Terroir

An Integrated Wine Science Publication

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An Integrated Wine Science Publication

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For further information about the project, please contact us at isci@mcmaster.ca

WINE SCIENCE

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

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 2014

Cover Image: Wine glass. Dean Hochman. Uploaded to Wikimedia Commons on 28 November 2014.
Table of Contents Image: Oak wine barrels Niagara On The Lake Ontario summer 2015. WayneRay. Uploaded to Wikimedia Commons on 12 July 2015.

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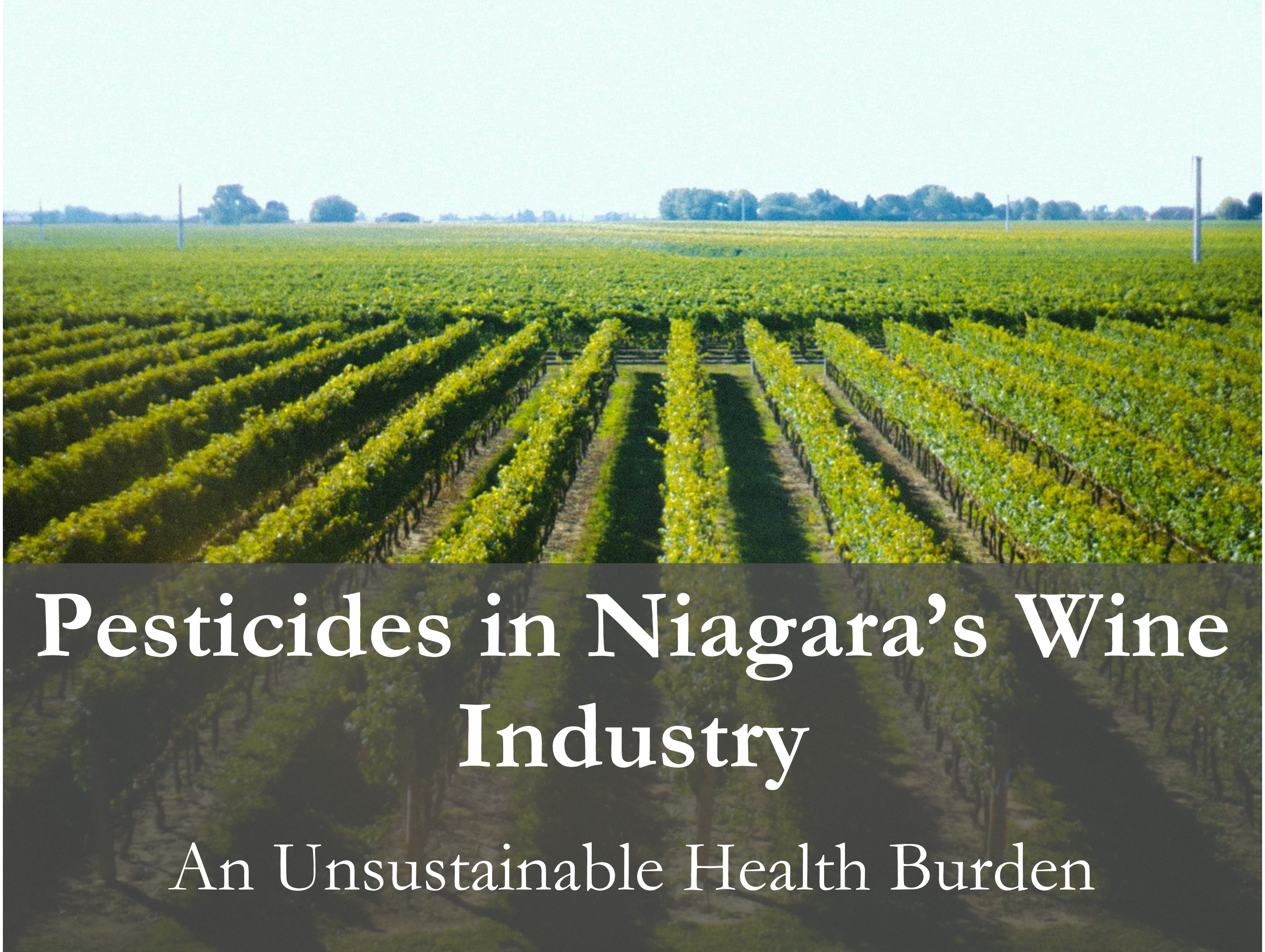

Pesticides in Niagara's Wine Industry

An Unsustainable Health Burden

Aaron de Jesus, Michael Gill, Carolina Weishaar, Katie Woodstock, Rui Xu

Pesticides have long been considered a necessary component of the agricultural process; however, more and more people are beginning to understand the severe toxicity these chemicals pose to humans. Many are also concerned there is little opportunity to limit exposure of neighbouring populations. Looking forward, the expansion of residential areas towards Niagara's vineyards will be one of the major factors fueling a greater health burden caused by vineyard pesticide usage. Another will be climate change, and the associated ecological disturbance it will usher in. As a result, the acute health costs due to pesticide usage in Ontario's vineyards are predicted to grow beyond the total revenue of the industry. For these reasons, there must be a rapid shift away from the pesticide-heavy practice of today. Luckily, promising alternatives do exist.

INTRODUCTION

The Niagara region is home to over 75 wineries. This distinct geographic region is Canada's largest and most diverse area of viticulture. Tucked in between Lake Ontario, Lake Erie, and the Niagara River (see Figure 1), Niagara provides microclimates ideal for growing numerous varietals of *Vitis vinifera*. Consumers are starting to take notice; in the past seven years, per capita wine consumption for Canadians has increased by more than 37%, (CVA, 2012). Paralleling this growth, the total area of Canadian vineyards has grown by 15% between 2001 and 2006 (Statistics Canada, 2014).

There is no reason to think that growth will stop here. Analysts expect that between now and 2018, Ontario will see a yearly increase of 2% in wine volume produced and 5% in revenue (EI, 2014). These local wines have also gained international acclaim in recent years, a fact reflected in export revenues increasing from $13 million in 1997 to over $25 million in 2007 (AAFC, 2014). Given this surging demand, it is natural to consider how the system will grow to accommodate the needs of consumers.

One stark reality of this expansion is an expected increase in pest control techniques (Zabadal, 1999). Currently, many vintners view pesticides as a mandatory response to the threat of grape damage posed by pests. This is reflected in the 170 000 kilograms of various pesticides utilized by Ontario's vineyards in 2005, a number which is growing every year (AAFC, 2005).

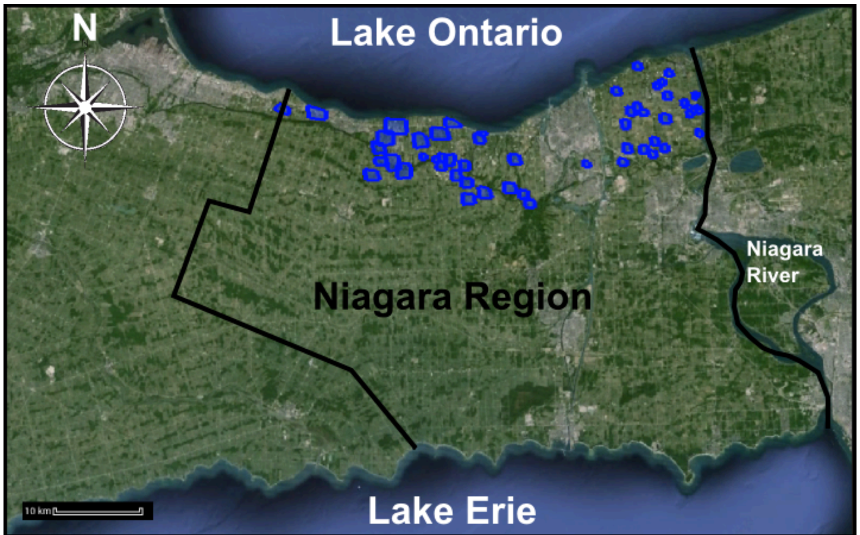

FIGURE 1: THE NIAGARA REGION.

The Niagara region, depicted within the black outline, is surrounded by Lake Ontario, Lake Erie, and the Niagara River. The blue sections show all the wineries within this region (Google Maps, 2014).

There is substantial evidence that suggesting current practice is unsustainable. Urban centers will edge closer to vineyards, leading to greater pesticide exposure of the general public. Climate change will lead to a more active and variable pest presence, demanding that farmers apply larger and larger quantities of these toxic chemicals. Ontario is at the point where the adverse effects associated with pesticide usage are frightening and real, and these effects will only grow larger in the future. Thankfully, alternatives do exist, but before we can discuss them we must fully understand the problems present in the current pesticide framework.

HISTORY REPEATING ITSELF

Following World War II, dichlorodiphenyltrichloroethane (DDT), an organochlorine, was promoted as the simple solution to any pest problem, big or small. These claims were not false advertisement; DDT is a very effective pesticide, even by today's standards: it requires a minimal number of applications and works against a broad range of species (Mellanby, 1992). As a result, the agricultural and commercial usage of DDT quickly became widespread around the globe. However it was soon apparent that the chemical properties, which make DDT an efficient pesticide, also make it toxic to a wide range of organisms. In humans, DDT produces several neurodevelopmental and reproductive abnormalities. With sufficiently high doses, these effects are both severe and permanent.

In the mid 1950s, many vocal scientists struggled to increase public awareness of the risks associated with DDT. A critical step in this effort came in 1962, when Dr. Rachel Carson published Silent Spring: a best-selling book which told the story of several towns, scattered around the United States, whose citizens and land had been poisoned by DDT and other pesticides. This book began an environmental movement that culminated in the 1969 ban of DDT throughout Canada. Since then, more than 60 pesticides have been banned across North America (Muir, 2012).

However, the problem is far from resolved. As of July 2006, there are 60 active ingredients used in pesticides, which have been banned in multiple western countries but are still acceptable within Canada (Boyd, 2004). In order to minimize the effects of these harmful chemicals, it is important that residents of Niagara understand the most common routes of exposure, as well as the severity of the adverse effects that common pesticides may present.

REACHING MORE THAN THE TARGET AUDIENCE

Many people wash their vegetables in hopes of reducing their interactions with pesticides; however, most cases of pesticide exposure come in the form of inhalation or dermal contact. As a result, individuals that handle pesticides, or live in close proximity to the affected areas, are at the highest risk of exposure and illness.

Further, the workers who apply the pesticides and harvest the grapes are most prone to direct exposure. While this form of exposure is the very detrimental to one's health, it is also relatively easy to protect against. The general public is much more likely to experience indirect exposure, which can occur through contaminated drinking water, dust, air, or food. This form of exposure often takes place over an extended period of time and is much more difficult to control, given the variety of forms it can take. Beyond reducing accidental pesticide spillage, the only clear route to consistently decrease indirect exposure is through limiting pesticide usage (Alavanja, 2004).

WHAT'S WRONG WITH A LITTLE EXPOSURE?

DDT presents a worst-case scenario as far as the adverse effects of pesticides are concerned; however, the effects of the pesticides used today are still alarming. In Niagara, a mélange of these chemicals are regularly used, including organophosphates, carbamates, and fungicides. Each pesticide leads to different symptoms, which makes tracking and recognizing the effects of pesticides as a whole very difficult.

Organophosphates are perhaps the most broadly used class of pesticide today. In the

Niagara region, they are used to combat leafhoppers, the multicoloured Asian lady beetle, and the largest scourge in the area: the North American grape berry moth (Pesticide Risk Reduction Program, 2006). These molecules irreversibly binds to the molecule acetylcholinesterase (AChE). ACHe is responsible for breaking down acetylcholine (ACh), a neurotransmitter responsible for muscle activation. As a result, organophosphates inhibit the breakdown of Ach, leading to the accumulation of ACh in both the central nervous system (CNS) and peripheral nervous system (PNS). From this, a few categories of symptoms may appear: nicotinic, CNS and muscarinic effects (Fiedler, 1997) (see Table 1).

TABLE 1: NEUROLOGICAL EFFECTS OF ORGANOPHOSPHATES. The symptoms of organophosphates are divided into three catgories: nicotinic, central nervous system (CNS) and muscarinic effects. Note that the muscarinic effects is also divided into two mechanisms: the stimulation of the motor nerves and the stimulation of the autonomic ganglion (Youakim, 2006).

Neurological Effects of Organophosphates			
Symptom Category	Nervous system affected	Mechanism	Symptoms
CNS	CNS	Overstimulation of the nicotinic acetylcholine receptors	anxiety, headache, convulsions, depression of respiration and circulation, tremor, general weakness, and potentially coma
Nicotinic	PNS	Overstimulation of the motor nerves	muscle weakness, fatigue, muscle cramps and even paralysis
		Overstimulation of the autonomic ganglion	hypertension, and hypoglycemia
Muscarinic	CNS and PNS	Overstimulation of the muscarinic acetylcholine receptors	visual disturbances, tightness in chest, wheezing, increased salivation and uncontrollable urination

The problems associated with organophosphate pesticides aren't exclusive to those applying them; these chemicals are potent enough to have strong effects through indirect exposure. It has been demonstrated that low levels of exposure to organophosphates in children is associated with an increased risk of Attention Deficit Hyperactivity Disorder (ADHD) (Bouchard, 2010). Further, a study conducted in 2013 demonstrated that exposure of pregnant women to low levels of organophosphates causes increased risk of their child will developing ADHD (Thapar, 2013). Alzheimer's disease has also been tied to low-level organophosphate exposure (Makhaeva, 2009). It is frightening to think that organophosphates are tied to two of the decade's most prevalent, and problematic diseases.

Carbamates are also widely used, but instead treat downy mildew, black rot, and powdery mildew (Pesticide Risk Reduction Program, 2006). The toxicity profile of carbamates is very similar to that of organophosphates; they also inhibit

AChE. However, with carbamates this process is reversible, producing the same symptoms as organophosphates, but with lower potency (Youakim, 2006).

Fungicides are a class of compounds used to halt the growth of fungi, such as powdery mildew, that otherwise would destroy crops (Pesticide Risk Reduction Program, 2006). The active ingredients in the fungicides used in Niagara are sulfur, copper and copper sulfate. All three can cause severe irritation to skin, eyes and respiratory tract. Copper sulphate, in particular, is corrosive to the cornea and mucous membranes. Chronic exposure to fungicides leads to vineyard's sprayer lungs. This aptly named disease causes lesions along the afflicted individual's airway and across their lung tissue (Youakim, 2006).

SHORT TERM GAIN, LONG TERM PAIN

Due to the widespread use of pesticides in agriculture, detectable levels of pesticides can be found in homes and bodies across the nation. The half-life of many active ingredients in these pesticides totals 30 years; meaning that, even when a pesticide is no longer used, it will continue to affect the exposed population for several generations (Alavanja, 2004). DDT is a testament to this. Today DDT still causes health issues, despite it being banned in 1969. Further, many of these chemicals continue to be toxic even after they have broken down into their constituent molecules (Woodwell, 1975). In the case of DDT, its constituent molecules have a similar structure to that expressed by estrogen. As such, girls exposed to these compounds are at an increased risk of developing early-onset puberty (Robinson, 1985). It is clear that pesticide usage as it currently stands is damaging to the human health. Further, it is incredibly likely that many of these issues are present in the population of Niagara. This alone should be cause for changes in practice; however, an even greater incentive for change exists if one looks ahead to the future.

THE URBAN ISSUE

Consider the following: vineyards are expanding, populations are increasing, yet each application of pesticides has the same potential to expand outwards and cause harm to the nearby population. Surely, one can predict problems for those living in the area.

This is exactly the situation seen in Niagara. The Regional Municipality of Niagara population is projected to grow by 17.8% from 2011 to 2031 (Min. of Finance, 2012). Meanwhile, the Niagara wine industry is expected to grow by 2% in wine volume and 5% in value each year (Euromonitor, 2014). As vineyards and residential areas encroach on one another, new issues with the use of pesticides will arise. These problems will likely occur due to two specific mechanisms of pesticide exposure: spray drift and groundwater contamination.

THE PERILS OF SPRAY-DRIFT

Many pesticides are sprayed in aerosol or vapour form, both of which are susceptible to spray-drift: the unwanted dispersion of the pesticide to non-crop areas. These pesticides often travel hundreds of meters, leading to the accidental exposure of nearby residential areas (Salyani and Cromwell, 1992). The reality of this danger is severe enough to warrant a place in provincial policy. The Ministry of Agriculture, Food and Rural Affairs publishes pesticide-spraying protocols to help reduce spray-drift (Felsot et al., 2011; Deveau and Beaton, 2011).

These protocols describe the Awareness zone, a one-kilometer boundary around the site of application, and the Buffer zone, the minimum distance between application and susceptible areas (Deveau and Beaton, 2011). An example of a Buffer zone is shown in Figure 2, with the Jackson-Triggs winery acting as our model location. Further, Health Canada provides a "Buffer Zone Calculator" designed to help vintners understand when and where to apply pesticides safely. While in theory these tools help to minimize the effects of airborne exposure, in practice they are far from perfect.

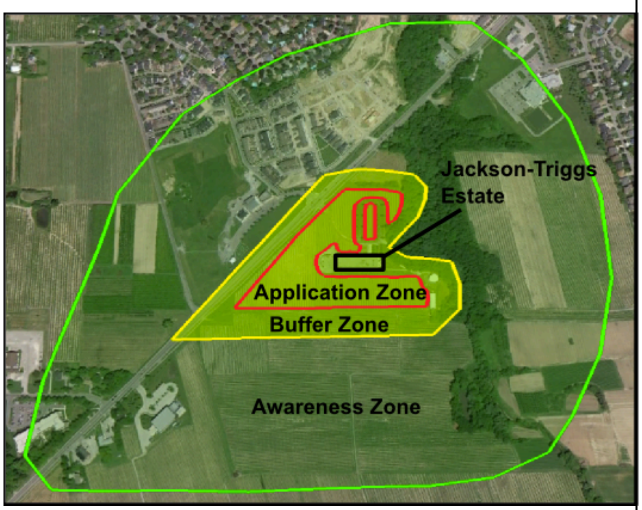

FIGURE 2: MAPPING SPRAY-DRIFT.

The Awareness zone and Buffer zone around the Jackson-Triggs Estate winery. Note that the Buffer zone envelops the winery, and the Awareness zone reaches a nearby residential area (Google Maps, 2014).

The reach and potential damage of spray-drift is incredibly difficult to predict; a huge number of variables can influence the distance the chemicals will travel. The weather, a vineyard's chosen spray equipment, the technique used by vineyard workers, and the physical properties of each pesticide all have the potential to encourage larger drift than is otherwise predicted (Ucar and Hall, 2001).

Many recommendations concerning spray-drift rely on ideal conditions, but rarely is this the case. Often, vintners are confronted with immediate problems, which demand non-ideal pesticide applications. For example, the grape berry moth is only susceptible to pesticides during the larval stages of its life cycle. If, at this time, there is also a strong breeze or the humidity is high, the vintners face a decision between potentially exposing the Niagara population to pesticides, or failing to sufficiently control the pest and damaging their crop (Isaacs, 2005). Worse still, the problem doesn't end here.

THE OTHER SIDE OF EXPOSURE

Regardless of how well spray-drift is contained, a very small portion of the pesticide applied to the crop will reach the target pest. This percentage has been estimated to be less than 0.1% (Pimentel, 1995). The remaining 99.9% doesn't simply disappear; once applied, its journey continues to nearby soils, streams, and groundwater. It is estimated that 95% of urban streams and 50% of rural wells are contaminated with pesticides in the US (Arias-Estévez et al., 2008).

Numerous biotic and abiotic factors affect the lifetime of pesticides in soils, which often span 20 years. For example, periods of intense rainfall cause pesticides to bypass their residency time in unsaturated soils. As a result, when these chemicals arrive in streams, rivers, and lakes, they remain active for a greater period of time. This effect increases the probability of human exposure (Paul and Meyer, 2001).

Another side of this problem is that the organisms present in these contaminated bodies of water are highly susceptible to biomagnification. Through this process pesticides and contaminants move up a food chain and result in pesticide concentrations that are orders of magnitude greater than those applied to crops. Biomagnification can be highly detrimental to natural ecosystems, not to mention costly in terms of human health repercussions.

Attempts have been made to classify regions by the likelihood of pesticides reaching groundwater systems. An example of this is the "DRASTIC" model, which uses linear combinations of hydrogeological factors to rank the susceptibility of a region. However, these models often lack accuracy; many assumptions are made and the predictions they generate are difficult to validate with real data (Arias-Estévez et al., 2008).

A NOXIOUS SITUATION

This paints a frustrating reality for the individuals operating vineyards: those that remain dependent on pesticides must either knowingly put the health of their own community at risk, or resign themselves to sub-optimal yields whenever situations for spraying are non-ideal. Further, even if these reduced spraying practices are employed, the fickle nature of spray-drift and the inevitability of groundwater contamination make it very likely that harm will still come to those in the surrounding area. When this sad reality is acknowledged in the context of Niagara, where vineyards and residences are pushing closer and closer together, utilizing pesticides quickly becomes an unethical approach. Worse, there is still one more damaging piece of the puzzle to consider: climate change.

ENTERING HOT WATER

There is no longer any dispute as to whether climate change is impacting our environment (IPCC, 2001a). Scientists have also reached consensus that these effects will continue to increase in their intensity and complexity (IPCC, 2001b). As climate change sets in, increased pesticide usage is expected, as a response to the greater insect herbivore activity that typically appears in warmer temperatures (Gutierrez et al., 2007). Similar undesirable effects may arise due to climatic changes, followed by the introduction of new species (Gutierrez, Ponti, and Gilioli, 2010). When we consider these factors specifically within the Niagara region, the picture does not get any rosier, largely due to challenges posed by the grape berry moth (AAFC, 2005). As a result, climate change will lead to greater pesticide usage across Niagara in the years to come.

ASSESSING THE SITUATION

By the year 2100, Niagara will see a 5 degree increase in temperature (Columbo et al., 2007) (see Figure 3). It is well established that the life history traits of insects, the characteristics that describe their reproduction and development, are susceptible to temperature change (Ratte, 1985). Specifically, insects are likely to produce more offspring and require less time to reach maturity in warmer climates (Bale et al., 2002). While a number of other variables may also impact pest abundance, these two key results suggest a greater prevalence of insects in the decades ahead. Such a conclusion is supported by the presence of greater herbivory in the fossil record during times of global warming (Wilf and Labandeira, 1999).

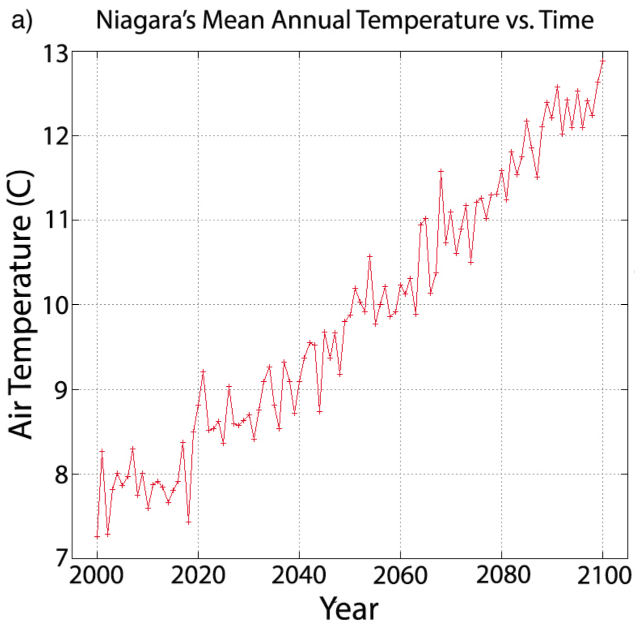

FIGURE 3: PREDICTED MEAN ANNUAL TEMPERATURE.

Between the year 2000 and the year 2100, an average increase of almost 5 degrees Celsius is expected in Niagara. As a result, greater pest activity and by extension pesticide use is expected.
(Data simulated by the AR4 Assessment, Model CGCM3T47 hosted via Environment Canada and the Canadian Center for Climate Change Modeling.)

WHY WARMING MATTERS

The instinctive reaction to greater pest activity is to increase pesticide usage. This is an especially likely response in Niagara, due to the unique insects present. Specifically, the grape berry moth is only susceptible to pesticides during its larval stages. As warmer climates cause these stages to shorten, pesticide spraying must increase to ensure that the pests are sufficiently exposed in during this critical period (Isaacs, 2005).

Further, climate change may lead to an additional cohort of a grape berry moth offspring being born each year. Currently, there are only two generations annually (Schmidt et al., 2003). Each generation requires it's own round of pesticide application, implying that the introduction of a third could increase spraying by fifty percent each year.

A final effect of warming on the pests themselves is the potential diversification of herbivorous insects. As temperatures increase, cold-limited species to the south may expand towards the Niagara region. This phenomenon has been observed with other pests across North America (Jepsen et al., 2008). Novel herbivore species have a tendency to present large threats when they take hold in an area, due to a lack of natural predators (Elzinga et al., 2007). In order to compensate, larger quantities of pesticides may be required. Even in the cases where novel herbivores don't become dominant, they may still impact total pesticide requirements via the need to introduce new chemicals, or to account for different periods of susceptibility.

Looking past the pests, climate change is predicted to cause an increase in the occurrence of extreme weather (Lemmen and Warren, 2004) (see Figure 4). It has been demonstrated that extreme weather increases contamination of groundwater (Kaushal et al., 2010; Auld, MacIver, and Klaasen, 2004). From this we may suggest that those health costs associated with pesticides contaminating groundwater are likely to increase in the years ahead.

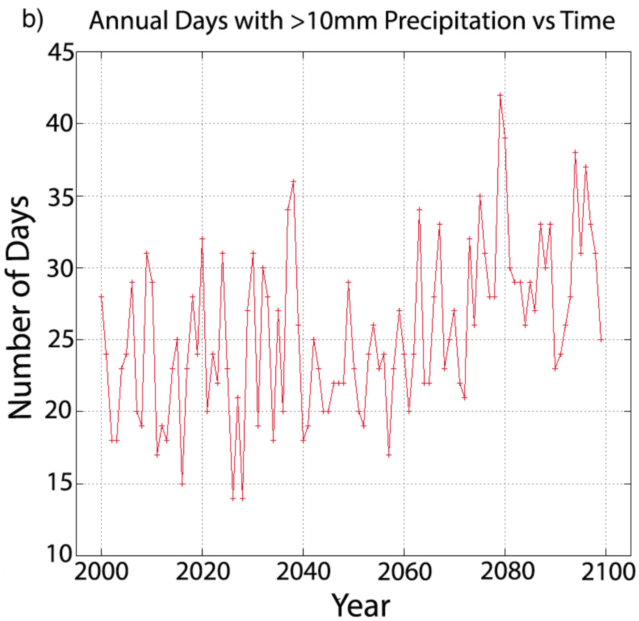

FIGURE 4: DAYS WITH OVER 10mm OF RAIN PER YEAR.

Predicted number of days with greater than 10 millimeters of precipitation annually for Niagara, between the year 2000 and the year 2100. While there is great yearly variation, maximum annual values increase by over ten days a year. This clearly indicates a shift to greater storm and heavy rainfall events. As a result, greater groundwater contamination by pesticides is expected. (Data simulated by the AR4 Assessment, Model CNRMCM3 hosted via Environment Canada and the Canadian Center for Climate Change Modeling)

WHAT IT WILL COST US

So far, discussion has revolved around qualitative descriptions of the issues posed by pesticides. If one hopes to put a rough number on the damage wrought by pesticides, predictions can be made based on the acute costs associated with these chemicals. By comparing experimentally values from other areas with the 5200 hectares of vineyard and 170 000 kilograms of pesticide applied in Niagara, the cost of acute health effects due to pesticide usage can be pegged at a whopping 430 million dollars (Pretty et al., 2009). This means that more than 10% of the total economic benefit associated with vineyards in Ontario is utilized simply to reconcile immediate adverse health effects. This value ignores all the costs associated with ecological damage, ground water contamination, and the more chronic health problems that arise from pesticide exposure (CVA, 2013) (see Table 2).

Further, this cost is only going to balloon in the coming decades (Koleva and Schneider, 2009). If the costs associated with climate change are included, this value will grow by another 160 million dollars by 2100. Finally, if expansion of vineyards continues at predicted rates, and a similar amount of pesticide is being used to treat each new hectare of vineyard introduced, this additional cost will grow to 420 million dollars, for a total of 850 million dollars of cost associated with acute health effects every year (see Figure 4). This value is more than the entire revenue generated by Ontario's wine industry in 2011.

TABLE 2: ACUTE HEALTH COST. Accounting for climatic change and vineyard expansion between 2014 and 2100.

