRs) are multi-pronged machines that calculate the speed of electromagnetic waves between the prongs. When the TDR sensor is buried in the soil, moisture slows the speed of the waves (Shortt, Verhallen, and Fisher, 2011). These tools can send data to a central computer, allowing viticulturalists easy access to soil moisture information for their fields (Shortt, Verhallen, and Fisher, 2011). Having easy access to moisture information is especially important to Niagara vineyards due to the heterogeneity of the soil.

Many strategies can be employed to modify the levels of soil moisture in Niagara. First, irrigation can be used to increase soil water content in the sandy soil regions of our classification map (Figure 4). In these areas, several different irrigation strategies can be employed to maximize grape quality and yield. For instance, regulated deficit irrigation (RDI) can be practiced. This irrigation strategy puts vines under mild water stress at certain periods of its development by adding less water to the soil than the crops lose by evapotranspiration (Reynolds, Shortt, and Carter, 2013). Shellie et al. (2014) found that sustained deficit irrigation method is most effective when 70% of the crop loses water through evapotranspiration. This method of soil water management is beneficial because it ensures the vine has adequate water during the budbreak and bloom phases, but it also allows farmers to induce water deficit during the veraison to harvest period (Reynolds, Shortt, and Carter, 2013). As a result, the vine will produce less vegetative growth and higher quality grapes (Balint, 2011). Similarly, partial rootzone drying (PRD) also allows Niagara grape growers to selectively stress their crop by applying moisture to one side of the roots at a time (Reynolds, Shortt, and Carter, 2013). However, this technique does not influence grape growth as effectively as RDI (Reynolds, Shortt, and Carter, 2013).

In more humid areas, or in soils that are more prone to waterlogging, it may not be necessary to irrigate in order to achieve adequate soil moisture levels. Our classification map shows that wineries in the Niagara region lie predominantly on clay soils. Under these conditions, it may be more beneficial to implement a drainage strategy. Tile drainage systems are commonly used to remove excess moisture from the vineyard (Ruark et al., 2009). Modern tile drains are corrugated, perforated plastic pipes buried one to two meters underground that remove subterranean water (Figure 6) (Ruark et al., 2009). They can be installed in a grid pattern throughout the vineyard to ensure consistent soil moisture. Simpler methods for soil moisture control include crop cover and mulching. Adding a living green crop can induce competition for available soil water (Monteiro and Lopes, 2007). On the other hand, a layer of mulch at the surface of the soil improves water retention and leads to more humid root conditions (Medrano et al., 2014). Due to the conditions of the area, most, if not all, Niagara wineries implement a drainage strategy (Balint, 2011). However, studies have shown that irrigation is also occasionally required for optimal crop yield, particularly in drier years (Balint, 2011). Ultimately, optimal land management techniques depend on the time of the growing season (Martínez et al., 2016) and the current weather as the soil may re-fill with natural precipitation (Pellegrino et al., 2005).

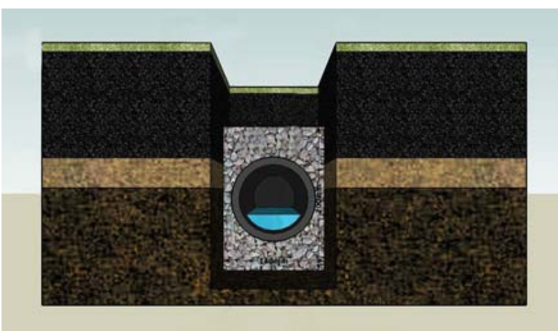

FIGURE 6: CROSS-SECTION OF A TILE DRAIN INSTALLED UNDERGROUND. Tile drains are are corrugated, perforated plastic pipes buried 1 to 2 meters underground that whisk away subterranean water (Modified from: Ybbor, 2007).

GOOD WINES AND GOOD TIMES

In summary, the soil in the Niagara region has a significant impact on the growth of its grapes. Many characteristics of soil affect grape growth, including pH, texture, and moisture. Through the classification map, it can be seen that the Niagara region mainly consists of clay, which has a good water holding capacity (Figure 4). Consequently, most Niagara wineries are found on clay-rich soils. This has both benefits and drawbacks for grape growth. To effectively grow grapes on all different types of soil in Niagara, farmers employ various land management practices, involving different techniques in irrigation and drainage. Future studies should use technology for more detailed investigations of soil moisture content in the area, which can be done through the analysis of emissive and scattering characteristics of the soil surface (Lakshmi, 2012). This is useful for identifying properties like soil texture in a vineyard, which relates to soil moisture. All in all, there are many factors that affect grapevine growth, and soils significantly contribute to the ultimate goal that is a great bottle of wine, leading to fun and good times.

MORE TO EXPLORE

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