Year	Acute Health Cost - $ / (kg of pesticide *area of application)	Vineyard Area (hectares)	Pesticides Applied (kg)	Total Cost ($)
2014	0.49*	5200	170 000	433 000 000
2100	0.65*	8430*	280 000*	856 000 000*

* indicates predicted value

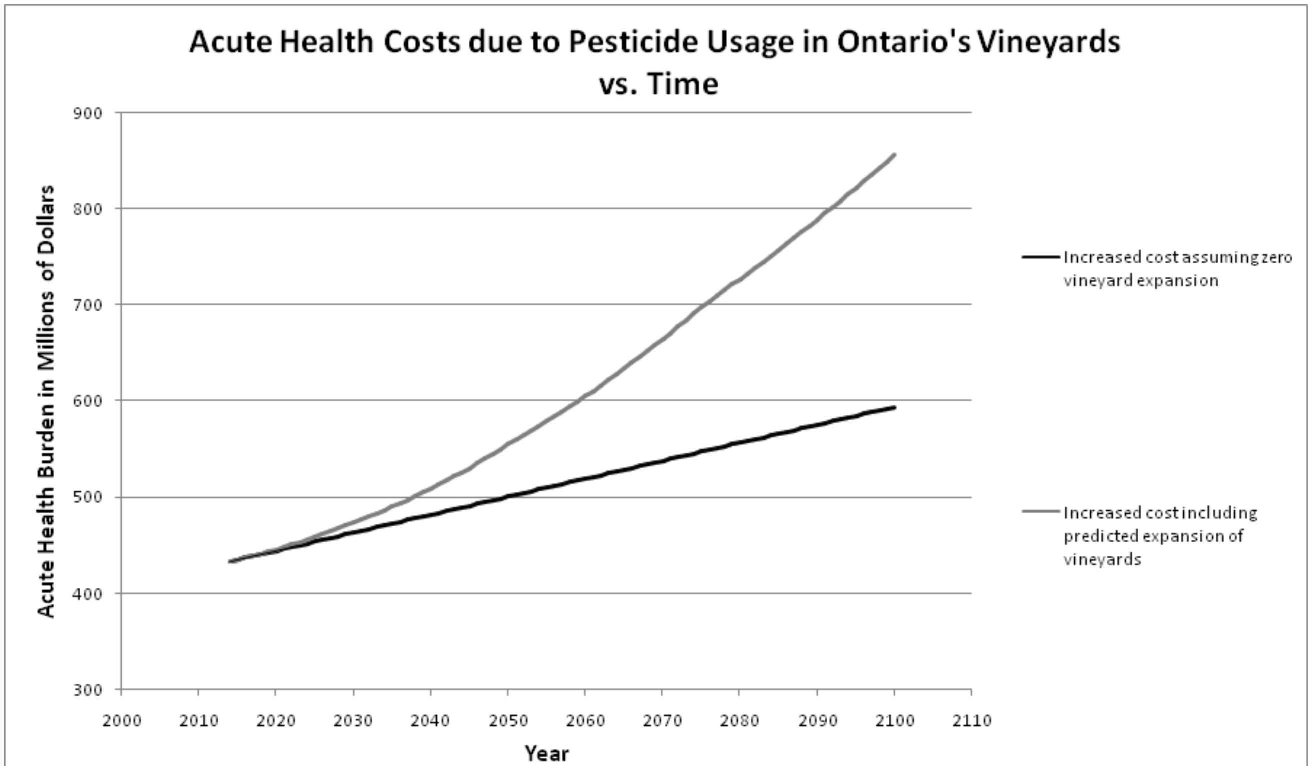

FIGURE 5: TWO POTENTIAL TRAJECTORIES FOR PESTICIDE RELATED ACUTE HEALTH COSTS.

Two scenarios are outlined which predict the future costs of pesticide usage in Ontario's vineyards. In the first, the increasing costs associated with climate change are accounted for, but it is assumed that zero growth in the vine industry occurs. In the second, the area of vineyards expands at a predicted rate, and the ratio of pesticides used to cover each hectare of vineyard remains the same.

Frightening for residents of Niagara, these costs will largely be borne by those who work and live close to the source of the contamination. For example, health costs are greatest in those who apply the pesticides or pick the grapes. As a result, many of the harmful effects will manifest themselves in the working demographic of Niagara. This is clearly an unsustainable route to proceed down, especially if the province hopes to continue to expand the viticultural landscape.

TOO MUCH TO BEAR

The severity of associated health effects, coupled with residential expansion in Niagara and inevitable climate change, paint the current usage of pesticides as unsustainable. It will soon be negligent to grow wine grapes with a heavy dependence on these chemicals, a fact reinforced by the enormity of costs that are expected to appear in the future. Thankfully, alternative approaches exist that show both economic and social promise.

Many of these initiatives fall into the category of Integrated Pest Management (IPM). IPM capitalizes on knowledge of the specific environment and pest populations present, so that pesticides can be applied in the most efficient manner (Kogan, 1998). This allows for vineyards to maintain pests at benign levels with the minimum amount of pesticide use. Several vineyards within the Niagara region have begun to utilize this approach to reduce their reliance on pesticides (Niagara Falls Info, 2014). Some vineyards have also begun to make use of more involved tactics, such as introducing predators of pest species and interrupting pests' mating patterns or development.

AN EDUCATED APPROACH

A major component of IPM lies in passively monitoring pest presence and comparing this to a known economic injury threshold (EIT). EIT is the population density of a given pest where intervention is necessary to prevent economic injury (Roubos et al., 2013). By comparing the cost of intervening to the loss of crop yield caused by a particular pest, an effective response can be determined. If vintners also included the predicted external health costs associated with usage, vineyards can operate in a socially-responsible manner.

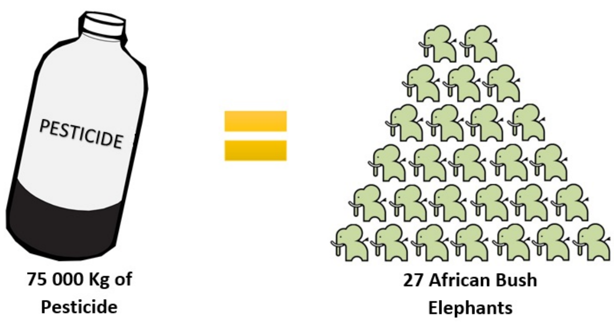

FIGURE 5: WEIGHT OF PESTICIDE SAVED IN NIAGARA

With the use of IPM, Niagara can cut its use of pesticides in half. This is a reduction in pesticide weight equivalent to that of 27 African Bush Elephants (AAFC, 2005; National Geographic, 2010).

Studies have been conducted which describe these thresholds for pests present in Niagara. For example, researchers found that in vineyards considering the use of pyrethroid, the grape berry moth must infest more than 9.9% of grape clusters before the intervention is economically beneficial (Roubos et al., 2013). This knowledge is important as it allows vintners to determine when pesticide use is absolutely necessary, and act accordingly. Dr. David Pimentel, a pest management expert from Cornell, estimates that the use of IPM techniques can reduce the amount of pesticide use in agriculture by as much as 50%, without a decrease in yield (Brenner, 1991).

ACTIVE MANAGEMENT THROUGH MATING DISRUPTION

In cases where intervention is necessary, active IPM techniques can be utilized. A particularly promising example of this is the use of pheromone-based mating disruption, a technique that has been studied in the Niagara peninsula since 1987 (Trimble, Pree and Vickers, 1991). In many common pest species, females utilize pheromones to help males locate them. Applying an artificial source of these pheromones has been shown to disrupt this process. Technology achieving this was first registered within Canada in 1992, and has been used to some degree in one third of Niagara's vineyards since then (Trimble, 1997; 2007). Previously, usage was limited by impractical dispensing methods; 1000 plastic dispensers had to be deployed in each hectare of vineyard.

New advancements in this technology utilize microencapsulated pheromones, which can be sprayed using the same machinery as pesticide spray treatments. In this form, pheromones can be concurrently sprayed alongside traditional pesticides, making the use of this technology much more practical. Further, spray-drift from

FIGURE 6: PHEROMONE DISPENSER.

Pheromone dispensers are used in the Niagara Region to control the grape berry moth population (BASF, 2010).

these pheromones poses little risk to human health and the surrounding environment, as the active chemical is inert: it only impacts the target pest species (Kong et al., 2014; Witzgall, Kirsch, & Cork, 2010). Therefore, the use of mating disruption has a great potential to reduce the Niagara winemaking industry's burden on both the healthcare system and the surrounding environment. Further advancements in this technology will only make it more valuable in the years to come.

EXCITING ALTERNATIVES

Although mating disruption is the most prominent IPM intervention method used within the Niagara region, there are several other methods that hold potential. One example of this is the use of insect growth regulator (IGR). These spray chemicals halt development in pests that are exposed early in their life, while having no effect on the associated ecosystem (Isaacs, Mason, & Maxwell, 2005; Siddall, 1976).

Another promising approach, which could be better implemented across Niagara, is the use of biological controls. Vintners can use their knowledge of pests' predators to encourage an environment where these pest populations are reduced. For instance, there have been several studies in which leafhopper populations have been controlled via the importation of Anagrus egg parasites (Pacific Agri-food Research Station, 2012). These parasitize the eggs of several leafhopper species, and are effective in maintaining leafhopper levels below the economic injury threshold. While there are always risks inherent to the introduction of new species in a given area, when done correctly this approach holds significant potential.

TAKING ACTION

As an industry that powers the economic development of an entire region, and has huge potential to grow, it is essential that the wineries of Niagara prioritize sustainable practice. Society now has a firm handle on the harmful nature of pesticide exposure in humans. It is highly likely that in the years to come more individuals will be living in close proximity to vineyards in Niagara. Climate change is a given, and will force current pesticide practice to grow. As a result, the costs of acute health effects due to pesticide usage will increase beyond the current revenue of the industry. Armed with this knowledge, vineyards should embrace a widespread shift towards integrated pest management. By taking the time to intimately know the pests in a given area, by fostering biodiversity, and by employing pheromone or hormone based pesticide alternatives, Niagara's vineyards should be able to exist in good conscience for the foreseeable future.

MORE TO EXPLORE

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The Unique Demands of Icewine Fermentation

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The production of wine has been traced back thousands of years, but it was not until the most recent decades that large efforts were placed into fermenting the thick, sweet nectar of grapes left to freeze in the winter. The production of icewines has left a niche in the winemaking industry for growers in the Niagara region. These wines, their distinct flavours, lofty pricing, and exclusivity come with new challenges for winemakers. The same sweet juice responsible for the wine's unique flavor makes the fermentation process nearly impossible in some instances. Here the topics of yeast fermentation and how icewine poses a challenge to the process are explored, as well as the solutions winemakers have constructed to produce a quality product in an efficient manner.

THE UNIQUE CHALLENGE

The production and consumption of wine can be traced back to 7000 BCE (Lockard, 2010). Whether through accounts of religious practices, celebrations, or everyday life, the prominence of wine throughout history is evident (Lockard, 2010). In 2013 alone, over 33 billion bottles of wine were produced, a testament to its unchanged cultural importance (OIV, 2013). In fact, relative to the 9000 years that have passed, the product itself has not changed much either. While there have been advancements in the machinery used and quality control measures, the end goal has always been to enhance the wine rather than drastically change it. So has anything really changed within this time-honoured and tradition based process? Well it turns out, one of the only significant changes to the production technique and taste of wine came in a bottle labeled "Eiswein," produced in Germany a mere 200 years ago (VQA Ontario, 2014). Introduced in Canada a mere 40 years ago, it has since taken the world by storm.

Since the late 1970s, global appreciation of icewine has increased steadily. Now regarded as a delicacy deserving of a premium price, it is sought after for its sweet flavour and high acidity. But what is the secret behind this special taste? Patience. If the winemakers let the grapes freeze on the vine Seen in Figure 1, they are left with a very unique wine must. Wine must is the term used to describe the juice provided from the grapes. It still contains the skin and seeds, as these are used later on in the process to provide extra flavour. Squeezing the grapes while they are frozen means that very little water content is extracted, resulting in an icewine must that is very high in sugar (VQA Ontario, 2014). Naturally, the fermentation of this must results in a sugary wine, hence the sweet-tooth satisfying icewine that is enjoyed by so many.

FIGURE 1: FROZEN GRAPES. Grapes are left to freeze at temperatures below -8°C for a few days, and harvested in the middle of the night to preserve the frozen interior (Rivard, 2008).

Icewine is a true game changer. Not only has it pushed the boundary of what wine can taste like, but it has also allowed for winemakers in non-traditional winemaking countries like Canada to get a foot in the door of the exclusive wine-producing club (Agriculture and Agri-Food Canada, 2014). What makes it more special, is that only a select group of climates in the world are able to produce icewine. This ensures that icewine will continue to be a highly demanded, limitedly supplied good. As great of a situation Canadian winemakers find themselves in, it is not to say they have an easy task at hand. Icewine production is still a very young concept that is relatively unrefined and definitely not void of difficulties. Besides annoyances such as harvesting the grapes in the middle of the night, one of the largest hurdles in icewine production has to do with the crucial step of fermentation. Fermentation is the process by which yeast turn sugars found in the must into ethanol, acids, and carbon dioxide (Prescott, 2005). It truly is the one step that makes wine, wine. Although yeast readily completes this step in table wine must, the unique traits of icewine must present a problem for the yeast. It often takes a very long time to complete the fermentation process, and sometimes it never reaches completion (Kontkanen et al., 2004). This is not a problem one can overlook or just live with. Winemakers needed to find a solution to this problem quickly, as no matter how good the finished product tastes, if you do not have any of it to sell, you will not be making much money.

Luckily, as icewine becomes a more marketable and lucrative product, research into optimizing the tricky production process is becoming more feasible for these revolutionary winemakers. Studies have now revealed that the key to an icewine's amazing flavour is also the source of its fermentation hardships. The high sugar concentration in the icewine must subjects the yeast to an osmotically stressful environment (Kontkanen et al., 2004). This externally-sourced osmotic stress causes the yeast cells to shrivel up, and hinders its ability to efficiently complete the fermentation process.

This leaves winemakers with quite the predicament. The very characteristic that is crucial to the flavour of icewine, is the source of most icewine production issues. In the context of a Niagara region wine producer, how do they maintain the wine's sweet flavour, while ensuring they produce an economically beneficial amount of product? As research is discovering now, there is a plausible answer, and it has to do with the yeast involved. And to better understand the solution, it is important to explore the evolutionary history of yeast.

THE EVOLUTION OF YEAST

Wine was first discovered when grapes and other fruit fell off trees after harvest season. Upon consumption by humans, it was discovered that the fruit had intoxicating effects. The naturally occurring yeast found on these fruits had produced alcohol from the sugar already present in the grapes. This began the start of making wine from grapes that were found to be naturally fermenting. Through time and experimentation it was determined that wine left to ferment on its own was variable and therefore unreliable (Sipiczki, 2010). This began the modern practice of adding yeast to wine.

Saccharomyces cerevisiae is the primary yeast used in the fermentation of most alcoholic beverages, primarily beers and wines (Heard and Fleet, 1985). This yeast's most important feature is its capacity to handle high levels of stress from the grape must (Erasmus, Vandermerwe and Vanvuuren, 2003). This includes high osmotic pressure and sugar content, especially with icewines. This yeast has a few crucial roles in winemaking including its ability to ferment, and its capacity to create the aromas and tastes indicative of different varietals. There are many theories as to how this yeast evolved. Researchers who have studied this species have determined that *S. cerevisiae* is not the yeast present at the time of harvest (Cocolin, Bisson and Mills, 2000). In fact, at the beginning of fermentation, this yeast is not even present at detectable levels. However, it later becomes dominant during the fermentation process due to its ability to handle high levels of stress (Cocolin, Bisson and Mills, 2000). This yeast outcompetes the natural yeasts present on the grapes during harvest. Historically, *S. cerevisiae* was left to grow on its own in order to ferment the wine. Over time this created inconsistencies as the wild version of this yeast could be temperamental and create bad batches of wine if the growing season had been particularly harsh (Aa et al., 2006). This led to the domestication of the yeast. Scientists began to harvest the yeast and created a specialized version that is able to be used in all fermentations of beverages. This removed the variability in the yeast, and now the changes to flavour are dependent on the metabolism of the yeast rather than the quality.

S. cerevisiae is dominant in wine production, but the process of its evolutionary advantage is still unknown. However, the roles of many different proteins in this yeast have recently been elucidated. In the experiment conducted by Erasmus, Vandermerwe, and Vanvuuren (2003) it was discovered that most of the proteins in this yeast were used only for the purpose of handling different stresses induced on the cell. These proteins respond to stress in general, rather than the specific factor causing the stress. This is likely due to an evolutionary trait where this specific yeast outcompeted the others with its ability to handle stress induced upon it by high sugars and therefore osmotic stresses. This species is thus ideal for use in fermentation, but most specifically in icewine fermentation.

OSMOTIC PRESSURE

Osmotic stress is the undesirable movement of water into or out of a cell and is the consequence of osmotic pressure. Osmotic pressure results from separating solutions with different solute concentrations across a semipermeable membrane (Janáček and Sigler, 1996). A semipermeable membrane selectively allows for materials to pass through, while stopping the passage of others. This trait creates a gradient between high and low concentrations which will try to achieve an equilibrium moving more of the solvent from the low concentration section to the section with high concentration (Janáček and Sigler, 1996). Since a volume of solvent is being added to one side, there will be an associated increase of pressure. The pressure continues to rise until it is enough to stop the flow of more solvent into the cell. This pressure at equilibrium is the osmotic pressure of the system (Janacek and Sigler 1996). Since biological cells envelope their vital machinery in a semipermeable membrane, the process of osmotic pressure poses immediate implications for living organisms.

OSMOTIC STRESSES IN CELLS

Biological cells may experience hypoosmotic or hyperosmotic stresses. Hypoosmotic stress occurs when the cell has higher internal solute concentrations than the surrounding environment. In such a case the cell would uptake water in attempt to lower its internal solute concentrations. Alternatively, a cell undergoing hyperosmotic stress would have a lower internal solute concentration than the cells surroundings and would lose water to the surroundings to try and balance the concentrations (Freeman, Harrington and Joan, 2008). Cells respond to such stresses in different ways to maintain cell function and protect their machinery from damage. A common response to osmotic stresses is the reorganization of the cell's cytoskeleton. The cytoskeleton is a system of twisted filamentous proteins that provide support and shape for a cell (Freeman, Harrington and Joan, 2008). With changes in a key component of the structure, it is obvious that cells would undergo morphological changes when under osmotic stresses.

OSMOTIC STRESS RESPONSE

In the production of wine the environment of the yeast is grape must, which contains a high concentration of sugar and, eventually, alcohol. With an elevated solute concentration outside of the cell, the flow of water is directed from the inside of the cell, through the membrane, and into the environment. Yeast morphology changes rapidly with exposure to elevated levels of sugars and ethanol. The membranes of cells in a hypertonic solution will shrivel and the cells shrink as shown in Figure 2 (Pratt et al., 2003). Studies have shown that the membranes of *S. cerevisiae* produce inward folds called invaginations, similar to those in other microbes and is associated with hyperosmotic stress tolerance (Morris and Winters, 1986). Other research has shown that these physical changes and the reorganization of the cytoskeleton of the cell membrane may allow the cell to detect the presence of the stress and react to it biochemically through various means (Hohmann, 2002). How a yeast strain responds to osmotic stress has been shown to have a notable effect not only on the ability to properly ferment icewines, but can also alter the taste of the final product.

SENSING OSMOTIC PRESSURE

Humans sense changes in our external environment, such as temperature through our skin. In the same way, yeast use proteins in their cell membrane to sense changes in their environment. Changes in the shape of the sensory protein in response to the external environment activate a chemical pathway inside the cell. The High Osmolarity Glycerol (Hog) pathway is activated in response to osmotic stress as shown in Figure 3. *S. cerevisiae* has two transmembrane proteins, Sln1 and Sho1. Low internal pressure in a yeast cell deactivates Sln1 and activates Sho1 (de Nadal, Ammerer and Posas, 2011). This combined effect activates the Hog pathway. The activation of the Hog pathway is important, as it is the primary mechanism by which the cells sense osmotic stress. A loss of turgor pressure is directly correlated to the activation of this pathway (Schaber et al., 2010).

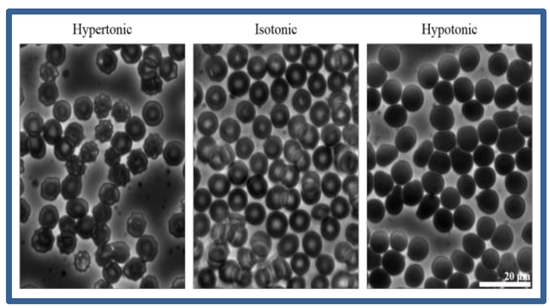

FIGURE 2: THE EFFECTS OF OSMOTIC STRESSES ON ERYTHROCYTES, OR RED BLOOD CELLS. The process relevant to the production of icewine is the hypertonic case, where the concentration of solutes outside of the cells is higher than that inside the cells. This causes water to move out of the cell and cause cell shrinkage, along with an irregular folded shape. The images are phase contrast micrographs (Wheeler, 2002).

BIOCHEMICAL RESPONSE

Activation of the Hog pathway changes the activity of the fermenting yeast, and results in the distinct taste and quality of icewine. The reaction of each strain to the icewine must is slightly varied, and can determine whether the resulting icewine is a delicacy or undrinkable.

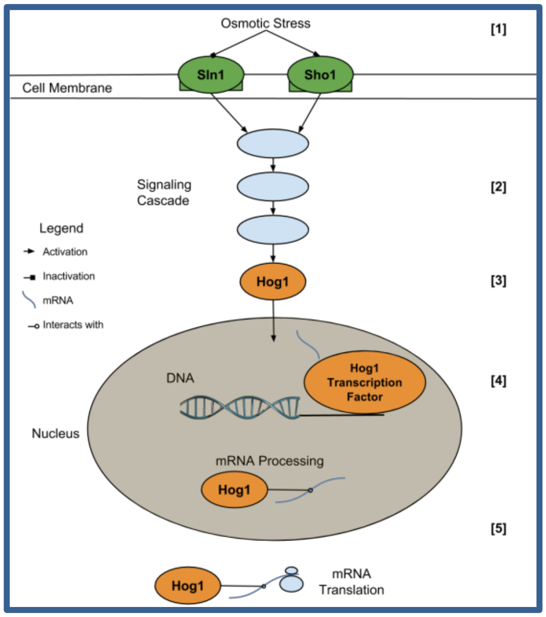

FIGURE 3: THE HOG PATHWAY, WHICH IS ACTIVATED WHEN YEAST SENSE OSMOTIC STRESS, AND LAUNCH A MULTI-STEP RESPONSE. When an osmotic change occurs in the external environment, the conformations of the transmembrane proteins Sln1 and Sho1 change (1). These changes cause a series of protein kinases (Ssk2, Ssk22, Ste11, and Pbs2) to be activated by a process known as phosphorylation. Once a protein is activated, it activates the next protein in series (2). Eventually, the final protein Hog1 is activated and enters the nucleus (3). The Hog1 protein forms a complex, known as a transcription factor. This binds to yeast DNA and helps express the DNA sequences which code for enzymes needed to respond to osmotic stress (4). Finally, Hog1 modifies mRNA after transcription to help express proteins (5) (de Nadal, Ammerer and Posas, 2011).

Certain yeast strains will have a fast fermentation speed, as well as a high level of completion, meaning they are able to convert a lot of sugar into ethanol. For icewine, a fast and complete fermentation is necessary to ensure that the wine reaches the minimum level of alcohol required to meet regulatory standards, and does not leave an unpleasant level of sweetness due to excess sugar (Galeote et al., 2010).

The variation in performance between the many strains of *S. cerevisiae* is due to removing, adding, or rearranging their genome, or even transferring genes between species (Carreto et al., 2008; Novo et al., 2009). These genes usually code for the expression of a specific protein, and are given different instructions to increase or decrease expression depending on what stresses are in the environment (Erasmus, Vandermerwe and Vanvuuren, 2003). This genetic variability results in unique strains that can respond to the high osmotic stress and be successful at icewine fermentation.

Two important changes that result from icewine fermentation are the increased levels of glycerol and acetic acid in icewine compared to table wine (Pigeau and Inglis, 2005). This reflects that these biochemical pathways within the cells are involved during osmotic stress situations, and receive instructions to be upregulated to improve cell survival (Erasmus, Vandermerwe and Vanvuuren, 2003). The first of these is glycerol, which could contribute to the sweetness of the icewine but more likely has a neutral effect on taste and quality (Erasmus, Cliff and van Vuuren, 2004). Glycerol is a compatible solute, which is a molecule that does not significantly interfere with important cellular processes (Nevoigt and Stahl, 1997).

Yeast experiencing osmotic stress can respond by increasing the intracellular concentration of compatible solutes. They activate the Hog pathway, discussed earlier, which results in an increased production of the compatible solute, glycerol (Erasmus, Cliff and van Vuuren, 2004). This is accomplished through several metabolic pathways, which are carried out by enzymes, illustrated in Figure 4. Important enzymes which complete this reaction are glycerol-3-phosphate dehydrogenase and glycerol-3-phosphatase. The production of glycerol also affects the ability of the cell to undergo many other reactions, because it produces the important electron accepting agent NAD^+, which is used throughout the yeast cell (Nevoigt and Stahl, 1997). This compound can carry electrons for other reactions in the form of NADH. Both molecules have to be in balance for the yeast to perform all life-sustaining metabolic reactions, therefore there has to be a consequence resulting from the increased NAD^+ levels.

Along with increased glycerol production, there is an increase in acetic acid, shown in Figure 4. Acetic acid is one of the volatile acids in icewine, which leads to an unpleasant vinegar aroma, and taste (Cliff and Pickering, 2006). The amount of acetic acid permitted in icewine is regulated to ensure the highest quality and best tasting wine, therefore keeping acetic acid production to a minimum is crucial for winemakers (Erasmus, Cliff and van Vuuren, 2004). Though it must be minimized, increased activity of this pathway must occur in order to balance the excess NAD^+ generated from glycerol production, and regain the balanced state of the yeast to ensure survival and complete fermentation (Erasmus, Cliff and van Vuuren, 2004). This pathway starts with acetaldehyde, which is also the precursor for ethanol. However, this reaction will produce even more NAD^+, further upsetting the state of the cell and producing more stress. Instead, using the enzyme aldehyde dehydrogenase, acetaldehyde gives away electrons to form acetic acid and produces NADH from the excess NAD^+ (Pigeau, Bozza, Kaiser and Inglis, 2007). Once again, it is detrimental to winemakers when their icewine tastes like vinegar, however this is balanced by the desire to keep the yeast alive and able to complete the fermentation. Some yeast produce a lower ratio of acetic acid to ethanol, so these strains are most valuable for a quality icewine fermentation (Erasmus, Cliff and van Vuuren, 2004).

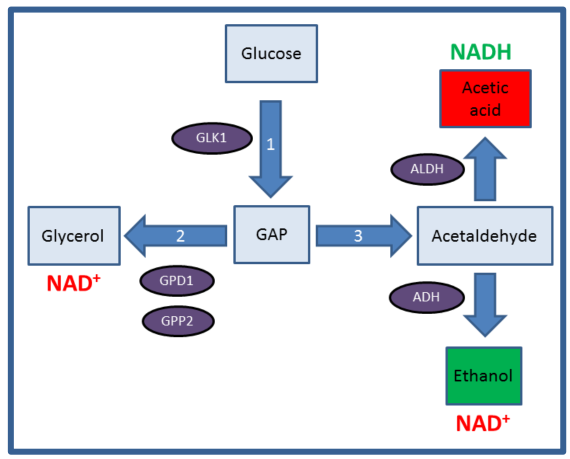

FIGURE 4: IMPORTANT PATHWAYS OF CARBOHYDRATE METABOLISM INVOLVED IN YEAST'S RESPONSE TO OSMOTIC STRESS. Pathway 1 is glycolysis, where glucose is broken down so that it may be oxidized for energy, using glucokinase (GLK1). One of the intermediate products of glycolysis is glyceraldehyde-3-phosphate (GAP), which may go on to several processes. Pathway 2 is glycerol production, which uses glycerol 3-phosphate dehydrogenase (GDP1) and glycerol-3-phosphatase (GPP2) to produced glycerol. Pathway 3 results in acetaldehyde, which will turn into either alcohol or acetic acid. Using alcohol dehydrogenase (ADH), the acetaldehyde may be converted into ethanol, a desired product. If aldehyde dehydrogenase (ALDH) is used the resulting product is acetic acid, which provides an unpleasant vinegar taste. NADH is also produced, and is necessary to the cell's survival. The glycerol and ethanol reactions produce NAD^+, which is overabundant in the cell. (Erasmus, Vandermerwe and Vanvurren, 2003).

The importance of these pathways is demonstrated by looking at the comparative expression of genes during osmotic stress, which may be up-regulated to increase, or down-regulated to decrease the activity of a pathway. The glycerol pathway is up-regulated through increasing expression of the enzymes glycerol-3-phosphate dehydrogenase and glycerol-3-phosphatase (Erasmus, Vandermerwe and Vanvuuren, 2003). Enzymes in the early steps of carbohydrate metabolism are also up-regulated, such as glucokinase, which enables the increased production of glycerol (Erasmus, Vandermerwe and Vanvuuren, 2003). Genes for acetic acid production are also up-regulated, resulting in an increase in the aldehyde dehydrogenase encoded by the ALD3 gene (Pigeau and Inglis, 2005). As mentioned above, this helps account for the large increase in acetic acid in icewine.

There are certain strains which are commonly chosen by winemakers to complete this arduous task, each with their own advantages and each leaving a signature on the final wine. The two main concerns in fermentation are producing sufficient glycerol, while still minimizing acetic acid (Erasmus, Cliff and van Vuuren, 2004). One type of yeast which possesses these characteristics is the commercial wine yeast strain, EC1118 (Galeote et al., 2010). Genomic analysis of EC1118 has shown several unique regions compared to other yeast strains. These genomic regions code for sugar transporters, and enzymes assisting with oxidative stress response (Novo et al., 2009). Due to these adaptations, EC1118 can survive in the high sugar environment during icewine fermentation, and efficiently complete the fermentation. This allows for improved wine quality demonstrated by studies which compare icewine produced by different yeasts. In a 2004 study comparing the glycerol, acetic acid, and quality of icewine fermented by several distinct yeast strains, EC1118 performed very well (Erasmus, Cliff and van Vuuren, 2004). Even in must with a very high sugar concentration, EC1118 was able to produce the required 11% alcohol without the fermentation getting stuck, or slowing down. This yeast was also able to produce a moderate amount of glycerol, sufficient to let the cell adapt to the high osmotic stress and allow for a fast rate of fermentation. EC1118 also produced a moderate amount of acetic acid, which is within acceptable legal and tasting limits of 1.3 g/L. As a result, EC1118 produced the experimental icewine with the highest perceived quality.

PUTTING IT ALL TOGETHER

After discussing the cellular mechanisms of how yeast respond to cellular stress, one may ask, how does this affect the production of icewine? Icewine producers such as Inniskillin and Jackson-Triggs must take special care when fermenting icewine must as it is prone to stuck fermentations, which produce unfavourable thiols that taste like rotten eggs or burnt rubber.

The first step that an expert winemaker may need to change is yeast acclimatization. Since commercial yeast is sold as active dried wine yeast, it is necessary to rehydrate the yeast. During rehydration yeast cells absorb almost all of the available water and dissolved nutrients. As the cells rehydrate, the cell membrane experiences a change of state to become more fluid. The main concern during rehydration is damage to the membrane as well as the loss of cellular components, both of which can kill a large number of cells (Kontkanen et al., 2004; Krieger-Weber, 2009). Winemakers can avoid this damaging process by having the sugar, trehalose present in yeast, and maintaining a temperature between 38-40 °C, helping yeast avoid this phase transition (Kontkanen et al., 2004).

Winemakers know though that this is usually not enough, as introducing the yeasts to a high sugar concentration overwhelms their osmotic stress coping mechanisms. Therefore, it is also advisable to do a stepwise acclimatization, rather than directly adding the yeast to the must, which contains 35% sugar. Instead the winemaker needs to create vats of diluted icewine must. This way yeasts are introduced to musts of increasing sugar concentration (Kontkanen et al., 2004). As much a specialty wine makers may wish, it is important to note that yeasts cannot acclimatize to all sugar concentrations. For musts with a concentration of sugar greater than 42%, the standard 10% concentration of alcohol cannot be achieved, and at 52.5% sugar, the must is theoretically non-fermentable (Pigeau et al., 2007). After the proper acclimatization has been carried out, the yeast are added to the icewine must.

Normally, the must is inoculated with 0.25 g/L of yeast, however to enhance performance in icewine fermentations doubling this is recommended, to 0.5 g/L of yeast (Kontkanen et al., 2004). The extra yeast make up for the ones that are lost due to the stressful conditions, and ensures that the fermentation completes.

CONCLUSION

In the developing field of icewine expertise, there is always room for improvement and still much to be learned. There are many challenges along the way to producing icewine, but the hardest workers are the yeast. *S. cerevisiae* is subjected to conditions of high osmotic stress, yet we still demand that they ferment the sugary must into ethanol quickly and without undesirable by-products. The yeast completes this task admirably using the genetically coded pathways that have been optimized over the course of their evolution. It is up to the human icewine producers to work just as hard as the yeast and manipulate the situation to produce the best icewine possible.

MORE TO EXPLORE

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(Wikimedia Commons, 2008)

Wine Barrels: Aging Through the Ages

Liming Chen, David Evans, Aaron Goldberg, Nicole Lindsay-Mosher & Aakash Shaw

The subtle, complex bouquet of a well-aged Chardonnay is a taste that many wine lovers appreciate and enjoy. However, the aging of white wines such as Chardonnay poses a challenge for winemakers; aging white wine in oak barrels can add complexity to the wine and smooth out undesirable flavours, but it can also add strong-tasting compounds that completely overpower the taste of the wine. Choosing the right type of barrel is critical to striking the perfect balance between full-bodied and disgustingly bitter. Several factors help to determine the taste of the wine, including the origin of the wood used in the barrel; French oak results in a more delicate taste, while American oak imparts stronger flavours. In addition, the barrel may help to preserve the flavour of a young wine if it has been used to store wine in the past, and well-toasted wood contributes more flavourful compounds than lightly-toasted barrel wood. Although the techniques used in barrel aging have been developed over hundreds of years, the future of winemaking may look very different. Artificial aging technologies have the potential to revolutionize the process of aging white wines, making the aging process faster, cheaper, and more effective. Ultimately, the many different factors that contribute to the process of barrel aging are what give rise to the variety of fine white wines available to the wine-loving consumer.

INTRODUCTION

7000 years ago, some grapes accidentally left in harvesting vessels fermented into a beverage that the inquisitive harvesters quite enjoyed (Chambers & Pretorius, 2010). This phenomenon was widespread; curious farmers such as these revolutionized the world.

Archaeologists have found that winemaking was quite advanced in Egypt by 3100 BCE, with at least 24 different types of wine. Depending on the type, wines were aged between two days and two decades in tall, ceramic jars (Rosso, 2012). Labelled for added value, fired for extra strength, and rope-slung for transportation ease, technologically advanced clay jars appeared in the 3rd millennium BCE as a means of transporting wine and other liquid commodities. By the 2nd millennium BCE, these "amphorae" became the standard vessel for carrying and storing wine throughout the Mediterranean region, due to the convenience of their production on a potter's wheel. This practice continued well into the Common Era, with standardization of amphora size and labelling. Large clay jars known as dolia were also used for wine fermentation, storage, and, with the increase in Roman demand for Mediterranean wines, transportation.

The Roman barrel slowly made its way into the wine transport industry, with the staves made of straight-grained woods such as pine and oak. By the early 16th century, wine was mostly shipped in wooden barrels, but upon arrival was immediately transferred into clay jars so as to return the barrels to the winemakers. By the end of the 16th century, clay jars once again dominated the wine transport business (Bevan, 2014). Over the next few hundred years, standard practice became that red wines be fermented first in a tank and later in a barrel, so as to maximize colour and tannin extraction from the grape skins, and white wines be fermented entirely in a tank (Hornsey, 2007). The aging process progressed towards the exclusive use of barrels, and eventually the range of aging periods narrowed from days-to-years to between three and eight months (Ortega-Heras, González-Huerta, Herrera and González-Sanjosé, 2004). Presently, various types of barrels undergoing different procedures during barrel formation are being introduced in a number of countries; scientists are beginning to realize that these all affect the quality of the wine produced.

WHITE WINES IN THE NIAGARA REGION

Although the history of winemaking in Ontario is relatively short, the Niagara Region has managed to distinguish itself on the world stage by producing fine white wines. The cool climate of the region allows wine grapes to ripen slowly and produce complex flavours, resulting in a unique bouquet of tastes and aromas in the finished wines (VQA Ontario, 2014). Most of the wines produced in Ontario are dry table wines, 60% of which are made from white wine grapes (VQA Ontario, 2014). Dry white wines can be sorted into four categories: neutral white wines, Chardonnays, Sauvignons, and aromatic white wines (Ribereau-Gayon, Dubourdieu, Doneche, & Lonvaud, 2006). Neutral white wines are typically refreshing and inexpensive, with few defining characteristics or interesting flavours; aromatic wines, by comparison, have complex fruity bouquets.

In the Niagara Region, the cool temperatures allow grapes to produce flavourless compounds that are converted to fruity-smelling esters by the yeasts during fermentation, resulting in excellent aromatic wines (Ribereau-Gayon et al., 2006). Unlike red wines, these aromatic wines do not benefit from aging in oak barrels, as the fruity flavours can often be lost during barrel aging. Chardonnays and Sauvignons, both of which are also produced by Ontario wineries, are the only dry white wines aged in oak barrels (Ribereau-Gayon et al., 2006). The range of techniques used to produce and age white wines contributes to the variety and uniqueness of the wines produced in the Niagara Region.

The aromatic white wines produced in Ontario are not aged in barrels, but they do undergo a long period of aging after fermentation. Many wineries in the Niagara Region, including Jackson-Triggs and Rosewood Estates, age their white wines in stainless steel (Merlaina, 2014; Roman, 2014). At the Jackson-Triggs winery, most white wines are kept for ten months in steel fermentation tanks, which are fitted with cooling jackets to keep the temperature low (between zero and 24 degrees Celsius, depending on how quickly the wine needs to develop). The capacity of the tanks can be adjusted during the fermentation and aging processes so that, as the volume of the wine changes, the volume of the tank changes accordingly (Figure 1). This minimizes the amount of oxygen that comes into contact with the wine (Merlaina, 2014). Although oxidation can help improve the flavour of some wines, oxidation of phenolic

FIGURE 1: AGING VESSELS. Stainless steel tanks and oak barrels for aging wine (Wikimedia Commons, 2009).

compounds by enzymes in the white wines tends to remove some of the fruity flavours. In addition, oxidation changes the colour of the wine from yellow to brown, making it look less appealing (Ribereau-Gayon et al., 2006). Unlike oak, stainless steel is inert and does not react with any compounds in the wines, allowing the aromatic white wines to retain their acidity and their delicate, fruity flavours.

The most notable exception to the practice of aging white wines in stainless steel is Chardonnay. Even compared to Sauvignon grapes, Chardonnay grapes have a strong flavour and possess high levels of acid and sugar. The high sugar content results in a relatively high alcohol concentration post fermentation, a factor that, when combined with the acidity of the wine, allows for optimal extraction of flavours from oak barrels. The flavours in the wine are not overpowered by those extracted from the barrel wood, so the process of aging in oak barrels adds complexity to the wine. Even so, Chardonnays are usually aged in barrels that have already been used to age wine, a factor that helps to keep the oaky flavours more subtle.

Used barrels are also ideal for the aging of icewine, a type of wine that is a specialty of the Niagara Region. Icewines, which are produced from grapes frozen in the fields, are incredibly sweet and tart. The award-winning Vidal icewine produced by the Peller Estates winery in Niagara-on-the-Lake is aged for four months in French and American oak, a process that helps to smooth out the acidity, and adds butterscotch and marmalade flavours to the wine (Peller Estates, 2013). The type of barrel in which white wines are aged must be selected carefully in order to introduce the desired flavours to the wine, while preventing chemical reactions that could spoil the taste of the finished product.

FACTORS AFFECTING BARRELS IN THE AGING PROCESS

The barrels used for the aging process are highly dependent on their treatment from where the oak is grown to the final seasoning and toasting of the oak (Cerdán, 2002). The treatment of the barrels determines the various levels of the flavonoids and volatile compounds present in wine, which in turn influence the taste and aroma of the wine. These include chemicals such as furfural, which provides an almond aroma; lactones, which produce coconut and oak aromas; ellagitannins which determine bitter and astringent flavor, and vanillin and syringaldehyde, which provide vanilla odours (Cerdán, 2002; Sáenz-Navajas et al., 2010). The process of aging releases these contents into the wine at various rates, making the length of aging a major factor in the final composition (Rous and Alderson, 1983). Finally, the type of barrel also determines the amount of oxygen present which as mentioned, is needed at different amounts depending on the type of wine. In addition, the type of barrel used, the processes of toasting and seasoning, and the number of prior uses all play different roles in the regulation of volatile compounds released into, and levels of oxygen available to react with, the wine.

Types of barrels

The use of different oak species produces different interactions with the wine, depending on the oak's chemical structure. The chemical structure is governed by the region in which the wood is grown and the treatment it undergoes. This is important in governing the amounts of the aforementioned flavonoid and non-flavonoid chemicals released from the barrel to the wine (Chira and Teissedre, 2014; Rous and Alderson, 1983). These chemicals either contribute directly to the flavour and aromas of the aged wine, or act as precursors for subsequent oxidation reactions that form flavourful and aromatic chemicals in the wine.

The three most commonly used oaks are of French and American origin. *Quercus robur* and *Quercus sessilis* are of French origin, while *Quercus alba* is of American origin (Cerdán, 2002). The differences in climate and soil conditions where the trees are grown cause alterations in the chemical composition of each species' cells (Rous and Alderson, 1983). In addition to the different growing regions, the treatment of the oak is different between French and American wood, which also plays a significant role in differentiating between their effects on wine (Chatonnet and Dubourdieu, 1998; Garde-Cerdán and Ancín-Azpilicueta, 2006; Grainger and Tattersall, 2008). French wood is split vertically down the grain to create barrel strips in order to maintain the outer grain integrity and a tight-grained texture (Chatonnet and Dubourdieu, 1998; Grainger and Tattersall, 2008). The tight grain size helps maintains small pores between oak grains, which reduce the amount of evaporation of wine, increase water retention, and control the exposure to oxygen during the aging process (Roman, 2014). American oak differs from its French counterpart in that it is sawed, which breaks the grains to produce coarser grain sizes and larger pores (Chatonnet and Dubourdieu, 1998; Grainger and Tattersall, 2008). A comparison of the cutting techniques can be seen in Figure 2. The effects of these different procedures is still being investigated; however, it is speculated that the higher water retention and reduced oxygen in French oak allows them to preserve soluble ellagitannins until they are extracted by the wine during the aging process (Chira and Teissedre, 2014).

American oaks are found to produce richer amounts of cis- and trans-b-methyl-g-octalactone and various phenolic compounds (Ortega-Heras et al., 2004; Towey and Waterhouse, 1996). For the oak lactone, cis- concentrations are much higher in American oaks than French, which provides wine with a greater oak or coconut sensation (Ortega-Heras et al., 2004). This is more common for red wines than white wines. White wines tend to elicit higher levels of terpenoids and ethyl cinnamates, producing more fresh, floral, and cinnamon aromas (Sáenz-Navajas et al., 2010). Low oxygen is the key to maintaining these fruity and floral aromas in white wines, making white wine production highly dependent on the choice of the barrel (Garde-Cerdán and Ancín-Azpilicueta, 2006).

White wines are ideally less altered during the aging process than red wines. Thus, to limit their oxygen exposure, French barrels are more commonly used, as well as barrels that have been used multiple times, which will be discussed further on (Cerdán and Ancín-Azpilicueta, 2006; Rous and Alderson, 1983). For example, Chardonnays are aged in French barrels, and tend to exhibit the fruitier and sweet flavours that occur in wines fermented from white grapes and aged with little to no oxygen exposure (Sáenz-Navajas et al., 2010; Towey and Waterhouse, 1996). The oxygen limit reduces various phenolic compounds, which are primarily responsible for the bitter taste in red wines, from being released from the barrel into the wine (Chira and

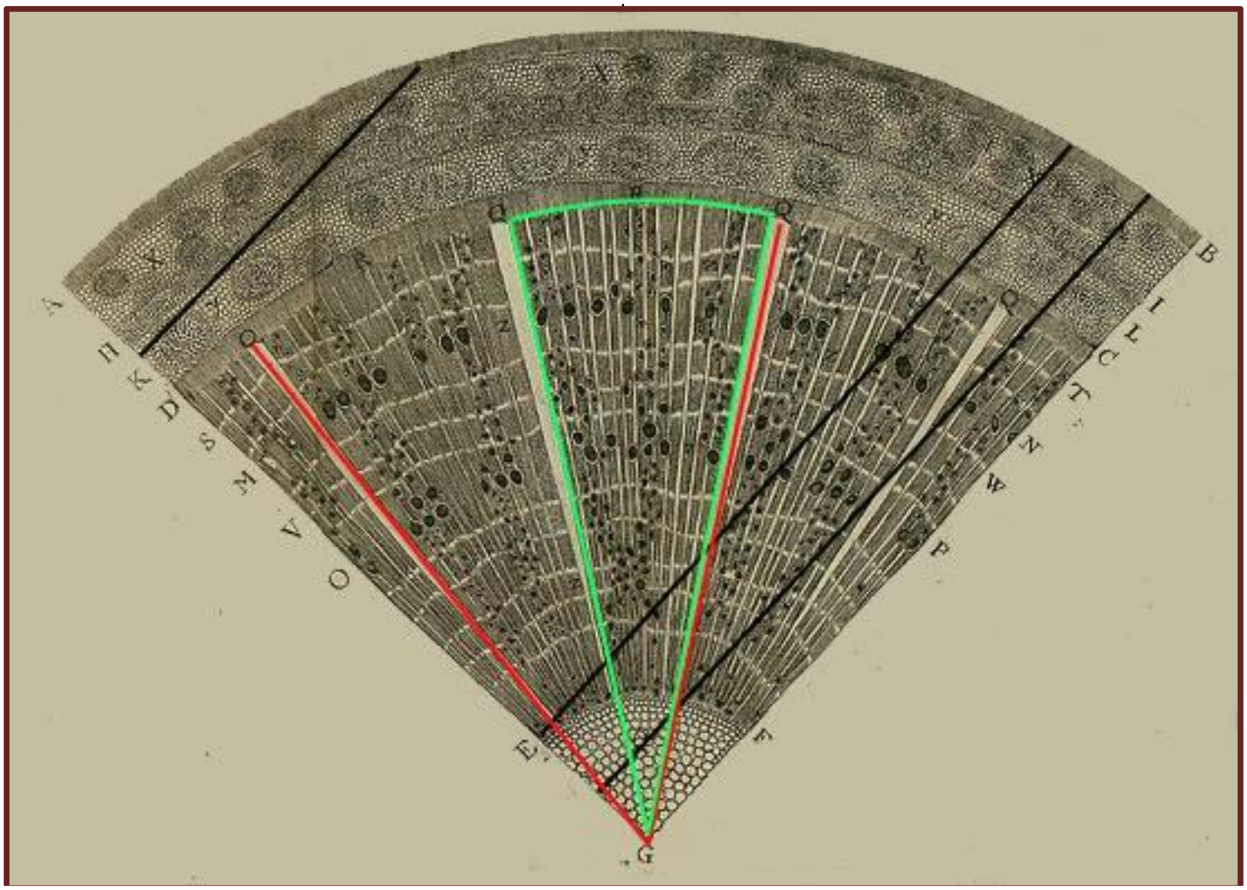

FIGURE 2: OAK CUTTING TECHNIQUES: SPLITTING VS. SAWING. This image shows the difference in cutting areas between splitting and sawing. The grains are represented by the area within the green lines. Splitting is shown in red, the cuts are made down the Q areas between grains of the oak. Sawing is displayed in black. It can be seen that the black lines intercept the grain areas, disrupting the structure of the oak, leading to larger pore formation (modified from Grew, 1675).

Teissedre, 2014). This oxygen limitation preserves the natural flavonoids released from oak barrels (Sáenz-Navajas et al., 2010). Later in this article, we will see how older barrels can also be used to limit oxygen interaction in the process of white wine aging. The differences in types of chemicals retained through different treatment methods suggest that there are other factors outside the method of cutting that regulate the amount of chemicals. These factors may include the toasting treatment used in the barrel processing.

Toasting

The degree of toasting on the wood used in wine aging has a direct impact on the breakdown, extraction, and formation of volatile compounds in wine from the oak wood. These different concentrations of compounds influence the aroma, appearance, and the taste of wine (Chatonnet P, 1999). Generally, the concentration of volatile compounds in wine increases as the degree of toasting increases from lightly toasted to medium toasted, including compounds such as vanillin, furfural, phenol, and oak lactone. The increase is less substantial when the toasting level further increases from medium to high (Chatonnet P, 1999).

Wine aged in normal French or American oak barrels tends to be clear or red colour in appearance. White wines tend to have fruity aromas and tastes. In the case of wine that is aged in oak with a *light* degree of toasting, there is usually a coconut-like aroma, a sweet taste, and a somewhat purple colour (Koussissi E et al, 2009).

The effect of toasting is most noticeable when the oak is toasted to a *medium* degree. These wines appear to be brown in colour, with a mix of earthy, nutty, vegetative, smoky, spicy, and even woody aromas. They often leave a bitter and astringent taste in the mouth after drinking (Koussissi E et al, 2009). As the level of toasting increases to a *high* toasting level, the wine tends to have even nuttier aromas and earthy flavours. The colour also darkens, and can even appear to become black (Koussissi E et al, 2009).

Ellagitannins are extracted from the oak wood to the highest extent in medium toasted oak. This leads to a bitter taste and astringent mouth feel after drinking. It has also been found that furfural and cis oak lactone are present at the highest concentrations in medium toasted oak, followed by light toasted oak, then highly toasted oak, and lowest in untoasted barrel-aged wine (Koussissi E et al, 2009). The presence of cis oak lactone produces wine with a smoky, oaky, and woody aroma and taste. In lightly toasted oak, cis oak lactone is found in very low concentrations; however, there is a high concentration of trans isomers of oak lactone. This is what makes the wine taste and smell like coconut (Koussissi E et al, 2009).

New versus used barrels

As mentioned previously, the number of times a barrel is used ultimately affects the levels of the different volatile compounds that are contained within the barrel wood. Each volatile compound contained in barrel wood has a unique concentration with a finite level. Every time a barrel is used for aging, volatiles are leached from the wood to the wine, so it is intuitive to expect a decrease in the volatile levels of the wood with increasing barrel age and use (Garde-Cerdán and Rodríguez-Mozaz and Ancín-Azpilicueta, 2002). However, the levels to which different volatiles are observed to diminish vary, with different compounds showing different amounts of leaching. For example, certain compounds, such as phenols and furfural, are seen to decrease significantly with barrel age. In contrast, other compounds, such as oak lactones, are exhausted far less significantly with increased barrel age. Regardless of the variation between the leaching levels of different volatiles, it is well-established that the amount of volatile transfer to a wine is less significant with an older, used barrel than a new barrel (Garde-Cerdán and Ancín-Azpilicueta, 2006).

Knowing that volatile oak compounds levels decrease with age makes the barrel age a crucial factor to consider when selecting a barrel for aging. A wine aged in a new barrel is expected to contain greater levels of volatiles that were present in the oak due to the toasting of the barrel wood than a wine aged in a barrel that has been previously used 3 or 4 times. It should be noted that certain compounds can still be extracted from older barrels in significant levels if a sufficiently long aging period is used. For example, oak lactones and other oak-based volatiles can show a similar level of accumulation from an older barrel compared to a new barrel, if a wine is aged for a significant period in the used barrel (e.g. 15 months). This is due to certain compounds being prevalent throughout barrel wood, and therefore being present in deeper layers of the wood, which can experience leaching after the initial layers are depleted of volatiles (Tao and Garcia and Sun, 2014).

A winemaker desiring high levels of certain volatiles, for example those introduced through toasting, will therefore need to select a newer barrel to ensure that the wine produced acquires sufficient volatiles levels to produce the desired characteristics . If, however, the winemaker desires a wine with characteristics that are not induced through non oak-based volatiles, it is possible for him/her to age the wine in older barrels, which show a decreased level of initial volatile accumulation (Tao and Garcia and Sun, 2014). Ultimately, barrel age contributes to the characteristics of a wine, because it limits volatile transfer, and so should be taken into account when selecting a barrel.

General practice for the aging of white wines, both within and outside of the Niagara Region, is to conduct aging within stainless steel tanks, as opposed to oak barrels. This is likely due to winemakers wanting to avoid the transfer of certain volatiles to their white wines. However, with the understanding that transfer of many volatiles decreases with increasing barrel age, it could be possible to avoid such unwanted transfers by selecting a barrel of sufficient age. Therefore, the use of older, volatile-leached, barrels could be proposed for the aging of white wines by winemakers for certain varietals. This practice of using old barrels for white wine aging is one that is indeed upheld by certain winemakers within the Niagara Region (Merlaina, 2014). The decision of whether or not to age in barrels ultimately depends on the preference of the winemaker, and there is evidence of a variety of decisions being made regarding the practise of using older barrels for white wine aging within the Niagara Region.

FUTURE DIRECTIONS: ARTIFICIAL AGING

Some scientists claim that the roots of biotechnology lie with the first winemakers (Buchholz, 2013; Chambers and Pretorius, 2010). From the dawn of experimentation in the 5th millennium BCE, with the testing and recording observations of different vintages, to the discovery of enzymes within yeast cells by Pasteur while studying the fermentation process, winemaking has always been on the cutting edge of science (Chambers and Pretorius, 2010). Regarding the yeast strain responsible for wine fermentation, it is no wonder that "we know more about this humble eukaryote than any other organism on the planet" (Chambers and Pretorius, 2010), as humans constantly attempt to optimize the winemaking process. Modern scientific techniques seem to be leading to a world in which it will be feasible to perform the entire wine aging process artificially.

Artificial wine-aging first appeared in the ancient Roman fumariums, houses in which amphorae and/or casks of wine were suspended over rustic baths, such that periodic additions of extra heat and vapour to the casks accelerated the desiccation and maturation of the wines (Barry, 1775). This was noted to impart the smoky flavour and pale colour of aged wines (Sarfaraz K. Niazi, 2012).

In more modern times, artificial aging with oak chips has become increasingly prevalent. Because the surface area between the oak and the wine seems to be the limiting factor in aging reactions, the aging process can be quickened by adding many small pieces of oak into a container of wine. In one study, it only took 5-6 days in wines treated with oak chips to get concentrations of compounds such as furfural similar to those in wines fully aged in oak barrels (Arapitsas, Antonopoulos, Stefanou and Dourtoglou, 2004). In another, polyphenol, resveratrol, and catechin concentrations in red wines aged with oak chips for 10 days matched the levels found in barrel-aged red wines (Gortzi, Metaxa, Mantanis and Lalas, 2013). Further, the artificially aged wines' sensory profiles noticeable increased in this short time (Gortzi et al., 2013). This effect has been sufficiently successful that methods of delivering powdered wood chips to wines for aging are highly coveted (Sarfaraz K. Niazi, 2012).

Another artificial aging method that is gaining popularity is micro-oxygenation. Micro-oxygenation simulates the barrel aging process by providing the wine with a low, continuous amount of oxygen for an extended period of time, mimicking the oxygen flow through the barrels (Caillé, 2010). This highly controlled method has been shown to improve the colour quality, fruity flavour, and phenolic content of red wines (Caillé, 2010). When done in tandem with oak chip aging, wines became noticeable softer, with beneficial increases and decreases in a wide variety of compounds (McCord, 2003). One drawback of this method is that the increased colour intensity conferred by micro-oxygenation deteriorates more quickly than similarly-coloured wines aged in barrels (Cano-López, López-Roca, Pardo-Minguez and Gómez Plaza, 2010). As a whole, micro-oxygenation promotes a fair number of the reactions catalyzed indirectly by oak barrels.

Many other methods of artificial aging are being tested and implemented. One method uses the application of ultrasonic waves to promote the equivalent of one year of aging in less than a week (Chang and Chen, 2002). Particularly in rice wine, this has been shown to reduce acidity, decrease alcohol degree to a level similar to normally-aged wine, decrease the acetaldehyde content, and improve the taste of wines subjected to the treatment. Ultrasound treatment has had mixed reviews, because its effects are highly dependent on the type of wine (e.g. rice vs. red, white, etc.) being studied (Chang and Chen, 2002).

Another method uses high-voltage, alternating current fields to accelerate the aging reactions of wines. This method is used in a number of Chinese wineries as a way of making fresh wines less extreme, and has been shown to significantly improve wines' tastes when applied at the optimum level for the correct amount of time (Zeng, Yu, Zhang and Chen, 2008).

Similarly, one last method involves the application of a pulsed, lower strength, electric field to the wine. This method has been shown to produce similar organic acid content to bottle-aged wines of both red and white varieties, with white wines requiring less strong fields than red wines (Wang, Su, Zhang and Yang, 2013). With all of these developing technologies, it seems inevitable that, in the future, it will be possible to purchase a bottle of wine that has been produced entirely artificially.

CONCLUSION

The process of aging white wines in barrels has come a long way. Since their early use as mere transport vessels, barrels have been extensively studied in order to optimize the winemaking process. Factors including location of wood origin, degree of wood toasting, and barrel age have all been shown to influence the concentrations of chemicals found in wines, which in turn dramatically affect wine character. In the Niagara Region, winemakers have used this research to select the optimal conditions for white wine aging, in either stainless steel tanks or older oak barrels. Further research hints at the potential to drastically improve the aging process by taking advantage of artificial aging methods. Taken in tandem, the aging of white wines is an involved process that yields measurably delightful results, the likes of which can be expected to improve even further in the future.

MORE TO EXPLORE

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The DaVino Code: Demystifying the Taste of Red Wine

Mankeeran Dhanoa, Jenin El-Sayes, Shawn Kurian, Geneva Neal, Alan Zhou

For thousands of years, people have been fascinated by the characteristics of red wine, such as astringency and bitterness. In order for us to appreciate the complexities underlying these characteristics, it is important to understand how the chemicals in red wine interact with our saliva. Moreover, there are many factors that can influence winemaking to create different experiences in perception for each individual. These factors need to be considered by Niagara winemakers if they wish to produce wines with unique tastes that set them apart from competitors.

What if we told you this glass of wine is drying, but full-bodied and bitter? Or that its mouthfeel is astringent and sharp? Does that mean anything to you?

Wine tasting is often considered the exclusive domain of sommeliers and winemakers because the jargon has quite a learning curve and taking part in wine tasting can be intimidating for those who lack experience (Figure 1). Upon tasting wine, most connoisseurs look for main characteristics such as sweetness, acidity, bitterness, tannins, fruitiness, and body (Puckette, 2012). Most of these characteristics are likely familiar to readers from personal experiences with other foods and beverages. Tannins, however, are often misunderstood. What does it mean for a wine to have high or low tannins? In fact, what are tannins and what is their role in wine?

The sensation associated with tannins, a subclass of a larger family of molecules called phenolics, is known as astringency. Astringency is the puckering feeling that causes our mouths to feel dry and is often confused with bitterness. Tannins are often uniquely associated with red wine in particular, but they are also present in other drinks such as tea (Puckette, 2013). Like astringency, phenolic compounds can also induce bitterness, which is a widely recognized flavour. However, unlike astringency, bitterness is described as a sudden, sharp, and unpleasant taste (Purves, et al., 2001).

In this article, we will discuss how the chemical nature of red wine creates the sensations of astringency and bitterness. In addition, we will look at the factors that can influence winemaking to create a different experience in perception.

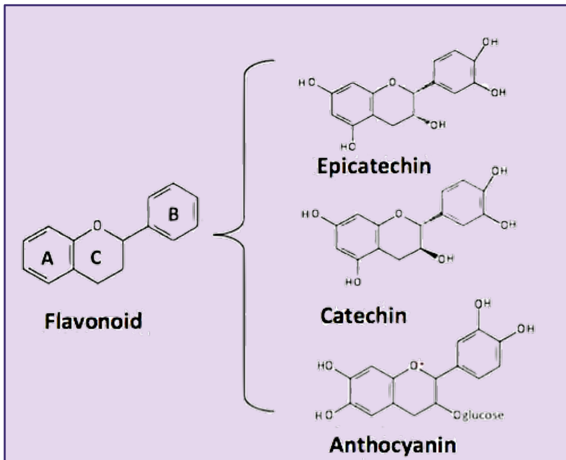
FIGURE 1: JARGON USED IN WINE TASTINGS.

But, why is this important? Understanding the molecular and biological basis of red wine's distinct taste characteristics, like astringency and bitterness, is necessary in order to tailor a wine according to consumers' tastes. Also, appreciating the complex interaction of molecules with the saliva, taste buds, and perception of the individual will help improve the tasting experience. This is especially beneficial for the Canadian wine industry, as it is growing and continuing to build both its domestic and international reputation. Ontario, and Niagara in particular, are responsible for the highest wine production in the country, with Ontario producing nearly twice as much wine as the second largest wine producer, British Columbia (Frank, 2013). However, environmental and geographical constraints limit the ability of Niagara wineries to compete with the international market, as large-scale production in Niagara is hindered by its cool climate and limited viable land (Agriculture and Agri-Food Canada, 2014). It is therefore advantageous for Niagara winemakers to concentrate their efforts on personalizing wines for consumer groups rather than large-scale mass production. For Niagara wine to stand out from the competition, winemakers must apply the science behind taste to finely manipulate their wines into premium products. This all starts with understanding the chemical basis of red wine.

WINE CHEMISTRY: A BRIEF OVERVIEW OF PHENOLICS

Phenolics are a diverse family of chemical compounds that contribute to the characteristic flavour, aroma, and appearance of red wine. Produced naturally at the onset of ripening within all varietals, phenolics can be found within the grape and are directly involved in the extraction and fermentation of red wine (Kennedy, Saucier, & Glories, 2006). In fact, without phenolics the aroma, colour, taste, and experience of drinking red wine would simply not be the same. Although phenolics make up a majority of the chemical composition of the grape, the distribution of these compounds differs between the skin and flesh components. The skin is rich in phenolics such as tannins, as well as pigmented anthocyanins that give red wine its robust colour. On the other hand, the flesh lacks anthocyanins and is colourless. It instead stores other phenolics like flavan-3-ols, in addition to tartaric and malic acids (Polášková, Herszage, & Ebeler, 2008).

In the midst of the chemical complexity of red wine, we have chosen to focus our discussion of phenolics on three in particular: flavan-3-ols, anthocyanins, and tannins. Collectively, these three phenolics impact astringency and bitterness in red wine, which are two key indicators of quality. Even though this has been widely acknowledged by winemakers and connoisseurs alike for decades, the mechanisms underlying these characteristics are not common knowledge (Kennedy, et al., 2006; Moreno-Arribas, Polo, & Carmen, 2009). In order to understand how flavan-3-ols, anthocyanins, and tannins play an important role in modulating astringency and bitterness, we must begin our search with their associated chemistry. Although they are broadly classified as phenolics, each of these three compounds can be further categorized as flavonoids since they share a common chemical structure. Each compound is distinguished from one another by the presence of a unique chemical group on this structure (Moreno-Arribas, et al., 2009).

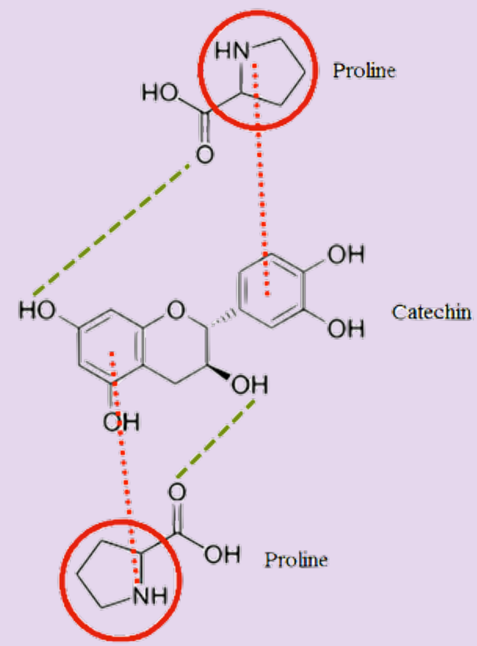


DID YOU KNOW…? STRUCTURES OF FLAVONOIDS. Flavonoids share a common chemical structure consisting of two aromatic rings (A, B) and a heterocyclic ring (C). Flavan-3-ols such as epicatechin and catechin have multiple oxygen-containing chemical groups called hydroxyl groups (OH). Anthocyanins have a glucose sugar attached instead at that position (Adapted from Moreno-Arribas, et al., 2009).

Flavan-3-ols have multiple oxygen containing chemical groups and link together to form tannins. These flavan-3-ols can take on two alternate orientations in red wine, termed catechin and epicatechin. Whereas catechin is present at a higher proportion in red wine and is believed to add a perceived fullness to its flavour, epicatechin is present in smaller amounts and is rather bitter (Kennedy, et al., 2006). In contrast, pigmented anthocyanins have a sugar molecule attached to the flavonoid chemical structure, and do not form large chains like flavan-3-ols. It is the unique chemical structure of these three phenolics that allows them to generate two types of chemical interactions. They can form neutral interactions that are classified as non-polar, as well as interactions that are chemically charged and polar. Together, these two types of interactions facilitate the experiences of astringency and bitterness when drinking red wine. Nonetheless, a chemical understanding of phenolics alone is not sufficient to explain how the phenomenon of taste occurs. As a matter of fact, this only extends our investigation of astringency and bitterness into the realm of biology and a discussion of something quite familiar to us – saliva (Moreno-Arribas, et al., 2009).

WHAT HAPPENS WHEN WE TAKE A SIP OF WINE?

Equipped with an understanding of the compounds in red wine, we are now ready to take our first sip of wine. Upon entering our mouths, the first point of contact for the phenolics is the proteins in our saliva. Our saliva contains hundreds of proteins that are important in the way we taste food. Most of these proteins are known as proline-rich proteins (PRPs) because they are abundant in the amino acid proline (Canon, et al., 2013). The prolines on the PRPs are involved in the interactions between phenolics in wine and the PRPs in our mouths that together create the taste experience of red wine.



DID YOU KNOW…? INTERACTIONS BETWEEN PRPs AND PHENOLICS. Prolines of PRPs initially interact with the ring structures in phenolics (red dotted lines) because they are both non-polar. Additional polar interactions (green dotted lines) between the hydroxyl (OH) groups in phenolics and the carbonyl (C=O) groups of prolines further strengthen these interactions (Adapted from Edgar181, 2009; NEUROtiker, 2007).

Initially, phenolics only weakly bind to the prolines within salivary PRPs to form protein-phenolic complexes. These complexes are soluble in saliva. Both the phenolics and the prolines of PRPs are non-polar and neutral in charge, and will prefer to interact with each other. Next, much like a snowball effect, adjacent protein-phenolic complexes slowly begin to attract each other and aggregate to form larger, insoluble complexes. As these complexes grow, they eventually precipitate out of our saliva to produce thousands of microscopic particles that fill our mouths (Figure 2) (Charlton, et al., 2002). These tiny particles rub against the inside of our mouths, constituting a fundamental step in the perceptions of astringency and bitterness in wine.

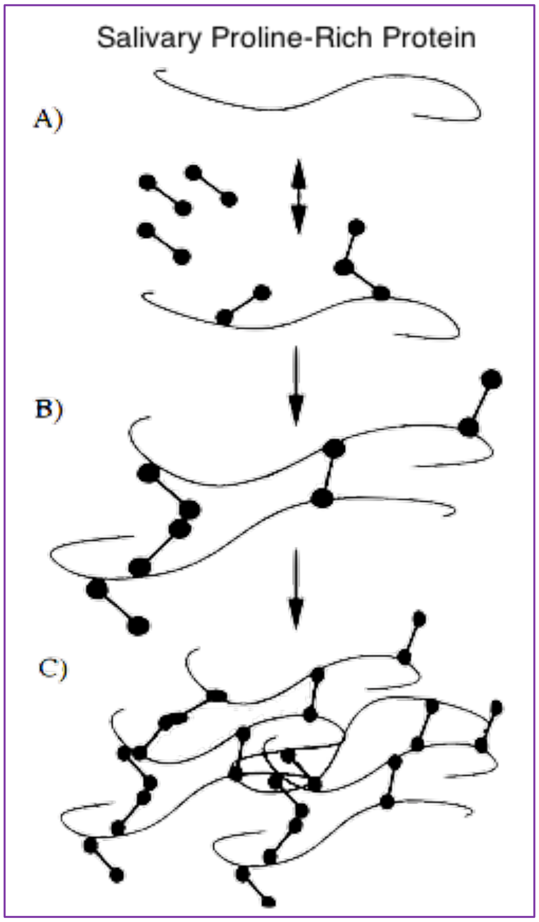


FIGURE 2: THREE STAGES OF PROTEIN-PHENOLIC COMPLEX FORMATION. A) Phenolics initially associate with PRPs through non-polar interactions to form soluble protein-phenolic complexes B) Phenolics begin binding to phenolics on adjacent PRPs, effectively linking the complexes together to become insoluble C) The complexes eventually precipitate out of solution when they further aggregate together (Adapted from Charlton, et al., 2002).

HOW DO OUR BRAINS PERCEIVE THESE INTERACTIONS AS TASTE?

Now that we are familiar with the protein-phenolic interactions that happen in our mouths, it is important to understand how these interactions contribute to the unique experience of drinking red wine. Our brains play a vital role in creating the experience of wine tasting, influenced by both the chemical interactions of phenolics with proteins and our own previous experiences. To look at the experience of wine tasting, we must consider the mechanisms underlying the perception of astringency and bitterness in the brain.

Let us first discuss the two current theories for the mechanism of astringency perception. The first theory is that astringency is a tactile sensation, experienced by specific touch receptors in our mouths called mechanoreceptors (Lesschaeve & Noble, 2005). This theory claims that the microscopic protein-phenolic complexes precipitate out of saliva and strip away the salivary film, resulting in less lubrication and thus greater friction that activates these mechanoreceptors. Once activated, the mechanoreceptors send a signal that triggers the perception of astringency in the brain (Ma, et al., 2014; Rinaldi, Gambuti, & Moio, 2012; Schöbel, et al., 2014). The second theory is that astringency is a taste sensation, as seen in mouse studies where phenolics appeared to activate taste nerves. In addition, scientists have discovered that phenolics activate ion channels in our mouths to elicit a taste, in a manner similar to bitter flavour compounds (Bajec & Pickering, 2008). Given these two contradicting theories, researchers today are exploring the novel idea that astringency may be a product of both taste and tactile sensations. It is possible that phenolics are not exclusively detected by taste receptors, but also activate tactile mechanoreceptors to produce the overall experience of astringency (Schöbel, et al., 2014; Bajec & Pickering, 2008).

Contrary to astringency, the mechanisms underlying bitterness perception are well established (Figure 3) (Purves, et al., 2001). When we drink red wine, the phenolics bind to bitter taste receptors on our tongues, called G-Protein Coupled Receptors (GPCRs). This triggers a signal cascade in the taste cell resulting in the release of calcium ions within the cell. Additionally, sodium ions enter the cell through sodium ion channels. The combined effect of the sodium and calcium ions causes the taste cells on our tongues to activate and send a nerve signal to our brains, allowing us to recognize the bitter tastes (Kinnamon, 1996; Huang, et al., 2007).

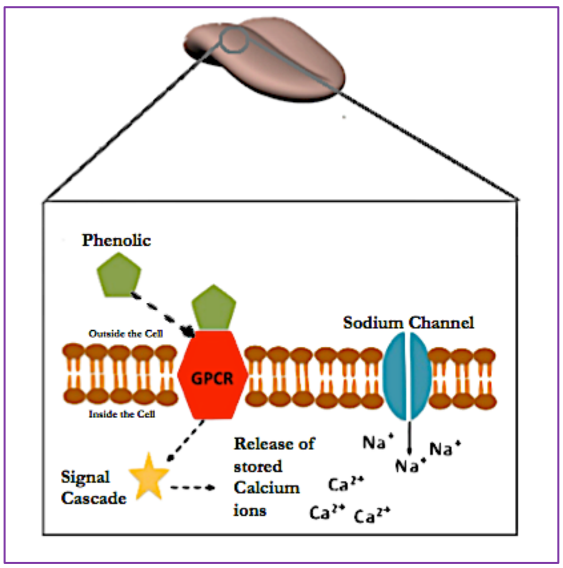


FIGURE 3: MECHANISM FOR PERCEPTION OF BITTERNESS. Phenolics bind to a taste receptor (GPCR) on the tongue, activating a signal cascade, resulting in release of stored calcium ions and sodium ions entering the cell, and ultimately activating the taste cell (Adapted from Ma, et al., 2014).

WHY DO WE TASTE DIFFERENTLY?

Although the biological mechanisms underlying astringency and bitterness perception are the same among individuals, we differ in our personal experiences of wine tasting. For example, some people describe Pinot Noir as having a tobacco flavour while others claim it tastes more like vanilla. These differences are due to a variety of factors including salivary flow rates, genetics, and culture.

People differ in the amount of saliva they produce, and scientists have characterized salivary production into categories. For instance, people with lower salivary production are classified as low-flow individuals, and those with higher salivary production are high-flow individuals. Experiments have demonstrated that low-flow individuals perceived astringency later, for a longer duration, and more intensely compared to those that are medium- or high-flow (Lesschaeve & Noble, 2005). Recall that astringency may be perceived when saliva is stripped off our tongues. With this in mind, a possible explanation is that high-flow individuals are better able to restore saliva due to their greater saliva volume, thus they perceive astringency less intensely (Bajec & Pickering, 2008). Contrary to astringency, high-flow individuals experience a stronger intensity of bitterness more quickly, however the sensation has a shorter duration than low-flow individuals (Noble, 1998).

As with many other sensations, our genetics also play a role in how we perceive different flavours or mouthfeels. We all have 25 different bitter receptors, however our genes lead to variations from person to person. Therefore, many of us may have different bitterness sensations and taste preferences (Hayes, et al., 2011). In addition, culture plays a role in how we experience wine by influencing individual behaviours, communication, taste preferences, and wine practices (Mouret, et al., 2013). Cultural tastes are established at a young age and tend to be reinforced through familial and social interactions, thereby becoming familiar to us (Cervellon & Dubé, 2005). Relying on this familiarity, we tend to favour wines that have a similar flavour profile to our own ethnic cuisines (Sáenz-Navajas, et al., 2013). As well, a culture's history with wine can affect an individual's wine practices, which can in turn affect wine tasting experiences. For example, in the West, tasting wine is usually more analytical and includes observation of colour and inhalation of aroma. The purpose is to enjoy the wine and take pleasure in tasting it. On the other hand, in China, wine is used as a tool of communication rather than for personal pleasure (Mouret, et al., 2013). For example, wine is an essential aspect in conducting commerce as business transactions are sealed by a toast, and refusing such a toast could result in a lost deal. Due to the different uses of wine, many of the flavours known to Western winemakers do not exist in the East. Collectively, these aspects of culture can either limit or expand an individual's vocabulary when describing taste, and their ability to compare and contrast flavours. This accounts for the variation observed across the population in their preferences for certain red wines. However, there also exists another dimension in our discussion of variation that lies in the hands of the winemaker.

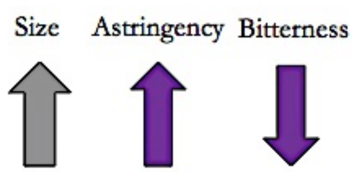
VARIABLITY IN RED WINES: WHY DO THEY ALL TASTE DIFFERENT?

While understanding the role of genetics and culture may help winemakers cater to different consumers, they do not provide winemakers with a method for directly altering the characteristics of their wine. To do so, winemakers must understand the role that factors such as phenolic size, acidity, sugar, and ethanol play in the sensory profile of wines. The winemaker with an extended knowledge of these factors will possess a competitive advantage over their fellow winemakers, as they would be able to subtly alter their wines to create unique identities. Such an ability is an asset especially for winemakers in the Niagara region where establishing an identity is important for gaining a reputation in the international market (Moreno-Arribas, et al., 2009; Pereira, et al., 2009).

One intrinsic factor that influences astringency and bitterness is the size of the phenolic compounds in wine (Ma, et al., 2014). In general, scientists have found that larger phenolics resulted in increased astringency and decreased bitterness of red wine (Figure 4) (Peleg, et al., 1999). This is because larger phenolics bind more strongly to salivary proteins, but are too bulky to effectively interact with bitter taste receptors (Ma, et al., 2014; Peleg, et al., 1999). Knowledge of how phenolic size influences the taste of wine can help winemakers design strategies to complement the intrinsic characters of their wine. These strategies require an understanding of how factors such as acidity, sugar, and ethanol can impact taste.

We examined trends across multiple studies that altered these three factors in red wine to observe their impact on taste attributes. Many findings suggest that an increase in acidity resulted in a greater perception of astringency, with no impact on bitterness. In contrast, an increase in sugar and ethanol content dampened astringency perception while having an opposing effect on bitterness. Whereas an increase in ethanol heightened the sensation and duration of bitterness, sugars tended to reduce it (Figure

5) (Demiglio & Pickering, 2008; Fontoin, et al., 2008; King, Dunn, & Heymann, 2013).



Data from a study conducted on the relationship between the size of the molecule and the perception of astringency and bitterness:

	Intensity (0-600)	
Size of Molecule	Astringency	Bitterness
Monomer	310	490
Dimer	400	400
Trimer	410	360

FIGURE 4: RELATIONSHIP BETWEEN PHENOLIC SIZE, ASTRINGENCY, AND BITTERNESS. As the size of the phenolic increases (monomer to trimer), the perception of astringency increases while that of bitterness decreases (Adapted from Peleg, et al., 1999).

To explain these trends, it is thought that an increase in acidity creates a favorable environment that enhances the formation of protein-phenolic complexes. This increases the rate by which the salivary film is removed and causes an increase in astringency perception (Brouillard & Dubois, 1977). On the other hand, the opposing effect of sugars, such as sucrose, on perception of bitterness and astringency is likely due to its relatively small size. The chemical nature of sucrose allows it to more easily interact with salivary proteins than large phenolics. Since the interactions between sucrose and the salivary proteins are more favorable, the protein-phenolic complexes do not form as effectively to produce astringency (Rinaldi, et al., 2012). Sucrose also functions to decrease bitterness, as sweetness and bitterness are opposing tastes. Finally, ethanol is known as a bitter compound, and it stimulates receptors to produce bitterness. In addition, ethanol is able to disrupt protein-phenolic complexes by a similar method to sucrose. It does so by preventing the proper folding of the salivary proteins, thus hampering their interactions with phenolics (Demiglio & Pickering, 2008).

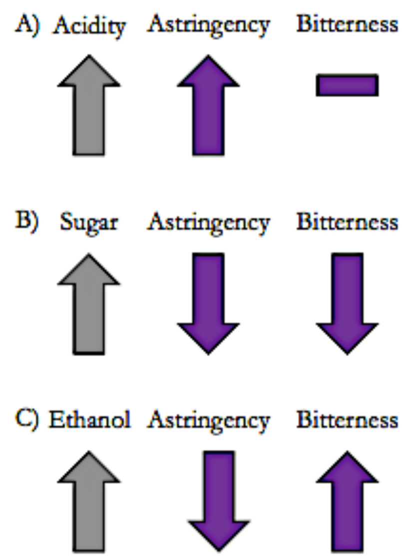
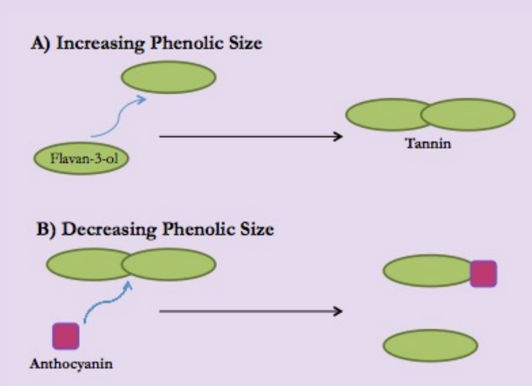


FIGURE 5: EFFECTS OF ACIDITY, SUGAR, AND ETHANOL ON ASTRINGENCY AND BITTERNESS. A) As acidity increases, astringency increases with no effect on bitterness B) As sugar increases, both astringency and bitterness decrease C) As ethanol increases, astringency decreases and bitterness increases (Adapted from Burns & Noble, 1985; Ishiawaka, 1994; Fontion, et al., 2008).

THE FINE ART OF MANIPULATING THE TASTE OF WINE

Over the course of the last few decades, several experiments have added to our knowledge of the molecular basis behind protein-phenolic interactions as well as different factors such as phenolic size, salivary flow rate, acidity, sugar, and ethanol that influence these interactions. Many of these factors can be manipulated by the winemaker to change the taste profile within a single varietal. This is why no two batches of wine are the same.

So how can a winemaker manipulate a wine's taste? Imagine we want to make a Cabernet Sauvignon with higher tannins and fewer flavan-3-ols, because we want a wine that is more astringent and less bitter. Our first decision is the amount of time that the whole grapes are soaked in their juices, and this is known as maceration. Longer maceration times generally result in more flavan-3-ols, while tannins are at highest concentration after a moderate maceration of six days (Ivanova, Vojnoski, & Stefova, 2012).



DID YOU KNOW...? CHANGES IN PHENOLIC SIZE. Phenolics are constantly undergoing chemical reactions during maceration. A) To increase their size, flavan-3-ols bind to each other B) In contrast, large tannins can be broken down by pigmented anthocyanins to produce flavan-3-ol subunits. As maceration time increases, anthocyanin content in the wine increases, increasing the flavan-3-ols in the wine, making it more bitter (Adapted from Salas, et al., 2003).

After maceration, the grapes proceed to fermentation. The length of fermentation determines the amount of ethanol and therefore the taste profile of the final wine product (Sacchi, Bisson, & Adams, 2005). In addition, an alternative fermentation style called *Sur lie* aging can be used to change the sugar content of wine. *Sur lie* aging involves leaving a finished wine in contact with dead yeast cells, called *lees*. By doing so, the *lees* will release sugars into the wine as their cell components break down over the span of a few days. These added sugars enhance the sweetness of the wine, and will reduce the astringency and bitterness. For our Cabernet Sauvignon, we would opt for traditional fermentation of moderate duration. This would result in a moderate ethanol concentration, which will balance the astringency and bitterness in our wine without it being overly sweet. Finally, the aging process can influence the phenolic content of the end product (Sacchi, Bisson, & Adams, 2005). Anthocyanins break down over the aging process, therefore, they are unable to break down the larger tannins and our wine will have more tannins than flavan-3-ols. At this point our Cabernet Sauvignon is now more astringent and less bitter, just like we planned.

Additionally, some of the phenolic content depends on the environmental conditions in which the grape was grown. In order to manipulate phenolic content properly, the winemaker must know how much is present in the grape to begin with. A new program in the Niagara Region called "Tannin Alert" aims to provide this vital information to winemakers (Kemp, 2014). Researchers from the Cool Climate Oenology and Viticulture Institute have been testing the phenolic content of Pinot Noir, Cabernet Sauvignon, and Cabernet Franc grapes from each harvest. Harvests categorized as low, medium, and high levels of tannins are then processed into wine either by the same technique for the base wines, or by novel techniques to determine best practices. By tracking tannin content over time, the Institute hopes to better predict future tannin content so winemakers can plan accordingly (Kemp, 2014). Quantitative information on tannin content will give Niagara winemakers an advantage over traditional winemakers from other regions.

IMPLICATIONS FOR NIAGARA VITICULTURE

Winemakers across the globe are faced with the task of producing quality wines with both flavour and character. With winemaking a growing industry in Ontario and Niagara having limited regions suitable for grape growing, our winemakers are faced with ever-increasing competition. Niagara winemakers must therefore possess apt knowledge of the chemical and biological aspects of winemaking, as well as the factors that affect taste, in order to apply specific techniques to manipulate their wines. For instance, knowing what phenolics are and how they influence the perception of both astringency and bitterness is important. As well, winemakers will benefit from knowing that the acidity, sugar, and ethanol content in the wine all influence the astringency and bitterness, and thus the taste. With this knowledge, winemakers can create signature wines to set them apart from competitors while widening their market niche (Figure 6).

The winemaking process as a whole is both an art and a science. It requires an understanding of how different components in the wine interact, but also how these components elicit a unique tasting experience.

Now when we tell you that this glass of wine is drying, but full-bodied and bitter, or that its mouthfeel is astringent and sharp, you will know exactly what we mean. Although red wine is complex, wine tasting does not have to be intimidating. In fact, the experience of tasting red wine is quite fascinating when we consider it from various perspectives, whether chemical or cultural. You are now an expert on the science behind tasting red wine, bypassing years of sommelier experience. So, next time you pick up a glass of Pinot Noir at a dinner party, you will be well equipped to show off your new wine knowledge.

FIGURE 6: A BLENDED RED WINE AT JACKSON-TRIGGS WINERY IN NIAGARA, CANADA.

MORE TO EXPLORE

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The Future of Niagara Wine: Will it Survive?

Bianca Bantoto, Alex Garbe, Jonathan Ho, Katie Maloney, Lauren Oldfield

By 2050, it is predicted that there will be a 3 to 4ºC increase in annual temperature, an increase in freeze days, and a 20% decrease in summer rainfall in the Niagara Peninsula. It is clear that climate change is already affecting the Niagara Region and its wineries. In light of this bleak future, winemakers across the Niagara Peninsula have many questions on their minds: What will happen to our vines? Will our current practices be sustainable in the future? If not, how can our viticultural practices be changed to meet this crisis, yet continue to maintain the quality of wines Niagara is known for? In order to determine the answers to these questions, the required conditions for the optimum growth of Pinot Noir, Cabernet Franc, Riesling, Chardonnay, and Merlot, the most popular wine grapes of the Niagara Peninsula, were explored. Applying the predicted climate change data to these varieties can help determine the effects that climate change will have on the region, and whether or not each variety will be sustainable in the future. Additionally, we have assessed the current strategies that are being employed in the Niagara region to combat climate change, as well as looking to Australia and Germany as historical analogues. Based on these findings, we have provided suggestions for strategies to implement in the Niagara Region to prepare for the predicted changes in climate and promote sustainability.

INTRODUCTION

The art of making wine, or vinification, is an ancient tradition rooted in the very beginnings of almost every early human civilization. The process of vinification is so delicate and intricate that even neighbouring regions have been known to produce wines with distinct differences in flavour. In the winemaking process, climatic and soil conditions play key roles. Each region possesses its own unique *terroir*, lending it the ability to create wines unique to the area, which other regions cannot fully reproduce. As such, wines with the finest tastes and textures are held with international regard, passing similar fame to the area from which they originate. The Old World is well known for its winemaking areas, particularly the French regions Champagne and Bordeaux, the namesakes of some of the most distinguished world wines. This non-distinction between the wine and region is indicative of the relationship between the two - that they are inexorably linked. It seems almost natural that the European methods of producing wine would follow them to the New World. In time, pioneers would develop their own distinct wines and winegrowing regions. One such region is our very own Niagara Peninsula.

The Niagara Peninsula is famous for producing Icewine and other cool-climate wines. But with climate change becoming increasingly apparent, many wonder about the threat of predicted warming trends and the future of the wine industry. In fact, predictions show a 3 to 4°C increase in annual temperature, an increase in freeze days, and a 20% decrease in summer rainfall (Penney, 2012). This may lead to consequences for the wine industry, including increased prices, variation in wine quality, and changes in the types of wine that can be made. This report will provide a comprehensive analysis of predicted climate change, and how the Niagara Peninsula is currently adapting, as well as how it can prepare for the future.

VARIETIES

To understand the effect of climate change on the wine industry, one must first understand the conditions required for each grape variety to undergo optimal growth, ripening, and maturation. This knowledge makes it possible to predict outcomes based on climate and develop strategies to create a sustainable industry. Winegrowing regions can be classified into temperature maturity groups: cool, intermediate, warm, or hot. These classifications are based on the average temperature in the growing season, which is April to October in the Northern Hemisphere (Jones et al., 2005). The Niagara Peninsula has an average growing season temperature (AGST) of 15.6°C (Shaw, 2012), placing it within the intermediate climate maturity group (Jones et al., 2005).

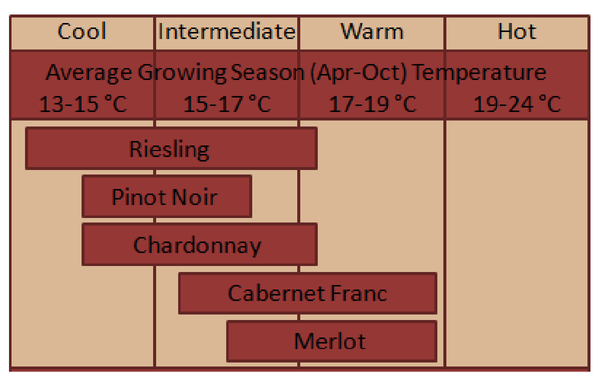

FIGURE 1: Different grape varieties prefer different climate regions, based on the average growing season temperature that the grapes require to mature (adapted from Jones, 2006).

While there are a large number of grape varieties grown in the Niagara Peninsula, five leading *Vitis vinifera* varieties produce the most popular Canadian wines. These include white wines, Chardonnay and Riesling, and red wines, Pinot Noir, Cabernet Franc, and Merlot (Shaw, 2005). Each variety has its own climate requirements, which dictate the regions it can thrive in. As seen in Figure 1, Riesling, Pinot Noir, and Chardonnay prefer cool to intermediate regions, while Cabernet Franc and Merlot prefer intermediate to warm regions (Jones, 2006).

The average precipitation for the Niagara Peninsula ranges from 700 to 800 millimetres, with excessive rainfall having a negative impact on grape quality (Jackson and Lombard, 1993). Excessive rainfall leads to an increase in Botrytis bunch rot and berry splitting, which will attract a pest known as Multicoloured Asian Lady Beetles (Bostanian, Vincent, and Isaacs, 2012). A negative relationship has also been observed between precipitation and the rates of grape growth and development (Jackson and Lombard, 1993).

Pinot Noir

Figure 2: Pinot Noir grapes on the vine (Peterson-Nedry, 2006).

Pinot Noir is one of the most popular red table wines. It is commonly grown in the Niagara Peninsula as it ripens early and is relatively good at withstanding cold temperatures compared to other red varieties (Reisch, 1993). It is an early season variety, meaning it experiences early budding and has a thin skin that is easily damaged by late spring frosts. However, there are also advantages associated with early season varieties, including the ability to reach full maturity in 160 to 170 frost-free days compared to the 180 days required by late season varieties (Shaw, 2005). It grows best in chalky clay soils (Steenwerth et al., 2008) and is often harvested early to avoid Botrytis bunch rot (Reisch, 1993).

Cabernet Franc

Figure 3: Cabernet Franc grapes on the vine (Rosenweig, 2006).

Cabernet Franc is one of the most cold-hardy varieties, making it a popular choice in the Niagara Peninsula (Reisch, 1993). It prefers an intermediate to warm region and has a large ripening temperature range. Despite being cold hardy, it will only reach its full ripening potential in warmer years (Jones, 2006). It is a late season variety, requiring a period of about 180 frost-free days for optimal ripening (Shaw, 2005). Cabernet Franc grows best in sandy chalk soil types (Clarke, 2001). One downfall of this otherwise resilient variety is its susceptibility to powdery mildew (BC Ministry of Agriculture, 2013).

Riesling

Figure 4: Riesling grapes on the vine (Maack, 2005).

Riesling is a white grape variety, and is commonly used in the Niagara Peninsula for the production of Icewine, a treasured dessert wine unique to a handful of countries across the world. Riesling requires a cool to intermediate climate during the growing season in order to fully mature, which is essential to wine quality (Holland and Smit, 2010). Cooler climates also contribute to the increased acidity and fruitiness of the Riesling, which gives the wine exceptional aging potential. A well-aged Riesling can often produce smoky notes and a highly prized petrol character (Douglas, Cliff and Reynolds, 2001). It is commonly grown in limestone-based shale or clay loam in the Niagara Peninsula. The susceptibility of Riesling to Botrytis bunch rot however, requires the consideration of techniques such as canopy management (Reisch, 1993).

Chardonnay

Figure 5: Chardonnay grapes on the vine (Morgan, 2009).

Chardonnay is planted in more regions than any other variety in the world due to its ease of cultivation (Robinson, 2003). The ability of Chardonnay to tolerate a large range of temperatures and soil types makes it a good candidate for wine production. The malleability of the grape allows different regions, and even different winemakers in the same region, to produce distinct flavours in their wines (Robinson, 2003). This, coupled with the generally ease of cultivation, makes Chardonnay a versatile variety with high potential for success. It can adapt to any vineyard soil type and is subsequently grown in many types of soil, such as chalk, clay, limestone, and sandstone, which each produce distinct and high quality wines (Clarke and Rand, 2001). Just as other grape varieties are susceptible to Botrytis bunch rot however, so is Chardonnay (Reisch, 1993).

Merlot

Figure 6: Merlot grapes on the vine (Boltseridge, 2005).

Merlot is a variety with very specific needs in order to produce quality wines. Merlot requires an intermediate to warm climate during its growing season (Holland and Smit, 2010).

	Pinot Noir	Cabernet Franc	Riesling	Chardonnay	Merlot
Climate Maturity group	Cool – low intermediate	Intermediate – warm	Cool - intermediate	Cool - intermediate	Intermediate - warm
AGST (°C)	14-16	15 – 19	13-17	14-17	17-19
Level of cold hardiness	Medium	High	High	Medium	Low
Harvesting time	Early season variety (very early bud-break time)	Late season variety	Late season varietal	Early season variety	Early season variety
Growing season (days)	160-170	180	194-208	194-208	160-170
Soil Requirements	Chalky clay	Sandy chalk	Limestone-based shale, clay loam	Any	Cold, Well Drained
Susceptibility / potential problems	Late spring frost	Only reaches full maturity in warmer years	Rain before harvest lead to bunch rot	Very adaptable	Late spring frosts
Insects and diseases	Botritys bunch rot	Powdery mildew	Botrytis bunch rot	High susceptibility to botrytis bunch rot	Powdery mildew, leafhopper insects, botrytis bunch rot

TABLE 2: Summary of optimal conditions, maturity group, and potential disadvantages of the major wine grape varieties of the Niagara Region (Jones, 2006, Holland and Smit, 2010).

This variety also tends to bud early, and is often at risk of late spring frosts in the Niagara Peninsula (Clarke and Rand, 2001). It thrives in cold soil but requires well-drained soil. Clay is a cold soil, but is generally poor draining; thus, the best locations for Merlot have a good level of clay to cool the soil but not enough to stop the drainage of water (Robinson, Harding and Vouillamoz, 2012). Additionally, Merlot is susceptible to powdery mildew and leafhopper insects.

APPLYING CLIMATE CHANGE PREDICTIONS

Brock University in St. Catharines, Canada has predicted climate change trends for the year 2050, and designed preemptive strategies for the Niagara Peninsula (Penney, 2012). Using case studies, an advisory committee consisting of Niagara Water Strategy specialists and members of the Environmental Sustainability Research Centre addressed the barriers to implementing adaptive strategies. Based on these projections, the Niagara Peninsula will witness a 3 to 4°C increase in annual temperature, an increase in freeze days, and a 20% decrease in summer rainfall (Penney, 2012).

The 3 to 4ºC increase in annual temperature would have the largest impact on the Riesling, Pinot Noir, and Chardonnay grape varieties (Jones, 2006). These varieties prefer to grow in cool to low intermediate climates, which range from 13 to 17ºC. As the region's annual temperature increases, it can be expected that the temperature of the average growing season will range from 17 to 21ºC. This will put the Niagara Peninsula into the high intermediate to warm temperature range, affecting the varieties that can be grown. While Cabernet Franc and Merlot can still be produced, other popular white whites and Icewine from the region will be less successful (Jones, 2006). As the acidity and fruitiness of the Niagara Riesling is also attributed to the cold climate, its taste profile may change drastically (Holland and Smit, 2010). The shifting climate windows will definitely impact the wine industry, and will either be detrimental or provide new opportunities depending on the variety.

The increase in annual temperature will result in current winegrowing regions being unable to support cool climate varieties. Instead, regions conducive to cool climate varieties will shift north, while the Niagara Peninsula will support more warm climate varieties. Unlike American wineries which cannot shift north to maintain viable wine production, Canada has the distinct advantage of being able to expand its potential wine growing regions.

The impact of an increased number of freeze days depends on their timing. More freeze days in the fall allows for earlier Icewine production, whereas in the spring it may cause permanent vine damage (Clarke and Rand, 2001, Shaw, 2005). Both Pinot Noir and Merlot experience early budding in the spring and will be heavily impacted by late spring freeze days. Increased freeze days could also reduce leafhopper populations, which destroy vineyards, especially in the late spring.

A 20% decrease in summer rainfall holds both benefits and costs for the wine industry. Benefits would be specifically related to an increase in flavour linked to lower water content and reduced predisposition to Botrytis bunch rot and other fungal diseases. However, there are costs associated with increased water use from irrigating crops. Water shortages may also affect the development of the plant (Jackson and Lombard, 1993). Overall, it is clear that the climate change predictions will force the wine industry to adapt in order to be sustainable in the future.

EVIDENCE OF CURRENT CLIMATE CHANGE IN THE NIAGARA PENINSULA

To help visualize the current climate change impacts in the Niagara Peninsula, this model has been created to illustrate vegetation loss within the region due to the harsh ice-ridden 2013 winter. This model was created using the analysis of remotely sensed images of the Niagara Peninsula from the Landsat 8 satellite. It uses a Normalized Difference Vegetation Index (NDVI), which represents the coverage of vegetation, soil, and water in the remotely sensed image. This analysis compares the vegetation cover between 2013 and 2014 following the harsh 2013-2014 ice storm that devastated crops. This is seen in Figure 2 through a difference overlay between the NDVIs of the two years indicating changes in ground cover.

The model indicates changes in vegetation cover density between the two years with a decrease in cover in 2014, a major part of which occurred due to the harsh weather. It can be seen that regions around most of the wineries shown have lost vegetation (in red) between the years. There are a few wineries which are surrounded by new vegetative growth (in light green), but the sheer number of wineries affected negatively is concerning as this change is a result of only one harsh winter. If this were to become the standard weather of the Niagara Peninsula, grape vines without sustainability measures will have many difficulties in combating the negative effects of climate change.

FIGURE 7: A Normalized Difference Vegetation Index (NDVI) analysis was run for the Niagara Wine growing region for August 2013 and August 2014. Changes between 2013 and 2014 are shown with increased vegetation in green, decreased in red, and negligible effects in white. The locations of the major wineries in the Niagara-on-the-Lake Region are shown.

CURRENT SUSTAINABILITY METHODS IN NIAGARA

Narrow climatic growth zones for grape vines demonstrate the importance of having contingency plans for climate change in the Niagara Peninsula and other winegrowing regions. A preemptive approach is necessary in reducing any and all possible impacts from the changing climate to maintain a sustainable industry. In Ontario, there are two methods that are used to protect crops from frost. Passive methods are used as preventive measures to protect future crops (Queen's Printer for Ontario, 2013). These include site selection, land clearing, crop management, planting and harvesting within available freeze-free period, and soil management. Active methods are taken just prior to or during a frost period and include covering the ground to reduce heat loss, using fog or smoke to reduce radiative heat loss, wind machines during radiative freezes, low rate water sprinkling, and heaters. These methods are effective under radiative frost when winds are light or calm in low-lying lands (Queen's Printer for Ontario, 2013). Wind frost is difficult to mitigate using active means.

Wind machines are primarily used in the wine region of Niagara to protect grapes from cold temperatures, especially during late spring frosts, early fall frosts, and mid-winter cold (Figure 3). The efficiency of these machines could be seen after significant cold temperatures in January 2005. Growers with wind machines harvested near normal crops, whereas those without had total crop failure and even plant loss (Fraser et al., 2009).

FIGURE 8: An example of a fan used to prevent frost in the fields of Jackson-Triggs Windery [Garbe, 2014].

Unfortunately, even with these methods, cold damage does occur. There are suggested measures in place from Cool Climate Oenology and Viticulture Institute (CCOVI) in order to recover from winter damage (Ker, Brewster and Willwerth, 2014).

The first recommendation by CCOVI and Brock University is using multiple trunks and regular trunk renewal. There are ideal standards for vine growth proposed by CCOVI; however growers have to change and adapt these guidelines to fit their particular need and growing style (Ker, Brewster and Willwerth, 2014).

There are many action plans in place for the Niagara Peninsula to prevent and recover from damage from climate change. There are storm water management plans, sewage backflow prevention, and flood alleviation plans for the management of water related climate stressors (Penney, 2012). Heat impact reduction methods are mostly passive and intended for use in urban areas. These include planting trees and vegetation for shade, using different building materials that reflect solar radiation, and reducing the carbon footprint of the urban area in order to decrease greenhouse gas emissions (Penney, 2012).

Perhaps one of the most important preventative methods in place currently is the warning system for heat waves and potential frosts. This warning system ideally allows growers to take action prior to the weather change and protect their vines (Penney, 2012).

HISTORICAL ANALOGUES

Just as the Niagara Peninsula is expected to become hotter, Australia and Germany have experienced warming trends in recent years. Although Australia and Germany have very different climates, the overall increase in temperature for both countries has had significant impacts on their respective winegrowing regions. From assessing the adaptive strategies used by Australian and German wineries to mitigate warming trends, perhaps there are important lessons that the Niagara wine industry can utilize.

AUSTRAILIA

Since the 1950s, Australia has grown warmer by 0.16ºC per decade. As a result of the El Nino Southern Oscillation (ENSO), there has also been significant variability in rainfall from year to year (Cai et al., 2001). The turn of the 21st century also came with the 2001-2009 "Millennium Drought", the longest uninterrupted period with below median rainfall in Southeast Australia since 1900. This period ended for southeast Australia in 2010 due to a La Nina ENSO effect which resulted in high precipitation and flooding. Meanwhile, Southwest Australia experienced its driest year on record at this time (Van Dijk et al., 2013).

Substantial increase in the frequency and severity of heat stress during the growing season has been detrimental for vine growth. A reduction in winter rainfall has also led to decreased water quality and increased salinity, resulting in soil degradation (WIC, 2014). This combined effect of increasing temperatures and declining soil water content has driven grapes to ripen earlier (Steffen and Hughes, 2013). This places greater pressure on winemaking resources and demands adaptive viticulture techniques (WIC, 2014). As Australian winegrowing regions experience temperatures at or above the optimal temperature window for most grapes, the warming climate will certainly have a negative impact on grape quality.

Australian wineries have implemented several adaptive strategies to address warming trends. To minimize damage, vines preferably with drought-tolerant rootstock are strategically watered to full capacity before the heat and the resulting moisture level is maintained as best as possible. Less heat damage is associated with shading exposed fruit, which is accomplished by encouraging canopy growth, strategic row orientation, and even the positioning of fruiting and foliage wires to protect against direct radiation. Placing mulch under vines and cover crops between rows of vines also mitigates radiation emanating from heated soil which affects berries found lower in canopies (Webb et al., 2009). Vineyards can also be shifted to more suitable sites, although this requires significant capital investment (Steffen and Hughes, 2013; WIC, 2014).

Australia's climate has been greatly affected by drought and temperature increases. Though the environment of Australia differs from Niagara, studying the effects and the response of the Australian wine industry can give us insight into possible methods to sustain the Niagara Peninsula wineries.

GERMANY

Germany can be used as a case study for cold climates (VQA Ontario, 2014). Although the Niagara Peninsula is one of the top global producers of Icewine, the concept of Icewine originated from Germany in the late 1700s. The production of Icewine in Canada requires a sustained temperature of -8ºC for at least a few days, whereas Germany requires the grapes to freeze below -7ºC, which due to fairly moderate winters does not always occur (VQA Ontario, 2014; Fuhram, 2008).

The temperature in the wine-producing region of Lower Franconia has increased by 1.44ºC (Bock et al., 2013). Precipitation levels are predicted to increase, with a tendency towards extreme periods of flooding and droughts (BMU, 2009). This differs from the Niagara Peninsula, which is projected to receive less precipitation (Penney, 2004). Warmer winters and increased rain mean the grapes will be on the vine for longer, making them more susceptible to Botrytis bunch rot (Fuhram, 2008). Although climate change will drastically decrease Germany's ability to produce Icewine, it may provide certain benefits. Increasing temperatures during the growing season results in a higher yield, higher sugar content, and a shorter growing season (Bock, 2013; Fraga, 2012; Nuemann and Matzarakis, 2011).

Germany is preparing to adapt to climate change by taking a synoptic view of several climate models (BMU, 2009). There are several methods being implemented to mitigate the effects of flooding including reconnecting old river branches and considering water flow and recharge during urban planning. By considering flooding effects on the vineyards, winemakers will be better prepared to adapt (BMU, 2009). In areas where vineyards are threatened by drought, water retention and irrigation structures are being improved (BMU, 2009). Germany's overall approach is to focus on climate protection and adaptation, and to combine the two whenever possible. The methods used to adapt to environmental changes should in no way undermine the efforts to protect the environment (BMU, 2009). As such, Germany has developed collaborative opportunities for nature conservation, agriculture, and water management authorities to discuss future strategies. Germany has seen the effects of climate change and has developed a comprehensive plan to adapt (BMU, 2009).

CONCLUSION

As changes in climate trends continue to threaten the sustainability of viticulture in wine regions across the world, it is important for the Niagara wine industry to adapt their practices in response to climate change. Climate projections indicate a shift in temperature windows and precipitation levels, which will greatly influence the types of varieties that can be grown within the region. A warmer annual temperature will cause the the decline of cool climate varieties such as Riesling, Pinot Noir, and Chardonnay, along with Canada's Icewines. Meanwhile warm climate varieties such as Cabernet Franc and Merlot will flourish at their optimal temperature conditions. The projected reduction in summer rainfall will also pose problems in maintaining necessary soil moisture levels while providing certain benefits against fungal diseases. Overall, the effects of changing trends in annual temperature, freeze days, and precipitation will depend on the climatic requirements of the different varieties.

By looking at the measures undertaken by Australian and German wineries in response to warming trends, vintners within the Niagara wine region can learn from their successes and failures. Australian wineries have employed adaptive strategies to combat extreme heat and drought. These include encouraging canopy growth and strategic row orientation to provide shade for exposed fruit; strategic water practices, and planting cover crops between rows of vines to prevent heated soil radiation. German strategies include selecting economically favourable varieties and the construction of water retention and irrigation structures.

The inescapable impact of future climate change looms over the heads of Niagara vintners and wine connoisseurs alike. Even though Niagara wineries will experience many hardships from this, current strategies as well as the implementation of various adaptive measures from Germany and Australia may help mitigate vine damage. With hard work and good fortune, it is certainly possible that Niagara will continue to thrive and flourish as one of Canada's greatest wine regions.

ACKNOWLEDGEMENTS

This project would not have been successful without the help and guidance of various members of the McMaster community. We would like to express our gratitude to Patrick DeLuca, Dr. Jay Brodeur, Dr. John Maclachlan, Dr. Carolyn Eyles, Russ Ellis, and Dr. Joe Hayward.

MORE TO EXPLORE

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Picture References

Title picture: Lauren Oldfield, Jackson-Triggs vine rows. Niagara-on-the-Lake, Ontario, September 2014.

Figure 2: Harry Peterson-Nedry. Chehalem pinot noir grapes. January 2006.

Figure 3: Rosenweig. Grapes and leaves of the grape variety Cabernet Franc. Weinsberg. September 2006.

Figure 4: Riesling Tom Maack, Riesling grapes and leaves. Rheingau, Germany, October 2005.

Figure 5: Chardonnay John Morgan Pictures from Mumm winery in autumn. Napa Valley, California November 2009.

Figure 6: Merlot Nathan Boltseridge Merlot Grapes September 2005.

Figure 7: Created by Lauren Oldfield using ESRI ArcGIS - ArcMap 10.2

Figure 8: Alex Garbe, Jackson-Triggs Winery wind machine among vine rows. Niagara-on-the-Lake, September 2014.

A Vital Combination: Pairing Varietal and Region

Natasha Dovey, Heather Fice, Leah Hayward, Braedan Huras, Nick Luymes

Housing 60% of the province's Vintners Quality Alliance wineries, the Niagara Peninsula possesses the ability to grow a wide range of grape varietals as a result of its diverse topography. The placement of particular varietals in the Niagara Region hinges on the correct pairing of varietal characteristics and geographic region. This pairing is essential for the optimization of wine quality. Here, we explore the factors involved in proper grape development and suggest suitable growing regions for three common varietals.

In the winter of 2014, temperatures dropped drastically below freezing to an astounding -24 degrees Celsius in Hamilton, Ontario (CBC News, 2014). Each year, the winter temperatures fall to sub-zero values, and force many Canadians to question their choice of home. However, there are issues that go much deeper than early, cold mornings, and extend to resources, industries, and livelihoods. Agricultural industries, such as the vineyards of the Niagara Peninsula, are often impacted in the most significant ways (Shaw, 2002). It takes just a small amount of inclement weather to ruin an entire crop. Whether it is the freezing temperatures mid winter, the early frost in the fall, or the late frost in the spring, Canadian climate holds the potential to be a significant detriment to various vineyards (Haynes, 2000).

To compensate for the challenges that are faced with growing grapes used for wine in Canada, where the weather reaches sub-zero temperatures for three or four months at a time, many vintners have taken to planting optimal wine varietals based on the specific requirements of that varietal (Haynes, 2000). Of these requirements, one could argue that the most unique and detrimental in Canada is the cold that is presented by the winter. In this article we will examine how the bud break timing, length of growing season and cold hardiness need to be considered when selecting appropriate sites that maximize crop output and survival.

We will suggest suitable growing regions using a Geographic Information System for three wine varietals based on innate grape characteristics and regional climate characteristics. This will then be compared to the current varietal distribution in the Niagara region. The three varietals we have decided to look at are Cabernet Sauvignon, Baco Noir, and Riesling. Currently, all three varietals are grown in the Niagara Region, and contribute to the wine industry of this area; we therefore hope to examine which sub-regions they are grown in, and the sustainability of their current locations.

COLD HARDINESS

The hardiness of grapevine tissues differs across all *Vitis vinifera* varietals. Intrinsic factors, such as plant vigor and cold hardiness genes, confer a specific hardiness to the vine itself. Additionally, management techniques such as pruning can help mitigate frost threats (Trought, Howell, & Cherry, 1999). The environment also largely impacts the success of a grape vine; geological factors such as elevation, slope, and lake proximity affect the microclimates of an area and directly affect grape protection during the dormant season (Shaw, 2005). It is the combination of these three factors—biological, management and environmental—that determine a vine's ability to survive the dangers of winter.

In terms of the biological aspect of cold hardiness, wine grapes can be ranked based on their intrinsic hardiness (Mussell, Willwerth, & Fisher, 2011). Varietals differ in the amount of energy they put into acclimating in preparation for the winter. Varietals that allocate a lot of energy can survive at lower temperatures and persist at sustained low temperatures for longer periods of time (Kalberer, Wisniewski and Arora, 2006). Methods of acclimating include the thickening of bud sheaths and the movement of nutrients to less exposed areas of the vine, like the roots (Keller, 2010). For example, Zinfandel, which is usually grown in California, is the least cold tolerant *V. vinifera* varietal, along with Sauvignon Blanc (Slingerland, 2011). Riesling and Cabernet Franc are the most cold tolerant *V. vinifera* grapes, while varietals such as Cabernet Sauvignon and Pinot Noir are intermediate in terms of cold hardiness (Mussell, Willwerth, & Fisher, 2011).

BUD BREAK TIMING

Bud break is the process that is responsible for initiating the growing season in flowering plants. It is defined as the time when the buds are released from dormancy and begin producing shoots (Figure 1). This process is important in development of the plant, and many different factors affect the timing at which bud break occurs. In the Niagara Region, the initiation of this process is dictated by the timing at which temperatures warm in the spring (Sánchez & Dokoozlian, 2005). As days without frost persist, the vines begin to induce metabolic pathways to promote bud break. Chemicals like hydrogen cyanamide are known to release buds from dormancy by impairing mitochondrial function and inducing respiratory stress (Pérez, Vergara, & Or, 2009). Respiratory stress triggers the process of bud break and occurs at different temperatures depending on the varietal (Vergara, Rubio, & Pérez, 2012). Regional climate conditions greatly influence the timing of dormancy release. If the buds of a particular varietal break early in a region that is prone to fluctuating spring temperatures, the vine may be subject to spring frost damage (Mills, Ferguson, & Keller, 2006). In contrast, if varietals with late bud breaks are distributed in a region that warms gradually but tends to have a lower frost risk, the vine will not be utilizing the growing period of the region to its full potential. Understanding both the bud breaking conditions of the varietal and the specific characteristics of a region's spring thaw period are important in creating optimal varietal-location matches (Nendel, 2010). Planting a varietal in a region that will promote the most beneficial growth with the varietal's innate characteristics will ensure low spring damage risks, high yields, and potentially lower wine prices (Keller, Mills, & Olmstead, 2014; Nendel, 2010).

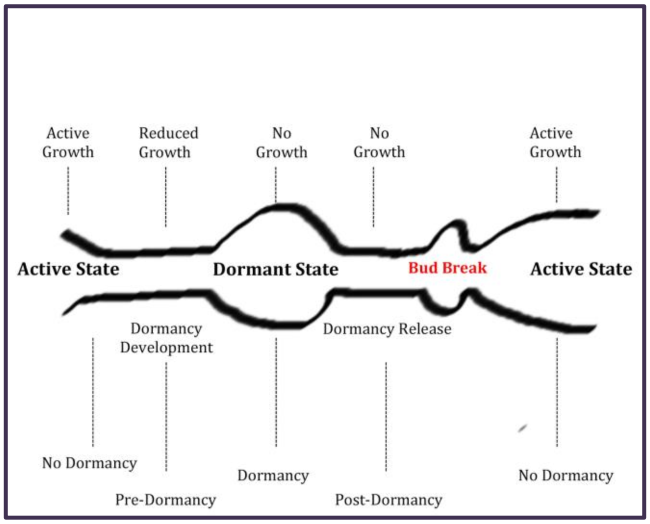


FIGURE 1: DORMANCY MODEL DISPLAYING BUD BREAK TIMING. The cycle begins with the active state, where growth is occurring and there is no dormancy. The plant then transitions into the dormant state where growth is reduced and dormancy is developing. Post dormancy includes dormancy release with no growth. Bud break then occurs and leads the plant into its active state. (Modified from Lavee and May, 1997).

GROWING SEASON

Growing season length is strongly influenced by the region in which a varietal is grown. To achieve the proper balance of sugars and acids, which optimize wine taste, the length of the required growing season will vary across varietals, which boils down to the nature of the grape itself (Jones et al., 2005). The growing season is based primarily on the number of frost-free days (FFD; Shaw, 2005). The growing season for a particular region is defined by the amount of FFD, which is determined by the amount of days between the last spring frost and the first autumn frost. It is intuitively defined as the minimum number of days without frost required for a certain varietal to complete the process of fruit production (See Table 1 for the FFD values of our three varietals; Womach, 2005). Therefore, FFD directly relate to the length of the growing season; since the climate of a region affects the number of FFD, we would expect to see a correlation between the required growing season of a varietal and the region in which it is grown.

TABLE 2: The approximate harvest time and required FFD for each varietal. *-(Mussell, Willwerth, & Fisher, 2011). **-(Ker, 2010).

Varietal	FFD Required*	Harvest Time**
Riesling	160	Late September – Mid October
Cabernet Sauvignon	190	Late October
Baco Noir	140	Early September

GEOGRAPHY OF NIAGARA REGION

The overall intensity, timing and duration of cold periods throughout the year is greatly affected by the topographic properties of vineyards in the Niagara region. The Niagara region cannot be characterized by one simple set of criteria; it is a dynamic area with many sub-regions that have their own climate-defining characteristics. We chose to focus on three main regions (Figure 2) in order to go over some of the broad differences one must take into account when choosing an appropriate grape growing site.

The Lake Iroquois Plain is situated to the south of Lake Ontario adjacent to the shoreline, which directly exposes it to the lake's temperature moderating effects. Due to the high specific heat capacity of water compared to air, Lake Ontario takes longer to cool in the autumn and winter, and takes longer to warm over the spring and summer. In the autumn, cool polar air flowing from the northeast is moderated by the warmer waters of Lake Ontario before crossing the Lake Iroquois Plain. The mass of cold, dense air that sits atop the escarpment forces the warm air from Lake Ontario back down along the Plain. These effects lead to a longer potential growth period and a cooler mean summer temperature for vineyards near Lake Ontario (Shaw, 2002). The elevation in the Lake Iroquois Plain is relatively low, around 80 meters above sea level, and slopes gradually from the base of the escarpment to the lake (VQA Ontario, 2014). Due to the low slope of the region, grapes grown here receive constant sun exposure, and can experience warm days and cool nights throughout the growing season. The Lake Iroquois Plain is well suited to growing grape varieties that require a more temperate climate. It also promotes a later bud break due to the cooling effects from Lake Ontario, which retains its cold winter temperatures far into the spring (Shaw, 2002).

The Niagara Escarpment is located south of Lake Ontario, at an elevation of 200 meters above sea level, or about 120 meters from the plain at the bottom of the escarpment to the brow at the top. The change in elevation from the plain to the brow creates a north-facing slope that allows for even sun distribution throughout the day and for the circulation of warmer Lake Ontario air to moderate the cold temperatures in the evenings when the sun cannot act as a source of heat (VQA Ontario, 2014). This slope also allows for better water drainage during the spring thaw when compared to flat lying regions. During the winter, the escarpment protects the bench region from strong, cold winds flowing from the southwest. Cool air is drawn up the face of the escarpment as it flows from the northeast over Lake Ontario (Nendel, 2010). High elevations like the escarpment experience cool temperatures in the early spring and late fall, but remain temperate throughout the growing season with gradual warming and cooling in the spring and fall, respectively. The elevation of the escarpment also increases the risk for crops atop the brow to succumb to frost damage, which poses a concern for less cold hardy crops. All factors culminate to result in a growing season slightly shorter than that of the Lake Iroquois Plain, and a late crop bud break in the spring (Shaw, 2002).

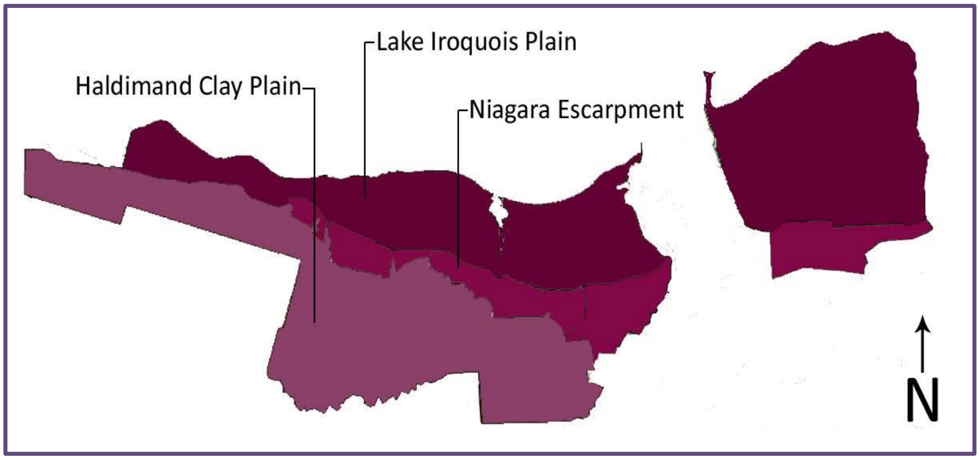
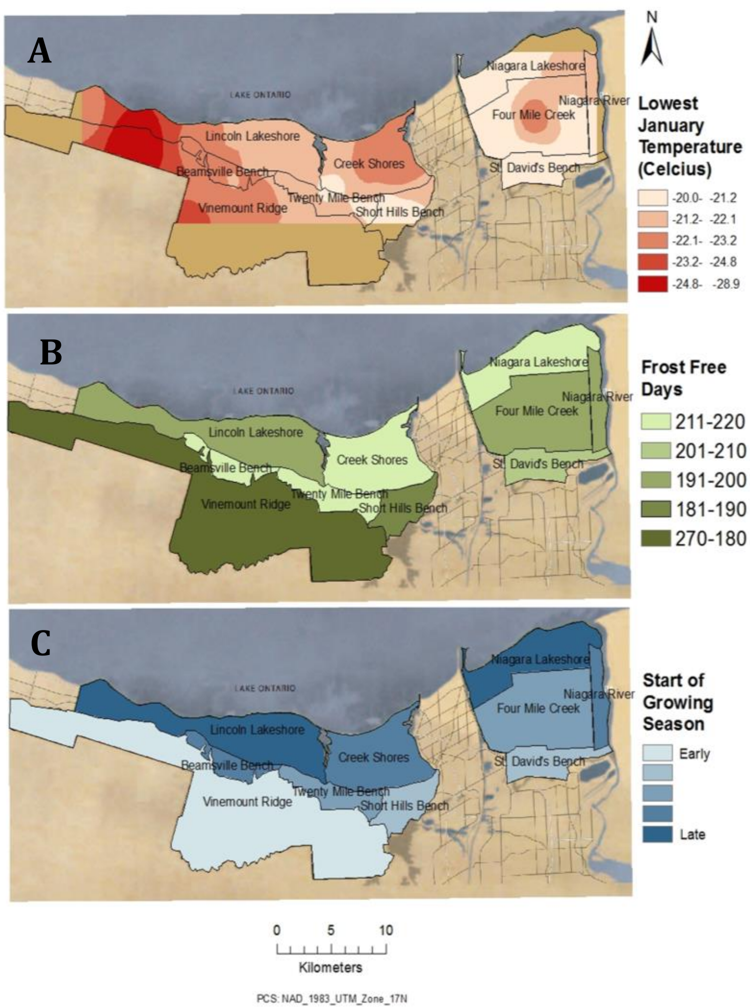


FIGURE 2: GEOGRAPHY OF THE NIAGARA WINE GROWING REGION. The Lake Iroquois Plain is under climate moderation by Lake Ontario, which it borders to the north of its shore. The Haldimand Clay Plain is the most southerly of the wine growing regions, and its climate is affected by Lake Erie, which lies south of this region. The Niagara Escarpment separates the two regions and experiences climate variations along its length (Modified from VQA Ontario, 2014).

The Haldimand Clay Plain lies between the Niagara Escarpment and Lake Erie. This geographical region is burdened with cold, harsh winters in comparison to the Lake Iroquois Plain (Shaw, 2005). Lake Erie is shallow and freezes over in the winter meaning it cannot provide the same moderating effects as Lake Ontario (Shaw, 2002). This inability to moderate winter temperatures influences the type of varietals that can survive the dormant season. Cold hardy varietals should be chosen for the Haldimand Clay Plain to ensure they can flourish in the spring following a harsh winter. Lake Erie also significantly influences bud break timing of *V. vinifera* because it remains frozen during the months of January, February, and March (Shaw, 2002). As such, the lake acts as a flat landmass for southerly prevailing warm winds. These warmer winds encourage earlier bud break and promote dormancy release. Early bud break puts vines at risk for spring frost injury because temperatures below 0°C can be expected twice each spring in the Haldimand Plain region (Shaw, 2002). The Haldimand Clay Plain also has the shortest growing season and the highest risk for grape damage in the fall due to frost (Mussell, Willwerth, and Fisher, 2011).

SUITABILITY MODELS

In order to exemplify the importance of location selection in terms of maximizing the available output and minimizing frost damage, we consider the aforementioned characteristics that differ between varietals and how they can be used to decide upon optimal growing regions. For the scope of this report, we present the reader with three varietals that give a good representation of the variety we can see within each characteristic. Models that show the relative suitability of locations within the Niagara escarpment were created for each varietal and are presented in Figures 3 and 4.



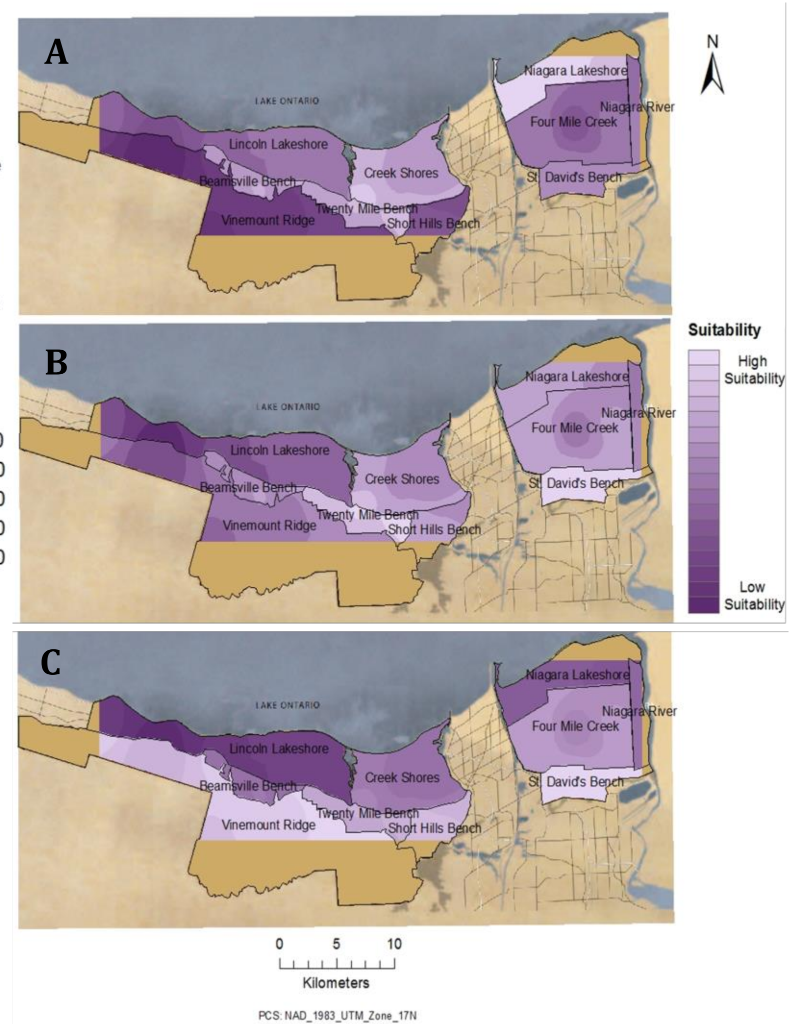


FIGURE 3: CLIMATIC DIFFERENCES IN THE NIAGARA PENINSULA. A) The lowest temperatures of January, 2013 serve a proxy for the rest of the winter in terms of the areas that experience the most extreme temperatures. B) The frost free days of the different sub-appellations give an indication of the length of the growing season for a particular region. C) The start of growing season represents the relative time in spring that the temperatures of the different sub-appellations become stable and warm enough to promote prolonged growth (Image modified from VQA Ontario, 2014).

FIGURE 4: SUITABILITY MODELS. Suitability models for A) Cabernet Sauvignon, B) Riesling and C) Baco Noir. Each model was created using different weights for the climatic differences. Large weights were given to climatic differences that had a high influence on the ability of the grapes to survive and grow to the desired potential without succumbing to frost damage. Once the most suitable regions are identified, we can determine whether or not these identified regions are reflected in current varietal distributions of the Niagara Peninsula (Image modified from VQA Ontario, 2014).

For Cabernet Sauvignon, the length of the growing season is the most influential as this varietal requires over 190 FFD (Table 1). Low winter temperatures are also influential because Cabernet Sauvignon is only moderately cold hardy. The start of the growing season is not as influential because the buds of this varietal break later in the spring, meaning there is less chance of spring frost damage (Mussell, Willwerth, and Fisher, 2011). The Niagara Lakeshore region, which has the highest suitability, is strongly influenced by its proximity to Lake Ontario (Shaw, 2002). This region warms gradually in the spring, which promotes late bud break, and cools gradually in the fall, allowing for a longer growing season (Shaw, 2002). Vintners can successfully harvest *V. vinifera* grapes that are less cold hardy due to the moderating effects of Lake Ontario; so although Cabernet Sauvignon is only moderately cold hardy, it can thrive in this region.

Riesling is influenced by each of the three climatic differences relatively evenly because it requires a moderately long growing season, is moderately cold hardy and has a bud break timing between the earlier breaking varietals and the later ones (Mussell, Willwerth, and Fisher, 2011). This map demonstrates that the bench regions of the Niagara Peninsula, St. David's Bench in particular, are the most suitable locations for growing Riesling. These regions differ from each other slightly in terms of their climate. For example, St. David's Bench experiences early warming in the spring, while Short Hills Bench experiences gradual warming. Riesling is a very versatile grape, and as such can be grown and harvested in several regions (Mussell, Willwerth, and Fisher, 2011). Riesling can also be harvested at different times which can be used to explain why it can succeed in various regions. A later harvest of the crop will effectively increase the length of the growing season. The timing of harvest affects wine characteristics such as sugar content and acidity, and Riesling has three distinct harvest times depending on the region and the vintner (Keller, 2010). We can determine what makes this grape so versatile by acknowledging its moderate growing requirements. When we take all of these characteristics into account, we find that Riesling can be grown in many regions on the Escarpment according to our suitability map.

For Baco Noir, the start of the growing season is the most influential factor because its buds break early and are consequently vulnerable. Therefore, regions that promote an early bud break and have less fluctuating spring temperatures are essential. The lowest winter temperatures and length of growing season do not have a huge impact on the placement of Baco Noir grapes because it is very cold tolerant and does not require a long growing season (Mussell, Willwerth, and Fisher, 2011). This suitability map indicates that Vinemount Ridge and St. David's Bench are the most suitable regions for growing Baco Noir. This region suffers from cold, harsh winters and promotes early bud break. However, this region typically only has two days of below freezing temperatures after the buds break which will decrease frost risk (Shaw, 2002). Baco Noir is a very cold tolerant varietal that also has early breaking buds; these characteristics of the grape make it easy to understand why the Vinemount Ridge is a suitable location for growing and harvesting this varietal (Mussell, Willwerth, and Fisher, 2011).

VARIETAL DISTRIBUTIONS IN THE NIAGARA REGION

Now that we have used our suitability maps to determine appropriate growing regions for three grape varietals, we are interested in seeing how this compares to the map of current grape distributions in the Niagara region.

In the Niagara region, Cabernet Sauvignon is grown in the Lincoln Lakeshore, Niagara Lakeshore, and St. David's Bench regions (VQA Ontario, 2014). Our suitability map implies Niagara Lakeshore is an acceptable region for growing Cabernet Sauvignon based on its long growing season and lowest winter temperatures. The Lincoln Lakeshore promotes late bud break similar to Niagara Lakeshore, and St David's Bench has similar values for lowest winter temperatures (Figures 3A and C). Since these two regions still provide grapes with long growing seasons and protection from harsh winter temperatures, it is no surprise that Cabernet Sauvignon is also grown in these regions. As further support for this distribution, our suitability map for Cabernet Sauvignon indicates that Lincoln Lakeshore and St David's Bench are moderately suitable for growing this varietal (Figure 4A).

Riesling is grown in all bench regions of Niagara with the exception of St. David's Bench. In addition, the Niagara River sub-region also grows Riesling grapes (Figure 5) (VQA Ontario, 2014). Considering that there are no significant differences between St. David's Bench and the other bench regions and that Riesling is a versatile grape, we believe the Niagara distribution of Riesling is a direct reflection of vintner preference.

Baco Noir is grown in the Vinemount Ridge area, most likely due to its requirement for early bud break and its ability to withstand the harsh winter conditions (Jackson, 2014). Therefore, our suitability map based on the characteristics

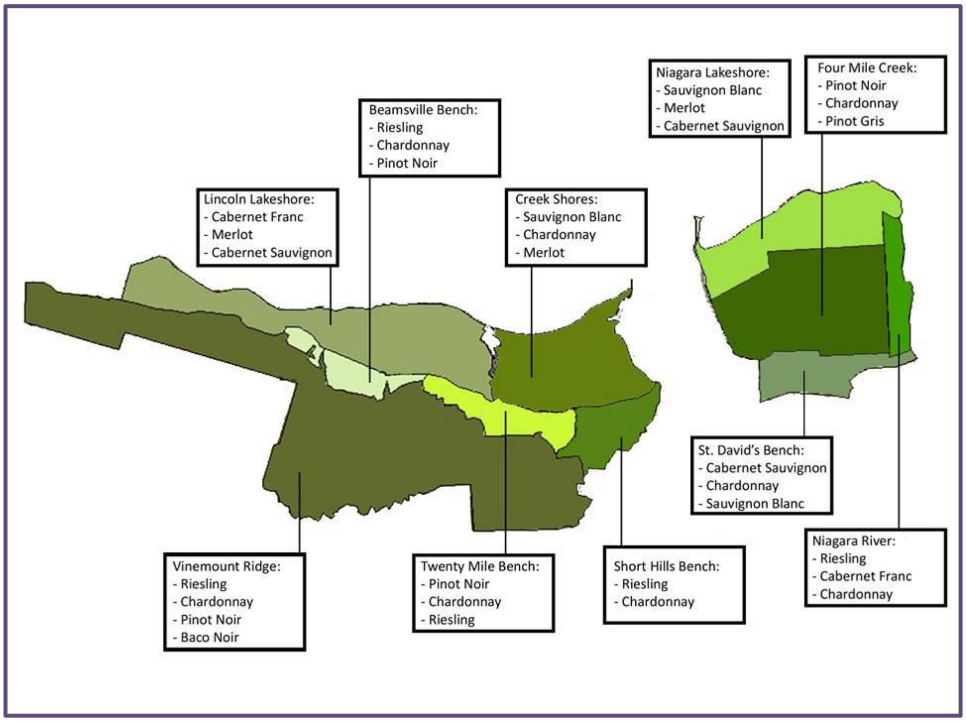


FIGURE 5: Current distribution of *V. vinifera* varietals in the Niagara region (Modified from VQA Ontario, 2014).

of Baco Noir shows a similar distribution of the varietal to that of the Niagara region.

EXPANDING VARIETAL RANGES

As we have demonstrated, wine varietals are sometimes grown in regions of Niagara that would not necessarily be regarded as the most suitable locations. We believe there are two main reasons for this, which are demonstrated in the cases of Riesling and Cabernet Sauvignon. Riesling, a very versatile grape, is not grown in the area we found most suitable, and we attribute this to vintner's preference. Vintner's preference may take other environmental characteristics into account that are not directly related to cold survival, such as water saturation during the growing season. However, when we look at varietals like Cabernet Sauvignon, which are not nearly as versatile as Riesling, how can we explain the success of these grapes in regions outside of the suitability zones we identified? We believe that vintners are able to expand a grape's suitable range by adopting different management practices, implementing frost management techniques, or using GMO crops. All of these factors can be used to expand a grape's suitability range. This can be significant for new vintners that need to find cheap usable land, but also for established vintners who may need to battle the implications of climate change in the near future.

The advance of genetic technologies may allow for specific genes to be transferred from one varietal to another without compromising the valued properties of the varietal, which may be lost during cross-breeding (Tillett, 2014). A major gene that regulates a host of processes in cold acclimation is CBF4. The overexpression of CBF4 has been shown to increase cold hardiness by 2 degrees Celsius in *V. vinifera* vines (Tillett, 2014). It is not hard to imagine that an artificial increase in the expression of CBF4 would have similar consequences. As more genes are found to be involved in the cold acclimation process, more specific gene transfers can be developed to further accommodate the

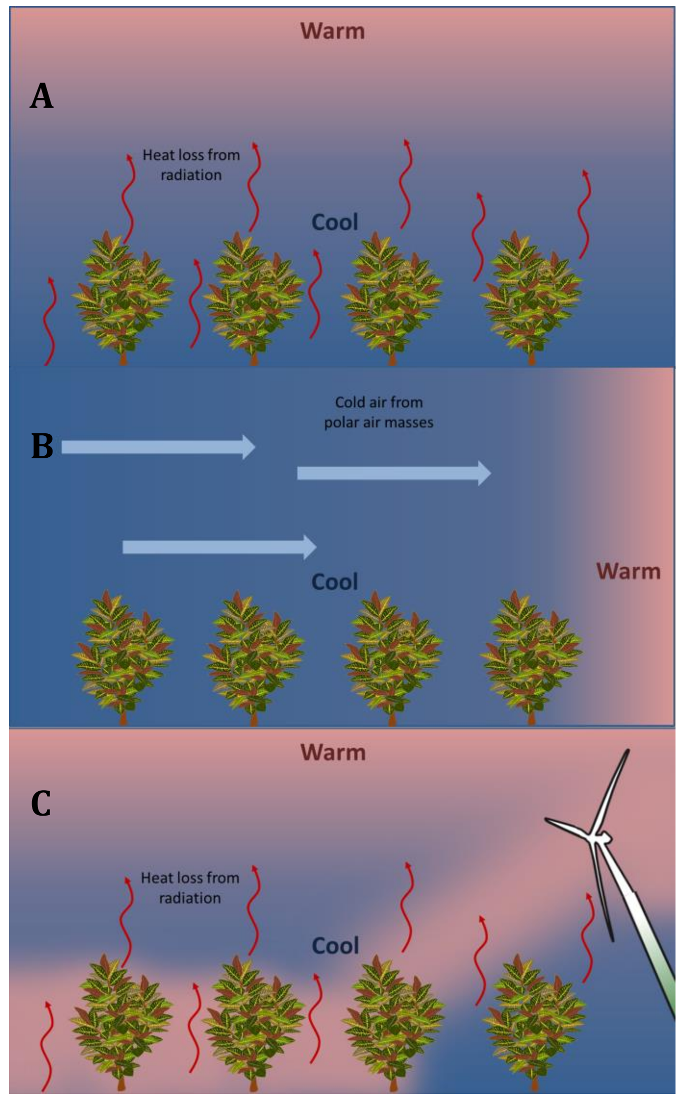


FIGURE 6: A) Radiative cooling whereby calm, flat conditions allow for heat to be taken away from the ground level by means of infrared radiation. This results in a temperature inversion with warm air on top and cold air below. B) Advective cooling whereby cold air masses are carried in by wind resulting in the displacement of any warm air. C) Wind machines can be used to move warm air back to the ground level in conditions prone to severe radiative freezing.

vines for a variety of conditions (Tillett, 2014).

Other techniques can be implemented during the most critical times of the year to actively mitigate frost damage. In flat growing areas that are prone to cold, calm conditions during winter, a system of wind machines can be placed throughout the vineyard to control dangerous temperature inversions (Shaw, 2002). Temperature inversions, which involve a significant change in temperature from the ground to several meters above the ground, have the capacity to cause radiative frost damage (Shaw, 2002; Figure 6A). Radiative frost is a process whereby dangerously cold air settles to the level of the vines and pushes warmer air up. Wind machines counteract this inversion by pushing the warm air located above the fans back towards the vines, which in turn causes the displacement of the cold air (Shaw, 2002; Figure 6C). This technique is not effective during advective freezing events characterized by moving bodies of cold air because there is no significant temperature gradient that requires displacement (Shaw, 2002; Figure 6B). Another process known as hilling can be used to insulate critical regions on the vine such as the graft union. A graft union is where the North American rootstocks are attached to the European trunks (Shaw, 1999). This area is more sensitive to disease and cold than other parts of the trunk. Hilling involves the use of soil, mulch or other insulating materials to cover the graft union in order to protect it during the coldest periods of winter (Shaw, 1999).

Chemical applications are useful methods for vintners looking to alter the onset of bud break in their vines. This can be beneficial in areas that have fluctuating temperatures in the spring or with varietals that require a longer growing season. A pathway that is important in the deacclimation of vines involves the return of respiration (Pacey-Miller et al., 2003). Stresses including increased daylight and temperature lead to an increase in oxidative compounds, which promote respiration. The introduction of artificial stressors, such as hydrogen cyanamide, can inactivate processes involved in the breakdown of oxidative compounds, leading to earlier bud break (Pacey-Miller et al., 2003). This can be beneficial in varietals that may not break early but exist in an environment where early breakage would not be detrimental to survival (Pacey-Miller et al., 2003). To delay bud breakage in areas prone to spring frosts, vintners can use special oils that can inhibit bud respiration (Qrunfleh and Read, 2013). The specific mechanism of action behind these oils is unknown but evidence suggests that they may block airflow into and out of the plant's stomata (Qrunfleh and Read, 2013).

IN CONCLUSION

Given the presented information, one can see that wine grapes have distinct growing requirements for proper development in order to produce optimal flavours. These requirements include cold hardiness, bud break timing, and length of the growing season; grape varietals differ with respect to each other regarding all of these requirements. If all of these factors are not properly acknowledged in viticultural practice, the sugar and acid content will be unbalanced and wine quality will be negatively affected. In order to accommodate for the requirements of each varietal, appropriate varietal-region combinations need to be established.

The most suitable region for growing any *V. vinifera* varietal can be determined when growing requirements are considered in conjunction with the climate characteristics of the growing region. We constructed suitability maps based on regional climate characteristics and determined that Cabernet Sauvignon should be grown in the Niagara Lakeshore sub-region, Riesling should be grown in the St. David's Bench sub-region, and Baco Noir should be grown in the Vinemount sub-region. Exceptions to these suitability maps became evident once we looked at the current distribution of these varietals in the Niagara region. We propose that deviations in the suitability range of a particular varietal can arise due to vintner's preference, or the adoption of management techniques. Vintners may need to adopt different viticultural practices in order to ensure they can continue successfully growing wine varietals despite possible shifts in their suitability zones brought on by climate change. We believe proper site selection must take all factors into account including nature of the varietal, regional climate characteristics, and viticultural practices in order to ensure the quality of each wine remains optimal when it finally reaches the glass.

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Can a Glass of Wine Help You Live Longer?

The potential of resveratrol and SIRT1 to improve aging and age-related diseases

YaChun Cao | Laura Hogg | Nathaniel Smith | Vincent So | Nicole Yokubynas

Since ancient times man has sought the elixir of life. Could this be found in a glass of wine? Recently, a natural molecule found in red wines known as resveratrol has been shown to prevent age-related diseases and promote longevity in plants and small animals. Researchers are currently investigating whether resveratrol can be used to treat human illnesses such as diabetes, cardiovascular disease, Alzheimer's disease and cancer. The curative properties of this molecule, if proven, may be the answer to delaying the onset of aging.

WHAT IS SO SPECIAL ABOUT

WINE?

It is natural for humans to be afraid of aging. It is an inevitable process associated with many debilitating ailments such as cancer, cardiovascular disease, neurodegenerative diseases, diabetes, and obesity (Smoliga et al., 2011). With the number of individuals over the age of 65 predicted to double by the year 2030, it will become socially and economically imperative for society to improve the aging process (Smoliga et al., 2011). It is encouraging then, to learn that a molecule has been found that may be able to extend the human lifespan and reduce the incidence of age-related diseases.

Interest in the benefits of wine consumption began with what is known as the 'The French Paradox'. Since the 1980's, epidemiological studies have found a surprisingly low incidence of cardiovascular disease in the French despite their characteristically high-fat diet. Scientists began to look to their frequent wine consumption as an explanation. Similarly, the recent discovery of the medicinal attributes of resveratrol, a small molecule commonly found in red wine has garnered much scientific attention (Hubbard, 2013). Evidence now suggests that this small compound promotes neurological and metabolic health, in addition to having cardiovascular benefits and anti-cancer properties. As well, interest in resveratrol has increased as it is found in red wine, making it easily accessible (Marques, 2009).

In addition to the observed French Paradox, interest in resveratrol has been sparked by another therapeutic program termed calorie restriction (CR), which has similar effects as resveratrol. This is a dietary regimen where a person consumes 30-40% less calories than with an unrestricted diet. CR has been shown to increase lifespan and slow the progression of aging. There is enormous interest in discovering mimetics, such as resveratrol, that provide the same health benefits as CR itself, without the need for such drastic lifestyle changes (Baur, 2010).

"Consuming wine in moderation will help people to die young as late as possible"

-Dr. Philip Norrie, The Wine Doctor

Identification of a potentially therapeutic molecule is only the first step in the process of developing therapeutic agents. It is essential to understand how resveratrol works in order to ascertain the dosage, contraindications and desired delivery format for a therapeutic program based on a given compound. Researchers believe that resveratrol's effect on the sirtuin family of enzymes is the key to understanding the metabolic processes involved in preventing age related diseases. Before we delve into these effects, we must first understand the characteristics of resveratrol and the functions of the sirtuin family of enzymes.

WHAT IS
RESVERATROL?

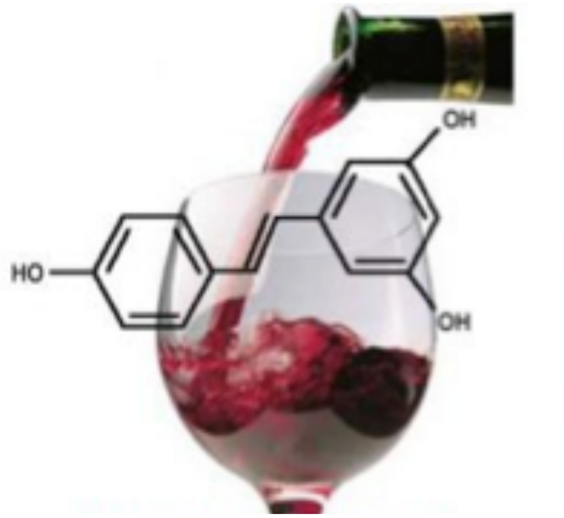


FIGURE 1: RESVERATROL STRUCTURE. The chemical structure of trans-resveratrol, a polyphenol commonly found in red wines.

Resveratrol was first discovered and isolated from the toxic roots of the white hellebore plant in 1940, however it wasn't until 1997 that it was recognized as a chemoprotective agent (Baur and Sinclair, 2006). Resveratrol (Figure 1), or 3,4',5-trihydroxystilbene ($C_{14}H_{12}O_3$), is a natural polyphenol characterized by a central carbon-carbon double bond attached to two phenol moieties (Quideau et al., 2011). It is found in various dietary sources including grapes, peanuts, and blueberries (Baur and Sinclair, 2006), with the highest dietary concentration found in red wine (Marques, 2009). Specifically, resveratrol belongs to the stilbene family of phytoalexins, a class of chemicals produced by plants as a protective stress response to UV light and pathogen infection (Knutson and Leeuwenburgh, 2008). Because resveratrol is a natural protective compound in plants, it is thought that perhaps other organisms, such as humans can also react to these stress-signalling molecules (Lamming et al., 2004).

WHAT ARE
SIRTUINS?

Sirtuins are a family of enzymes that are silent information regulators and are present ubiquitously throughout the body. In response to stress signalling molecules, they regulate several key biological pathways involved with aging. Sirtuins work by modifying the structure of proteins by either activating or suppressing factors which contribute to the aging process (Hubbard and Sinclair, 2013). The function of the sirtuin family of enzymes is highly conserved between the three domains of life. There are seven main classes of human sirtuin enzyme homologs (SIRT1-SIRT7) (Anekonda, 2006). SIRT1, predominantly located in the nucleus of cells, is one of the most promising and highly studied members of the sirtuin family (Hubbard and Sinclair, 2013). The plant equivalent of SIRT 1 is Sir2, and lower organisms, such as the yeast, *Saccharomyces Cerivasiae*, showed a 70% increase in lifespan mediated by the overexpression of Sir2 (Howitz, et al., 2003). It is this finding, that sparked the proliferation of research into the human equivalent, SIRT1.

HOW DO
SIRTUINS
WORK?

Fundamentally, sirtuins work by removing the acetyl group (deacetylation) from many important protein targets involved with the regulation of age-related diseases. These protein targets include histones and transcription factors, which regulate cell

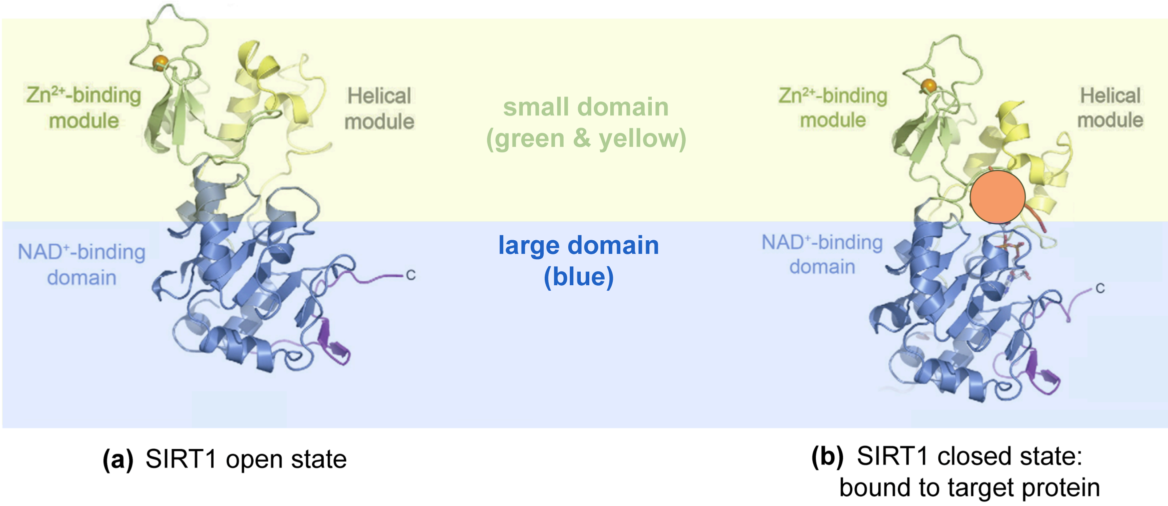


FIGURE 2: PROTEIN STRUCTURE OF SIRT1. Imaging showing the conformational change of the human SIRT1 homolog when bound to its substrate and dependent co-factor, NAD^+. The SIRT1 enzyme is composed of a larger NAD^+ binding domain and a smaller sub domain composed of a helical module and a Zn^{2+} binding module. A target protein (orange molecule) is shown bound to the active site (Modified from Davenport, Huber and Hoelz, 2013).

survival, immune responses, and energy metabolism. Histones are used to wrap and store DNA polymers within the nucleus. Deacetylation of histone tails allows DNA to wrap more tightly, slowing the transcription process. Transcription factors, on the other hand, bind directly to specific DNA sequences to affect transcription rates. Sirtuins are a class of nicotinamide adenine dinucleotide (NAD^+) dependent enzymes. The structure of SIRT1 (Figure 2) is composed of two domains. The larger of the two domains binds the NAD^+ molecule, and the smaller domain is composed of a helical molecule and a Zinc (Zn^{2+}) binding molecule. Once the sirtuin is bound to NAD^+, the enzyme undergoes a conformational change, which allows the target protein to be deacetylated. Figure 2a depicts an open state of the enzyme in which neither the NAD^+ nor the target protein are bound. However, when SIRT1 is bound to NAD^+ (Figure 2b), the smaller domain of the enzyme forms a tight inter domain bond with the larger domain. This creates a groove between the two sections, resulting in a hydrophobic active site for the protein substrate. During this process, the larger domain does not undergo any significant structural changes (Davenport, Huber and Hoelz, 2014). Details of this reaction can be found in Box 1. By understanding the activity of SIRT1, we can now look further into how resveratrol interacts with this key regulatory enzyme.

BOX 1: THE SIRT1 CHEMICAL REACTION

Before the reaction, the acetyl moiety of the target protein is covalently attached to an ADP-ribose molecule, which contains an acetyl-lysine bond. During deacetylation, this acetyl-lysine bond is hydrolyzed, which produces a compound named 2'O-acetyl-adensosine diphosphate-ribose (O-AcADPR) and the deacetylated protein target. The acetyl group from the reaction is transferred to NAD^+, thus creating nicotinamide (NAM) as an end product (Hubbard and Sinclair, 2013).

HOW DOES RESVERATROL RELATE TO SIRT1?

Resveratrol elicits its known effects by modifying sirtuin activity. The exact means by which this is accomplished is currently the subject of great debate and controversy in the scientific community. Overall, it is accepted that resveratrol affects the SIRT1 longevity pathway by increasing the overall activity of the enzyme. This occurs by increasing the binding affinity of the active site, which in turn increases the affinity for both the NAD^+ substrate and the bond (as noted in Box 1) of the target protein (Sinclair and Guarente, 2014). In vitro testing has demonstrated that the use of resveratrol has the potential to increase binding affinity 35 fold in terms of the protein target (highlighted bond in Box 1), and 5 fold in terms of its NAD^+ binding activity (Howitz et al., 2003). There are currently two very different proposed models that explain the resveratrol and SIRT1 interaction. Both models are complex and controversial, and perhaps they co-exist together, however, further research in this area is required to solidify the answer. The direct model proposes that resveratrol is able to bind at a regulatory site other than the active site (the allosteric site) on the SIRT1 enzyme to increase the affinity of the active site; while the indirect model proposes that resveratrol indirectly activates SIRT1 (Sinclair and Guarente, 2014).

DIRECT ACTIVATION MODEL

In this model, resveratrol, binds allosterically (see Figure 3) to the smaller domain of the SIRT1 enzyme. When bound, this causes an additional conformational change, which allows the smaller domain to form an even tighter groove with the larger domain, and increases stability for target protein binding.

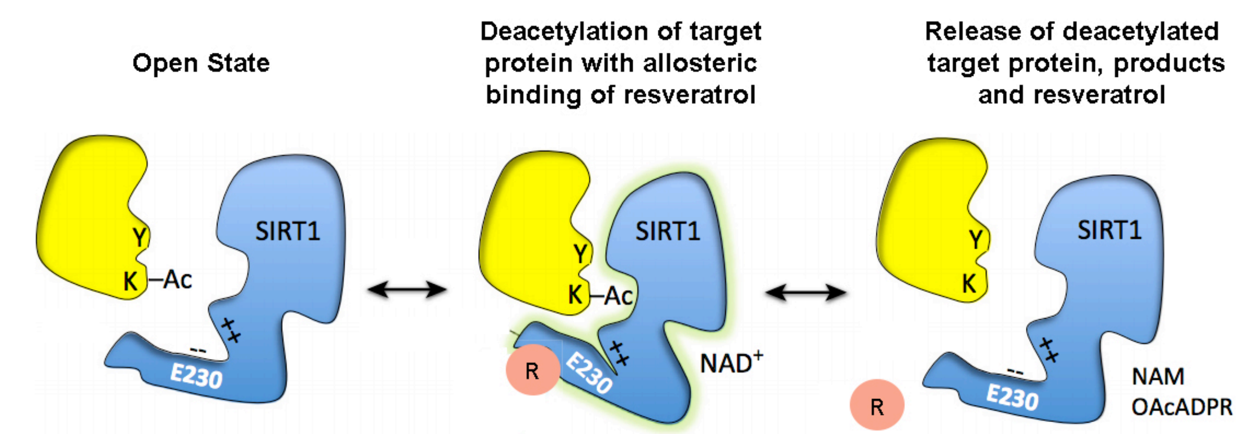


FIGURE 3: SIRT1 DEACETYLATION. Proposed mechanism for allosteric activation of SIRT1 by resveratrol. The Resveratrol (peach compound) binds to the N-terminus of the small subdomain of SIRT1 (blue molecule), which in turn, results in the formation of a tighter and more stable inter-domain binding grove for the deacetylation of the substrate (yellow molecule). The K represents the lysine residue, which is attached to the acetyl group (Ac) in the substrate. The Y represents the necessary hydrophobic residues that must be present on the substrate for increased binding affinity. The location of the mutation that supports this model of activation is indicated on the N-terminus of the SIRT1 enzyme (Modified from Hubbard and Sinclair, 2013).

As seen in the diagram, bound resveratrol enhances charged interactions of the amino acid residues, which provides enhanced stability (Hubbard and Sinclair, 2013). Initially the direct activation model was discredited as the first experiments testing the direct activation hypothesis used fluorescence assays. Critics argued that in fact it was the fluorescence molecules that were responsible for resveratrol's direct binding (Hubbard et al., 2013). It has since been shown that fluorescent molecules are not required, but instead, the substrates themselves (such as FOXO and PGC-1α), must contain hydrophobic residues near the site of deacetylation for optimal binding (Sinclair and Guarente, 2014). The conclusion being that the enhanced effect of resveratrol through allosteric binding on SIRT1 is substrate-specific (Lakshminarasimhan, et al., 2013). Evidence of this theory has been provided by mutations at the allosteric site in SIRT1, such as the mutation E230K, which prevent resveratrol from binding. This in turn prevents the desired increase of SIRT1 activity (Sinclair and Guarente, 2014).

INDIRECT ACTIVATION MODEL

The indirect model of activation states that resveratrol triggers a signalling cascade that is then responsible for up-regulating SIRT1. In one example of this model, resveratrol inhibits the protein cyclic AMP-specific phosphodiesterase (PDE), which results in SIRT1 activation. PDE works by reducing the cyclic AMP (cAMP) levels in the cell, which in turn, inhibits an AMP-activated protein kinase (AMPK). AMPK is responsible for controlling NAD^+ levels in response to the energy status of the cell (Sinclair and Guarente, 2014). Activated AMPK raises NAD^+ levels, which as a result, increases SIRT1 activity. Through down-signalling cascades, inhibition of PDE by resveratrol increases the concentrations of cAMP, which activates AMPK, leading to increased NAD^+ and increased activity of SIRT1 (see Figure 4). This second model also has a connection to the calorie restriction hypothesis, as calorie restriction also increases cAMP to elicit the same SIRT1 activating response as inhibiting the protein PDE (Park et al., 2012).

While these processes are complex, they are also controversial due to the different models of resveratrol activation, the and potential of other yet discovered interactions of resveratrol in the body. However, despite this discrepancy, there is sufficient evidence that resveratrol does increase the activity of SIRT 1 as a stress response (Hubbard and Sinclair, 2013). Understanding the process however is essential not only in the development of resveratrol as a therapeutic agent, but also in the overall understanding of the aging process in humans. It is evident that much more research is needed in this area to determine the accuracy of the proposed models.

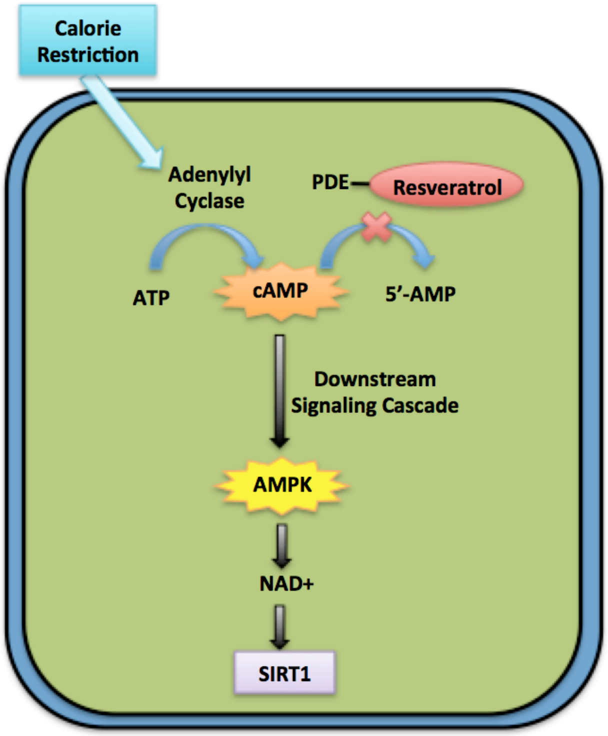


FIGURE 4: INDIRECT ACTIVATION OF SIRT1 BY RESVERATROL. Proposed mechanism for indirect activation of SIRT1 by resveratrol. Resveratrol binds to the enzyme PDE which inhibits the conversion of cAMP to 5'-AMP, thus increasing the overall concentration of cAMP. This increase leads to a down-signalling cascade, which activates AMPK to increase NAD^+ levels and SIRT1 activity. This mechanism is analogous to calorie restriction as calorie restriction also increases cAMP levels (Adapted from Park et al, 2012).

PARELLELS BETWEEN RESVERATROL AND CALORIE RESTRICTION

The simple explanation is that calorie restriction, while effective, can be difficult to maintain. Scientists are hoping that resveratrol can have the same efficacy with greater ease, and perhaps pleasure if consumed with wine. It is also hoped that an understanding of the processes involved with CR and resveratrol will further our knowledge of the aging process. Resveratrol has demonstrated a similar potential to CR to extend small animal and yeast lifespan, and it is thought to produce similar protective effects at the cellular level (Baur, 2010; Sinclair, 2005). It is believed that SIRT1 attenuates stress-induced apoptosis, and can increase or decrease apoptotic activity depending on the cell and the stimulus (Sinclair, 2005). One possible explanation concerning the similarities of CR and resveratrol in lengthening lifespan is that these molecules interact with similar age-related genes and might therefore exhibit similar effects in the body. In fact, there is a noticeable similarity in the genes targeted by CR and resveratrol (Ghosh, 2013).

As an organism matures, genes involved in the aging process are transcribed more rapidly, while the opposite is true for genes linked to repair and cell reproduction. These changes in transcription rates are a useful way of quantitatively measuring both the effectiveness of an anti-aging pathway, as well as its primary mechanism. A study using lab rats indicated that for genes associated with cardiac aging, both resveratrol and CR were found to prevent 76% of age-related changes in transcription. Additionally, they acted on almost all of the same genes, indicating mechanistic similarities (Ghosh, 2013). There were only slight differences in the specific genes targeted. These findings indicate that resveratrol mimics many aspects of calorie restriction, and that the mechanism of action occurs just before transcription, either through the function of deacetylating transcription factors, or deacetylation of histones. These findings are consistent with

BOX 2: HORMESIS AND XENOHORMESIS:

A prominent theory concerning why CR promotes longevity is the hormesis hypothesis (Sinclair, 2005). Recall, that it states that a low caloric intake will put the body under mild stress, which will activate the body's survival response. This hypothesis takes an evolutionary point of view, stating that an organism's goal in life is to reproduce. When times of scarcity occur, reproduction tends to be less successful due to low offspring survival; so investing resources into body maintenance becomes more beneficial. This can explain why CR seems to have so many effects, because it can trigger multiple innate pathways that respond to stress and nutrition. The hormesis hypothesis has seen some success in yeast and other model organisms, where different types of mild environmental stress were all shown to induce longevity (Sinclair, 2005).

The discovery that plant signalling molecules like resveratrol can cause CR-like effects has lead to an expansion of the original hormesis hypothesis, named xenohormesis (Sinclair, 2005). This newer hypothesis suggests that resveratrol and other CR mimetics do not induce hormesis in animals by chance, but instead are stress molecules developed based on reactions from plant-eating animals. It is thought that the presence of stress molecules in plants may warn of upcoming environmental hardship, and that organisms able to respond to this signal have a better chance of survival. While this hypothesis is still fairly untested, it may serve as the link between CR-mimicking molecules and longevity (Sinclair, 2005).

the mechanisms by which SIRT1 is suspected to slow senescence. As we noted earlier, the indirect model of SIRT1 activation also has a connection to calorie restriction (Park et al., 2012). Although resveratrol might work through a transcriptional mechanism similar to CR, the effects have yet to be definitively shown in humans (Ghosh, 2013).

Another interesting fact that was touched upon briefly was that resveratrol is known to be released by stress-induced plants in times of scarcity and a similar stress response occurs with the CR pathway. These two pathways might have evolutionary merit, which may explain how it is that resveratrol is able to increase activation of the longevity pathways, as explained through the xenohormesis hypothesis (See Box 2).

ROLE OF SIRT1 & RESVERATROL IN DISEASE PREVENTION

Imagine a molecule that would be effective in preventing and potentially providing treatment against almost all of the major health issues related to aging, such as cardiovascular health, cancer, type 2 diabetes, liver disease, and neurological degeneration. It would be more pleasant (and cheaper) if society didn't have to deal with these diseases, or at least, if the onset of these diseases were delayed. Research indicates that the over-expression of SIRT1 may have far reaching health benefits, which is related to the increased deacetylation activity of SIRT1 while interacting with resveratrol. Here are just a few examples of health benefits that have been investigated in conjunction with resveratrol and SIRT1. To start, heart specific SIRT1 activation has been shown to decrease cardiac hypertrophy, apoptosis and dysfunction (Knutson and Leeuwenburgh, 2008). It has also been suggested that SIRT1 overexpression can improve glucose homeostasis, enhance glucose-stimulated insulin secretion, and decrease body weight (Baur, 2010). These health effects are possible due to deacetylation of some of the key transcription factors involved in anti-aging processes including: p53, forkhead box protein transcription factors (FOXO), peroxisome proliferator activated receptor gamma co-factor 1α (PGC-1α) and nuclear factor (NF-κB) (Knutson and Leeuwenburgh, 2008). For example, deacetylation activates known regulators of energy metabolism, such as PGC-1α. In this way, mitochondrial biogenesis can be activated to help maintain blood glucose levels in times of starvation (Finkel et al., 2009; Baur, 2010). These findings indicate that SIRT1 activation is a promising new therapeutic approach for treating metabolic disorders such as type 2 diabetes (Milne et al., 2007). When it comes to cancer treatment, the role of SIRT1 is contradictory (Finkel et al., 2009). SIRT1 has been shown to decrease the activity of p53 and FOXO transcription factors, which are known to affect cell apoptosis and tumorigenesis (Finkel et al., 2009). While this decrease in apoptosis will prolong the lifespan of healthy cells and induce longevity, there is ongoing research regarding whether this same effect is seen in cancer cells, where it would be undesirable. On the other hand, SIRT1 may increase genomic stability through reactions with Werner helicase and NBS1, known factors that are involved in DNA repair (Finkel et al., 2009). This would help to prevent the onset of cancer. SIRT1 might play an even more important preventative role through interactions with NF-kB. This transcription factor induces apoptosis in cancer cells. Conversely, NF-kB is able to prevent apoptosis in neuronal cells, which has implications for various neurodegenerative related conditions such as Alzheimer's disease (Finkel et al., 2009).

Overall, SIRT1 exhibits cell-specific activity, where activating SIRT1 activity may have very different effects depending on the cell type (Tang and Chua, 2007). Resveratrol, a potent SIRT1 activator holds immense promise in treating many diseases (see Figure 5) such as type 2 diabetes, cardiovascular disease, neurodegeneration and inflammation (Knutson and Leeuwenburgh, 2008).

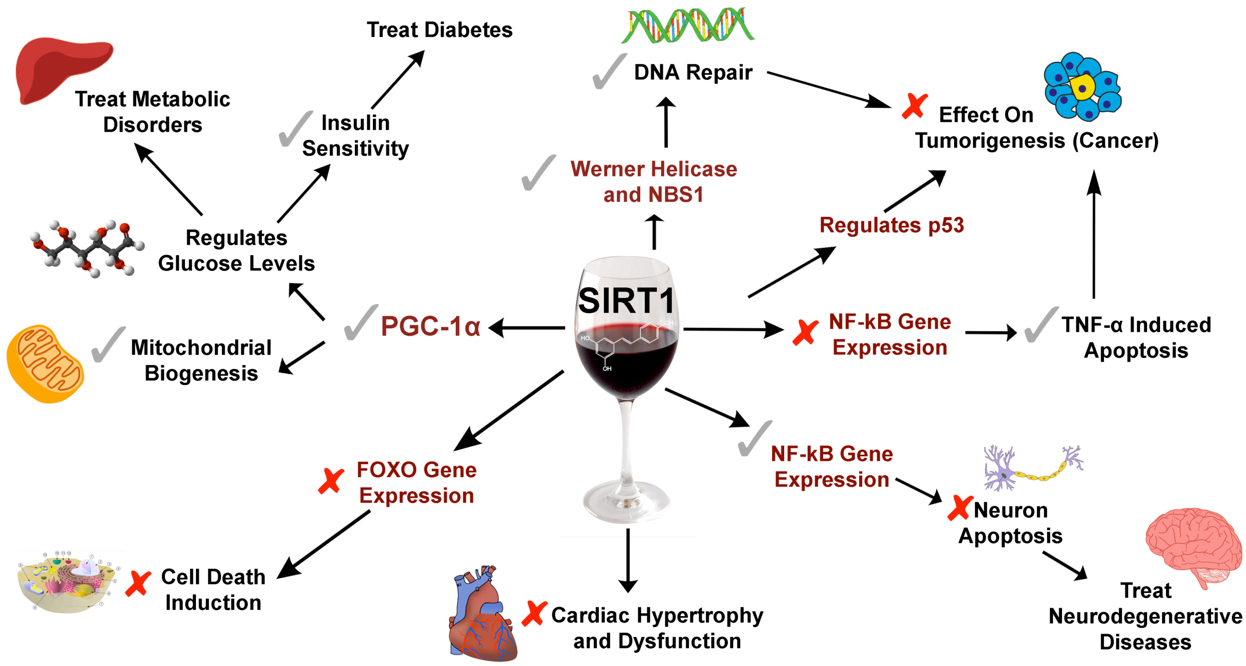


FIGURE 5: EFFECTS OF SIRT1 ON THE HUMAN BODY. Summary showing the effect of resveratrol activated SIRT1 on genes and gene products (potential proteins) that are involved in a variety of cellular processes. Red X's represent an inhibition or deactivation of that gene or gene product. Grey checkmarks represent an activation of a gene or overexpression of the gene product.

IS RESVERATROL A VIABLE THERAPEUTIC AGENT?

The biochemical effects of resveratrol on the SIRT1 pathway are still highly contested. Studies that compare in vitro and in vivo animal studies have presented various oppositional findings (Walle et al., 2004). The primary issue revolves around resveratrol's short half-life, and its resulting ability to reach target sites when ingested (Walle et al., 2004). This lack of bioavailability was attributed to its extensive metabolism, low systemic circulation, and limited stability which lead to a rapid decline in blood concentration (Walle et al., 2004). Studies indicate that metabolism through glucuronidation and sulfation may be the main limiting factor in resveratrol bioavailability (Walle et al., 2004). Furthermore, the presence of food with resveratrol administration can delay the absorption (Cottart et al., 2010; Vaz-da-Silva et al., 2008).

However, it has also been suggested that oral administration of resveratrol, such as in wine, could reach intestinal epithelial cells, oral cells and esophageal cells (Kaldas et al., 2003). These cells exhibit rapid uptake of resveratrol during the moderately brief transit time after oral ingestion, thus allowing resveratrol to have an effect (Kaldas et al., 2003). In addition, resveratrol has shown to be highly absorbed by epithelial tissues, and have the possibility to serve as protection against oral and colon related diseases (Walle, 2011).

Despite these results, resveratrol still holds promise as a therapeutic agent if its bioavailability could be enhanced. Fortunately, recent results show that the addition of an alkaloid compound known as piperine can significantly enhance the bioavailability of resveratrol in serum (Johnson, 2011). In addition, piperine is soluble in alcohol, making it possible to ingest wine with piperine present (Raman and Gaikar, 2002). This has major implications, as the rapid metabolism of resveratrol is thought to be the main limiting factor in observing resveratrol's health effects in human subjects (Johnson, 2011). Piperine is believed to inhibit glucuronidation of polyphenolic compounds, such as resveratrol (Johnson, 2011). This is complementary to previous findings that resveratrol is metabolized via glucuronidation and sulfation (Walle et al., 2004).

Resveratrol is considered well tolerated and non-toxic (Cottart et al., 2010; Williams et al., 2009). Adverse effects of the high dose of 5 g of resveratrol for 70 kg of body weight caused kidney toxicity, which only lasted a few days (Cottart et al., 2010). Other minor adverse effects include headaches, muscle pain in the lower extremities, and dizziness (Cottart et al., 2010; Almeida et al., 2009). For perspective, a typical bottle of wine has less than 5 mg of resveratrol (see Table 1). In summary, it has been shown that resveratrol is not available in its unchanged form after ingestion. Although this severely limits its ability to exert its various proposed health effects, there are methods that could be used to increase the concentration of unchanged resveratrol, and therefore increase its potential as a therapeutic agent.

HOW MUCH RESVERATROL IS AVAILABLE FROM WINE?

As it turns out, the type of wine and place of origin highly affect the concentration of resveratrol in wine, although finding the ideal combination is not easy. Resveratrol exists in both the cis and trans-isomeric forms, which have been suggested to have varying effects within the cell (Goldberg et al., 1996). Trans-resveratrol is considered one of the most potent phenolic constituents of wine (Goldberg et al., 1996). Most of the therapeutic potential literature focuses on trans-resveratrol; although researchers have recently hypothesized that cis-resveratrol may hold similar biological properties (Goldberg et al., 1996). Cis-resveratrol is a less stable compound than its trans counterpart, and is considered a byproduct of ultraviolet or visible light reactions (Cottart et al., 2010; Vaz-da-Silva et al., 2008). It is therefore important to study the regional differences in resveratrol isomer concentrations in wines from various cultivars. There are several trends that arise when isomers were being studied in relation to their geographic location (as seen in Figure 6). For example, the highest concentrations of both isomers were produced in areas of harsher climates, such as Canada (Goldberg et al., 1996).

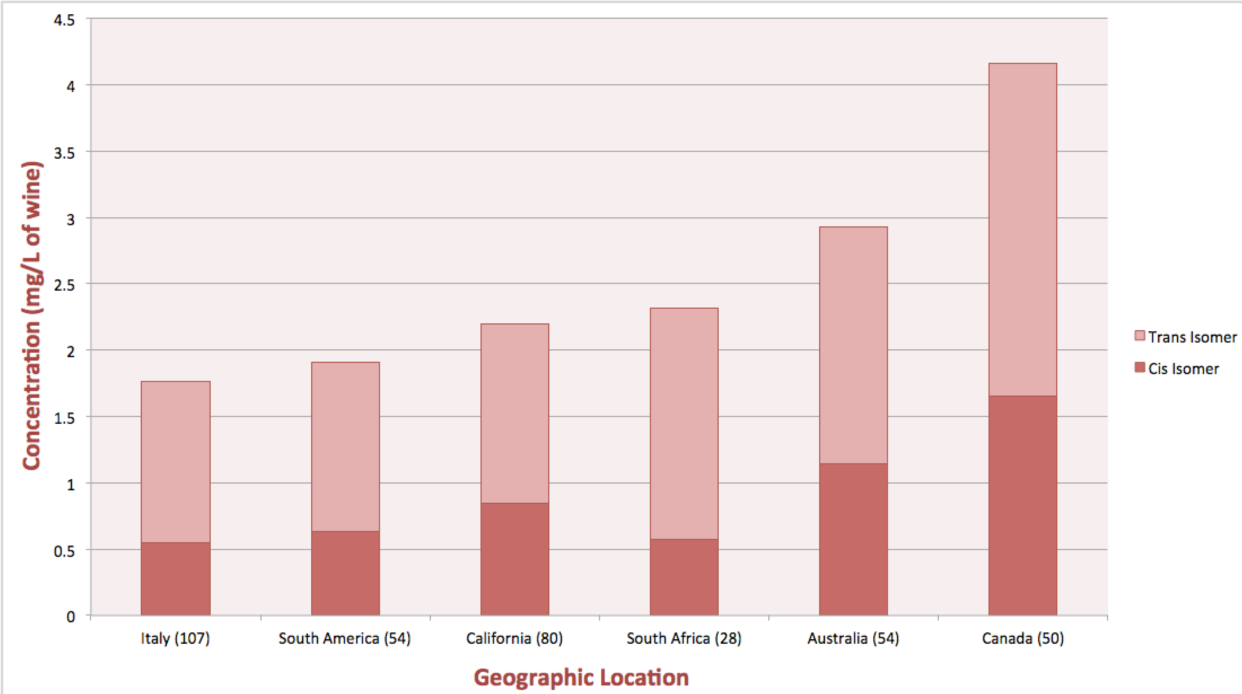


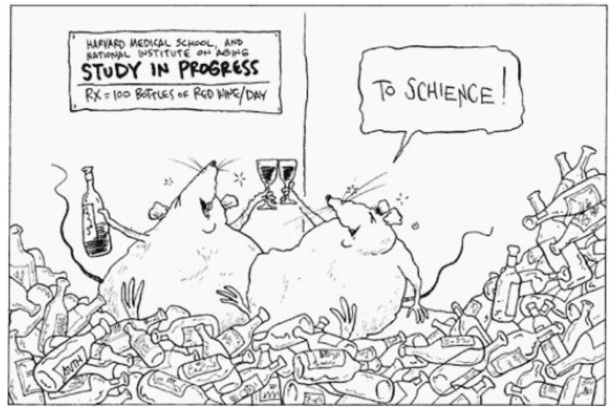
FIGURE 6:REGIONAL DIFFERENCES IN RESVERATROL CONCENTRATION.
A graphic representation of the geographic variation of both cis-resveratrol and trans-resveratrol concentrations. The values in the graph represent mean values in mg/L of wine. The number of wines utilized for the calculation of the mean is in parentheses in the data table. This table was modified from Goldberg et al., 1996).

When looking at the varietals, Cabernet Sauvignon had the lowest concentrations of resveratrol isomers, while Pinot Noir had the highest concentration (Goldberg et al., 1996). However, among the Cabernet Sauvignons, Canada had the highest overall resveratrol concentrations when compared to other regions (Goldberg et al., 1996). On the other hand, among the Pinot Noirs, Canada had the lowest concentration of resveratrol when compared to other regions (Goldberg et al., 1996). The concentration and ratio of isomers has been attributed to variations in climate, soil conditions, grape varietals, oenological practices, geographic location, and viticultural techniques (Goldberg et al., 1996). For example, oenological practices, such as aging in oak barrels and treatment with charcoal has been shown to cause major losses in both resveratrol isomers (Goldberg et al., 1995). Geography can also play a large role in the resveratrol isomer concentrations in wine, where even geographic sectors, known as terroirs, within the same appellation can be highly variable with respect to isomer concentrations (Goldberg et al., 1995). When comparing the three locations of Niagara-on-the-Lake, St. Catharines, and Grimsby, regions that are only 20 miles apart, the trans-resveratrol concentrations of the same varietals differed immensely (Goldberg et al., 1995). This has widespread applications for the Niagara wine region, where various terroirs can only support distinct varietals and therefore will produce varying varietal-dependent concentrations of resveratrol (Goldberg et al., 1996).

Overall, the concentration of cis and trans resveratrol isomers is highly erratic. Many factors such as geographic location, aging process, grape varietal, type of wine, and soil conditions all play a hypothesized role in the concentration and ratios of the isomers. All these factors must be considered before a wine is chosen, and potentially marketed for its therapeutic benefits.

CONCLUSION

Is the resveratrol that is found in wine the magic elixir that everyone is looking for? The honest answer to this question at this time is that it is unknown. Indeed, there are many mechanisms where these molecules may provide beneficial effects against age-related diseases. Within the past two decades, researchers have turned their focus to finding confirming evidence of health benefits from the resveratrol activated SIRT1 pathway. However, there are many conflicting results and a better understanding of the underlying mechanisms is needed. In addition, the issues surrounding the bioavailability of resveratrol and the dosages required need to be resolved. The aging demographics of our population have given rise to a great societal need for such a curative substance. In spite of promising preliminary evidence of the health benefits of resveratrol, years of research stand between our current understanding of this molecule and the therapeutic use of this substance. In the meantime, there is no rush to place an order for a lifetime supply of wine. However, if you are already a frequent wine consumer, you might want to keep an eye on the literature concerning resveratrol's role in activating the SIRT1 pathway. In fact, you might consider pairing your next Pinot Noir with some food for thought.



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A Glass of Wine a Day Keeps the Doctor Away

Jessica Kun, Drake Lee, Jonathan Park, Daim Sardar, and Lauren Smith

Na Zdorovie, a Russian phrase meaning "To good health", is commonly used when glasses clink around friends and family at celebrations. Remarkably, simply by drinking the red wine held in these glasses, you are already on your way to good health! Indeed, studies have shown that the presence of certain organic compounds, called polyphenols found in wine is linked to a lower incidence of cardiovascular heart disease. A large amount of epidemiological data exists on this topic, leading to the hypothesis that the French typically experience less heart disease than North Americans because of their routine consumption of red wine. This article will investigate whether wine produced in the Niagara region would be able to yield similar health benefits compared to French wine. In order to understand the motivations behind this, we will focus on atherosclerosis, a specific and potentially deadly cardiovascular disease, and investigate the mechanisms behind ethanol and polyphenol action in the human body. So without further ado, pour yourself a nice glass of red wine, sit back, and enjoy this paper while your heart enjoys the health benefits.

The day is March 6th, 1972. The Johnson family sits down for dinner in their lovely suburban home in Madison, Wisconsin, after a long day. Mrs. Johnson spent hours laboring in the kitchen to prepare a lovely and especially healthy meal for her husband and son. She has been reading about the best foods to prepare to live a long and healthy life. She is being extra careful to not give her husband foods that are high in fat, as in some of her readings, a high fat diet can potentially lead to the onset of coronary heart disease (CHD), and she has no plans of burying her husband for a long while. Thus, the Johnsons enjoy a meal of sautéed chicken breast, seasoned vegetables and roasted potatoes with a glass of water to wash it all down.

On the same day in Marseille, France, Mme. Dubois prepares a meal for her family before they come home. Being raised by her grandmother who was a well-respected culinary artist, she greatly values traditional French meals and takes great pride in her cooking. She prepares a traditional French meal of filet mignon and baked potato sprinkled with bacon bits. Afterward, she sets out a glass of wine with baked Camembert for her and her husband, as she does every night.

What are the differences between these two household meals? At first glance, we can see that the American household has a stereotypical, healthy meal compared to the French household as it contains a significantly smaller amount of fat. Mrs. Johnson was extra careful to cut down on the fat as she knows that it is a contributor to CHD, specifically atherosclerosis. Atherosclerosis is one of the largest contributors to heart disease. In fact, globally, it is the leading cause of disease and death. Its multifaceted nature makes it nearly impossible to prescribe preventative measures for, short of simply eating less fat (Bentzon et al., 2014). However, statistics have shown that the French have less incidence of coronary heart disease than Americans, regardless of the fact their dietary differences would suggest the opposite. Now why would that be? What is the major difference between these households that allows for this?

This trend was first noticed in the early 1980's and has since been coined the "French Paradox". Thirty years later, the mystery is still not completely understood; nonetheless, many scientists believe that it is the French populations' habitual drinking of red wine with their meals that may have something to do with it. Alcohol on its own is known to have beneficial effects on heart disease when consumed moderately. As well, wine is thought to be even more effective as a therapeutic agent due to its high content of polyphenols, which are known to have a wide range of health benefits due to their powerful antioxidant capabilities.

In order to evaluate the validity of this claim as a potential explanation to the French paradox, it is necessary to understand the etiology of coronary heart disease and therapeutic effects of polyphenols. Additionally, not all grapes contain the same amount of polyphenols; in order to attempt to extend the health benefits of red wine beyond the scope of France, a comparison of the polyphenol content of varietals grown in contrasting geographical locations must be made.

"Atherosclerosis is the leading global cause of death and disability (Benzton et al., 2014)"

THE PROBLEM

Atherosclerosis is essentially a plumbing issue. It is defined as the hardening and thickening of the arterial walls as a result of plaque buildup triggered by the accumulation of white blood cells. This leads to a variety of issues, often including calcification and plaque buildup, which can ultimately lead to increased blood pressure and CHD. In fact, atherosclerosis is the leading global cause of death and disability (Bentzon et al., 2014). Atherosclerosis is a difficult disease to label and track as there are a wide number of independent causes making it a multifaceted disease. A wide number of different risk factors such as smoking, gender, complimentary diseases like diabetes, and even genetic composition make universally effective preventative measures difficult to come by. In addition, this makes the disease present itself in a variety of ways, despite having a fairly consistent mechanism. For example, smokers are much more susceptible to heart attacks while those with high blood pressure are at increased risk for the development of strokes (Bentzon et al., 2014). The five main stages of atherosclerosis are depicted in Figure 1.

The natural accumulation of smooth muscle cells in arteries is a precursor to atherosclerosis (Figure 1A). The cause of this is still unknown; however, it appears to develop spontaneously after birth. The areas with higher levels of smooth muscle cells are more susceptible to the development of foam cells. Foam cells are white blood cells which attempted to break down too many fats, and are instead surrounded by the lipids they attempted to

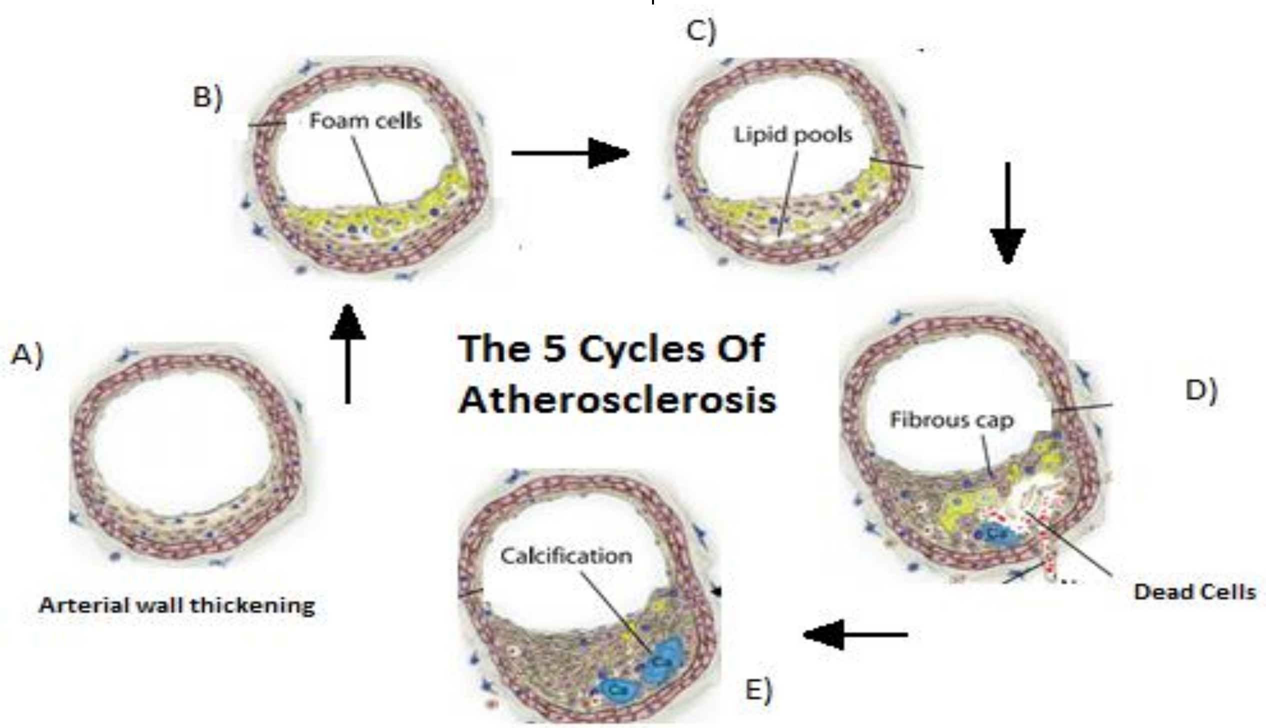

FIGURE 1: The five stages of atherosclerosis. A) Areas of the arterial wall which experience the accumulation of smooth muscle cells are more susceptible to atherosclerosis. B) The first real step is the accumulation of Foam Cells. C) Foam cells can trap lipid pools underneath them. D) Lipid pools can create large graveyards of dead cells. E) These create calcium buildup which can aggregate to form calcified plaques. The entire process severely weakens the arterial wall (Bentzon et al., 2014).

attack, giving them a foamy appearance (Figure 1B) (Bentzon et al., 2014). This can actually be seen by the naked eye after several layers have formed. Often, the disease does not progress any further than this. However, some will begin to develop lipids underneath the foam cells. These will combine into small lipid pools which don't dramatically alter the structure of the arterial wall. Again, this stage is fairly harmless as the structure has not been greatly perturbed, and the inflammation so far has been minimal (Figure 1C) (Bentzon et al., 2014). These harmless lipid pools can be transformed into large graveyards of cells with the arrival of apoptotic inducing white blood cells. It is thought that these bringers of death are actually constantly present, and serve to balance out the creation of foam cells; however, when the remnants of the dead cells are not sufficiently removed this can lead to a core of dead cells, referred to as a necrotic core (Figure 1D). It is not understood why certain people will develop these necrotic cores while others do not, and as mentioned earlier this is likely due to the multifaceted nature of atherosclerosis. The development of these groups of dead cells increases the rate of cell death by further preventing the leftover waste from being removed. This acts further to decrease the ratio of dead cell removal to production (Bentzon et al., 2014). Finally, from this debris, clumps of calcium can aggregate and form calcified plaque deposits (Figure 1E). The necrotic cores and calcium deposits severely weaken the integrity of the cell walls and notably change the structure. In addition, a large amount of inflammation is present at this stage from both of these materials. This leaves the individual susceptible to CHD via many different mechanisms. Some of the main causes come from blood clots blocking the flow of blood through the arteries or by sudden plaque hemorrhaging in the affected artery (Bentzon et al., 2014).

Generally speaking, the most effective way to stop the progression of the disease would be to prevent it from occurring in the first place. With that in mind, scientists have put a lot of effort into the first stage of atherosclerosis development, the accumulation of foam cells. This is in fact a fairly complicated series of events, the first of which is the trapping of low density lipoproteins (LDL), featured below in Figure 2.

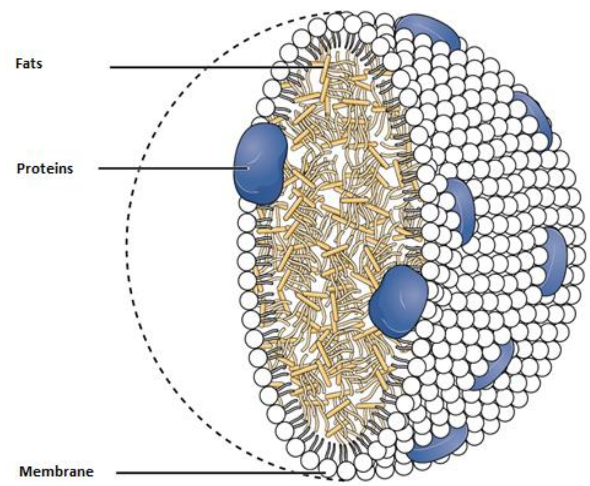

FIGURE 2: The structure of a typical Low Density Lipoprotein. The majority of the molecule is composed of fats. The oxidation of the proteins is far more dangerous than the oxidation of the fats (Wikimedia, 2014).

LDLs are large molecules composed mainly of various fats, with a few proteins embedded into its surface. These cells are responsible for cholesterol transportation to the arteries and as such, high levels of cholesterol in the diet will result in a high LDL level around arterial cells. This occurs because as LDLs are transported across the arterial wall, some can get trapped in the fibrous tissue in the wall (Berliner et al., 1995). There are numerous, incompletely proven theories surrounding how LDL goes on to promote foam cell formation. One major theory suggests the cells in the arterial wall secrete oxidative products, which initiate fat oxidation in the LDL. This oxidation predominantly targets the fats in LDL, however it also results in the cells covering the arterial wall producing promoters for strong oxidizers called monocytes (Berliner et al., 1995). These are yet another type of white blood cell that then lend their oxidative power to the fight, resulting in both the fats and proteins being oxidized. Once the proteins are oxidized, they are no longer recognized as LDL by other macrophages. Instead, they are simply viewed as a generic molecule that needs to be attacked. The main issue is that the macrophages only attack a LDL molecule if there is an acceptable level of fats in the environment. When it loses sensitivity, it completely demolishes the LDL, thereby releasing an enormous amount of fat. This results in a massive uptake of lipids into the cell, forming foam cells (Berliner et al., 1995). On top of all this, the oxidized LDL is a large promoter of inflammation or multiple cytokines in the same way they sparked the promotion of monocytes (Bentzon et al., 2014). Finally, extremely oxidized LDLs have been found to be toxic to macrophages. This further increases inflammation and cell death, assisting in the formation of the core of dead cells (Bentzon et al., 2014). The overall process feeds on itself, each step aggravates the previous, resulting in a cascade of oxidizing and toxic materials being released. Virtually all of the signs and symptoms of atherosclerosis appear to be preventable by inhibiting the oxidation of LDL. This is where our story extends to how consistent, small doses of red wine may prove beneficial to cardiovascular health.

THE MICROSCOPIC SOLUTION

In order to understand what it is about red wine that can help reduce the symptoms of atherosclerosis and perhaps save Mrs. Johnson's husband from an early grave, we have to look at the little things. The really little things. In particular, the molecular components of the grapes. Red wine is thought to have large antioxidant properties due to the high polyphenol content in grapes. The general structure of a polyphenol involves one to three six carbon rings with oxygen bound to hydrogen bound to some of the carbons on the rings (Figure 3). Within a grape, the largest concentration of polyphenols is found in the seeds, followed by the skin,

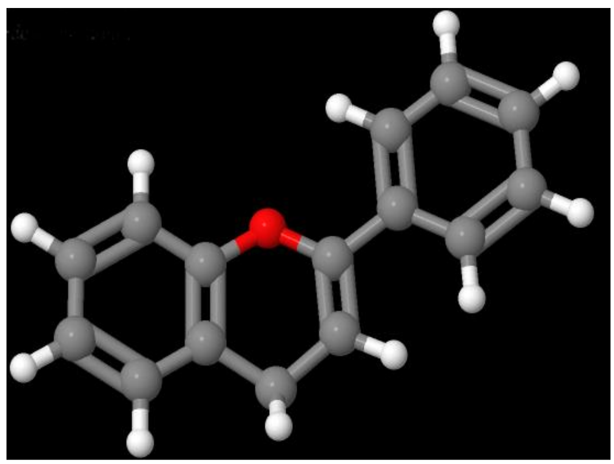

FIGURE 3: The general structure of a flavonoid. Carbon atoms are grey, hydrogen atoms are white and oxygen atoms are in red.

leaf, and flesh (Xia et al., 2010); the high polyphenol content in grape skin is why white wine does not have a similarly therapeutic reputation. Polyphenols are sorted in multiple subclasses based on their structure. The most prominent one found in wine is flavonoid (Manach et al., 2004).

As we know, the onset of atherosclerosis is triggered by the initial oxidation of LDL molecules. The lipids in LDL are oxidized by free radicals, usually in the form of the unstable hydroxide ion. LDLs can undergo lipid peroxidation - the oxidation of lipids by free radicals, usually unstable OH-radicals. This occurs when the radicals steal electrons from the lipids to become stable themselves, consequently damaging the lipids (Rice-Evans, Miller, and Paganga, 1996). The formation of free radicals can be catalyzed by metals such as copper found in the body, and because of their structure, antioxidants have the ability to bind these metal ions, thus reducing their negative effects (Rice-Evans, Miller, and Paganga, 1996). It is the antioxidant properties of the flavonoids that aid in the stability of LDLs. Two main methods of antioxidant activity that aid in preventing LDL oxidation are by binding metal ions and scavenging lipid free radicals by acting as hydrogen donors. The structure of the flavonoids gives great insight into its antioxidant properties. When a lipid radical is formed through the reaction of a lipid with a free radical, the polyphenol donates electrons to stabilize it, and a phenoxyl radical is the result (Rice-Evans, Miller, and Paganga, 1996). This radical is stabilized by the sharing of electrons within the rings of the molecule, thus resulting in a molecule that is not as reactive as before. Flavonoids with varying placement of the oxygen and hydrogen groups around the carbon rings have different antioxidant strengths.

While theoretically the polyphenols in red wine should reduce LDL oxidation via antioxidant effects, the question about whether these effects are evident remains. A wide array of studies conducted on this topic show that drinking red wine does in fact have a pronounced effect on decreasing LDL oxidation. Up to a 20% decrease in LDL oxidation has been shown in various studies when comparing red wine to white wine (Fuhrman et al., 1995). This is as expected because there are little to no polyphenols in white wine as the grape skin is not left in the must (pressed grape juice) during wine production.

KEEP CALM AND DRINK ON

Are polyphenols the only players in the game when it comes to red wine that helps to lower the Dubois family's incidence of CHD? Why is it that we do not extend the French Paradox hypothesis to include additional alcoholic beverages? Research has compared the antioxidant effects of various alcohols to conclude that red wine is the only kind to show positive health benefits. As we already know, red wine polyphenols can lower the incidence of atherosclerosis but another major component of wine is ethanol, which similarly plays a role in lowering LDL oxidation (Guilford and Pezzuto, 2011).

Currently, there are three main theories regarding the effect of ethanol on atherosclerosis. The first theory states that ethanol reduces the risk of atherosclerosis by performing a function similar to that used by polyphenols. The second theory is that ethanol does not have any effect on atherosclerosis, and that it is only polyphenols that participate in preventing atherosclerosis. Finally, the third theory proposes that ethanol and polyphenol must be present together to produce a synergistic effect that hinders the development of atherosclerosis.

One of the most prominent hypotheses among researchers is that there is an inverse relationship between light or moderate alcohol consumption level and the risk of atherosclerosis (Di Castelnuovo et al., 2002). Human studies have shown that moderate intake of ethanol, alcoholized and dealcoholized red wine, and sparkling wine led to the outcome of lower atherosclerosis risk (Vazquez-Agell et al., 2007). In addition to lowering the level of LDL oxidation, some animal models suggest that ethanol may also demonstrate anti-inflammatory effects (Li and Mukamal, 2004), as some studies indicate inflammation as a potential mechanism of atherosclerosis (Imhof et al., 2008). On the other hand, researchers have demonstrated that high consumption of red wine (>100mL per day) displays a tendency to enhance the formation of LDL cholesterol and increase atherosclerosis onset, so it is important to recognize that moderate consumption (~50mL per day) of red wine is most beneficial (Kiechl et al., 1998).

A few studies have proposed that ethanol does not have any effect on the formation of atherosclerosis. It was hypothesized that components other than ethanol in red wine must induce additional benefits to lowering the LDL oxidation since the ethanol content in red wine is similar to that of most of other alcoholic beverages (Rimm and Stampfer, 2002). Further studies have demonstrated that dealcoholized red wine increased the concentration of plasma antioxidants and decreased the level of atherosclerosis development, particularly in the aorta (Stocker and O'Halloran, 2004). This simultaneously displayed a resistance to the LDL cholesterol concentrations which suggests that ethanol may not have any effect on preventing atherosclerosis. In addition, other studies have shown that occasional alcohol consumption (<1 per week) had no effect on atherosclerosis (Kiechl et al., 1998).

Lastly, research indicates that ethanol and polyphenol components must be present together to induce a synergistic effect, which could potentially be one of the explanations of the French Paradox (Vazquez-Agell et al., 2007). It was found that an ideal amount of red wine intake is no more than approximately 50mL per day on average, since the light drinkers of red wine were associated with lower risk of atherosclerosis compared to heavy drinkers or abstainers (Kiechl et al., 1998). It was even proposed that this additive effect of ethanol intensifies when there is a higher concentration of polyphenols in red wine, suggesting that red wine varietals that vary in polyphenol concentration can have different levels of efficacy in terms of decreasing LDL oxidation. A decreased onset of atherosclerosis is also observed when red wine is consumed with meals (Figure 4) that contain flavonoids, such as fruits and vegetables (Locher et al., 1998; Da Luz and Coimbra, 2004).

FIGURE 4: Having a meal with red wine. The consumption of red wine with meals such as fruits and vegetables can lower the risk of atherosclerosis better than drinking red wine only (Locher et al., 1998; Da Luz and Coimbra, 2004).

Researchers still do not know exact mechanisms of how ethanol decreases the risk of cardiovascular disease, particularly atherosclerosis (Das and Vasudevan, 2007). Due to the lack of understanding and on-going controversies on the mechanism and potential side effects of ethanol consumption, there exists a common misconception among the public that "if some alcohol is good, then more is better"

> "Ideal amount of red wine intake is no more than 50mL per day on average (Kiechl et al., 1998)"

(Wollin and Jones, 2001). Although few studies have indicated that ethanol does not have any effect on atherosclerosis, still the prominent finding is that ethanol in alcoholic beverages can reduce the risk of atherosclerosis and when combined with polyphenols in red wine, it may induce a greater effect. Nevertheless, this is an area of research that requires further studies (Das and Vasudevan, 2007).

IS FRENCH WINE REALLY THE BEST?

The French Paradox refers to the relatively low incidence of CHD in the French population despite a diet rich in saturated fats, compared to the higher incidence of these diseases in the North American population. There are many hypotheses that attempt to explain this supposed trend, including one that focuses on the relationship between regular consumption of red wine and reduced risk of CHD. The regular intake of red wine being correlated with healthier hearts in the French population could either mean that the French consume more wine than North Americans or that French wines contain compounds that are more beneficial to cardiovascular health than wines produced elsewhere.

Although all red wines contain polyphenols, the degree to which they are expressed is potentially varied depending on the winemaking process. Different geographical locations have their own established terroir that has a pronounced effect on the type of red wine produced. This begs to ask the question whether varying geographical locations have anything to do with the polyphenol content in red wine. A comparison of wine produced in the Niagara region and that in Europe (particularly in France because of the French paradox) on the compound called resveratrol will shed some light on this question.

Terroir is described as the specific environment comprised of the soil, climate, and cultivar in which grapevines (Vitis vinifera) grow in (Thiollet-Scholtus et al., 2013; Leeuwen et al., 2004). Along with the production process, this is one of the most important factors affecting the quality of wine. The climate of northern France is best comparable to that of Canada's because they observe winter temperatures that do dip below 0° C (Mcdonald et al., 1998). A popular wine making region in France is Bordeaux, located in the southwestern region. The soils in this region vary from gravelly soil containing lots of stones to sandy soil which contains clay (Leeuwen et al., 2004). A variation in the soil type allows for a variety of effects on nutrient uptake and availability to the vine. Comparatively, outside of France, the influence of terroir on wine quality is rarely taken into account and is just recently being studied for wines from the Niagara region. Ontario grapes are typically grown on gleysol and luvisol - wetland soils that are saturated in groundwater (Geenough et al., 2005). It has been shown that differences in specific climates have a much greater influence on wine quality than the type of soil the grapes were grown from (Reynolds et al., 2013). A review paper by Reynolds et al. found that different soil types in the Niagara region do have a significant impact on grape yield, but not on the overall quality of the wine produced from the grapes. The Niagara wine-growing region is situated in such a unique location that the lake effect from Lake Ontario and Erie allow a much milder climate than the surrounding areas with a greater amount of rainfall in the spring and autumn (Haynes, 2000). There have been seven possible terroir regions caused by specific air flow over the Escarpment identified in the Niagara Peninsula (Haynes, 2000).

In order to compare Canadian Niagara wines with European wines, details about the possible health benefits of Ontario wines must first be understood. For most Ontario wines, total polyphenol content was found to be between 5 and 20-fold higher in red wines than white wines (Solease et al., 1997). The most predominant polyphenols found in Niagara white wines were ferulic acid, caffeic acid, and p-coumaric. Red wines dominated in concentrations of other polyphenols including gallic acid, catechin, and spicatechin but also contained high concentrations of caffeic acid (Solease et al., 1997). The highest concentrations of polyphenols in white wine were found in Reisling while the highest concentrations in red wine were from Pinot Noir varietals (Solease et al., 1997).

Focusing on one type of polyphenol can allow direct comparisons between concentrations found in Niagara wine and European wines. Trans-resveratrol is a natural polyphenol that is found in various plant species and acts as a line of defense for fungal infections (Goldberg et al., 1995(a)). Studies have shown that trans-resveratrol could act in the human body to block the oxidation of LDL, inhibiting a mechanism of atherosclerosis onset (Frankel et al., 1993). In fact, studies using solely Niagara wines showed significant in vivo increase in beneficial high density lipoprotein cholesterol and apolipoprotein, which both aid to clear LDL build up in the arteries (Goldberg et al., 1995(b)). A similar study showed that both Niagara red and white wine showed a significant antiaggregatory effect of platelets in human subjects (Pace-Asciak et al., 1995).

Research has been done to compare concentrations of trans-resveratrol in wines grown from regions around the world, and found that Niagara wines contained levels comparable to French wines (Goldberg et al., 1995(a)). Trans-resveratrol levels in white wines were found to be very low (>0.01mg/L) in wines from all regions, however red wines seemed to contain significantly higher concentrations. VQA Niagara wines (made from locally grown grapes) had a mean trans-resveratrol concentration of 3.16mg/L, which was significantly higher than Italian red wine concentrations. While the mean trans-resveratrol concentrations in French red wine were higher than Niagara wines at 3.89mg/L, it was not significantly higher taking error calculations into account (Goldberg et al., 1995(a)). One hypothesis to explain the similarities of trans-resveratrol levels in French and Niagara wines claimed that the cool and humid climate common to both regions, compared in Figure 5, could affect the

"Niagara wines contained [*trans*-resveratrol] levels comparable to French wines (Goldberg et al., 1995(a))."

growth and overall trans-resveratrol levels in the grapes (Goldberg et al., 1995(a)).

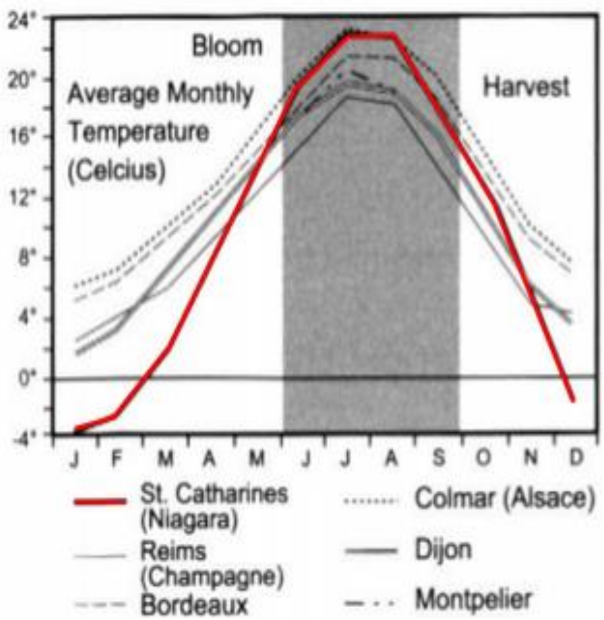

FIGURE 5: Average Temperatures between Geographical Regions. Comparison of monthly temperatures in wine-growing regions in Ontario and areas within France shows a very similar pattern (adapted from Haynes, 2000).

CONCLUSION

Revisiting the Dubois family from earlier, we may now come to understand why they experience positive health benefits from drinking wine. Dodging heart disease had more to do with the consumption of red wine than the avoidance of fatty foods. In particular, this study looked at the incidence of atherosclerosis, a potentially fatal CHD quite prevalent in our modern society. Atherosclerosis is caused by the buildup of plaque and white blood cells within arterial walls and is thought to be a result of poor diet and lack of exercise. Inside the body, this results in LDLs becoming trapped in artery walls and being oxidized by free radicals in the bloodstream.

While both the Dubois and Johnson families indulge in a diet with similar levels of high-fat foods, the addition of French wine to the meal resulted in the introduction of anti-oxidizing polyphenols. Polyphenols are organic compounds found in many fruits and vegetables and in very high levels in red wine via grape skins. This explanation is adapted from the French Paradox, which hypothesizes that the regular moderate consumption of red wine can lead to anti-oxidizing effects in the bloodstream that lowers the overall incidence of atherosclerosis and thereby coronary heart disease for an individual. It was found that this moderate consumption would be approximately 50mL of red wine consumption per day in average and led to better results when consumed simultaneously with other meals such as fruits and vegetables.

Are French wines simply more beneficial to health by having higher polyphenol levels than North American wines, specifically those from the Niagara wine-growing region? Investigating a handful of studies conducted on Ontario and French wines, we found that red wines from the Niagara regions boast similar concentrations of specific polyphenols such as trans-resveratrol compared to wines from France. This may be a result of the very similar climate during grape growth and harvest between the two regions. From this, we are able to conclude that if the Canadian population consumed a regular moderate amount of Ontario wines just as the French do, they may be able to experience cardiovascular health benefits associated with a glass of red wine. After understanding the ways in which wine can combat deadly cardiovascular diseases, there is no question of which alcoholic beverage is the most superior. So next time you find yourself at a dinner party, opt for a glass of red wine and your heart will surely thank you.

MORE TO EXPLORE

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Figures

Figure 1: Adapted from; Bentzon, J.F. et al., 2014. Mechanisms of plaque formation and rupture. Circulation Research, 114(12), pp.1852–66. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/24902970>.

Figure 2: Adapted form; Wikimedia Commons. (2014). Chylomicrons Contain Triglycerides Cholesterol Molecules and Other Lipids. Retrieved November 18, 2014, from <http://commons.wikimedia.org/wiki/File:2512_Chylomicrons_Contain_Triglycerides_Cholesterol_Molecules_and_Other_Lipids_gl.jpg>.

Figure 3: Image created from; The PyMOL Molecular Graphics System, Version 1.5.0.4 Schrödinger, LLC.

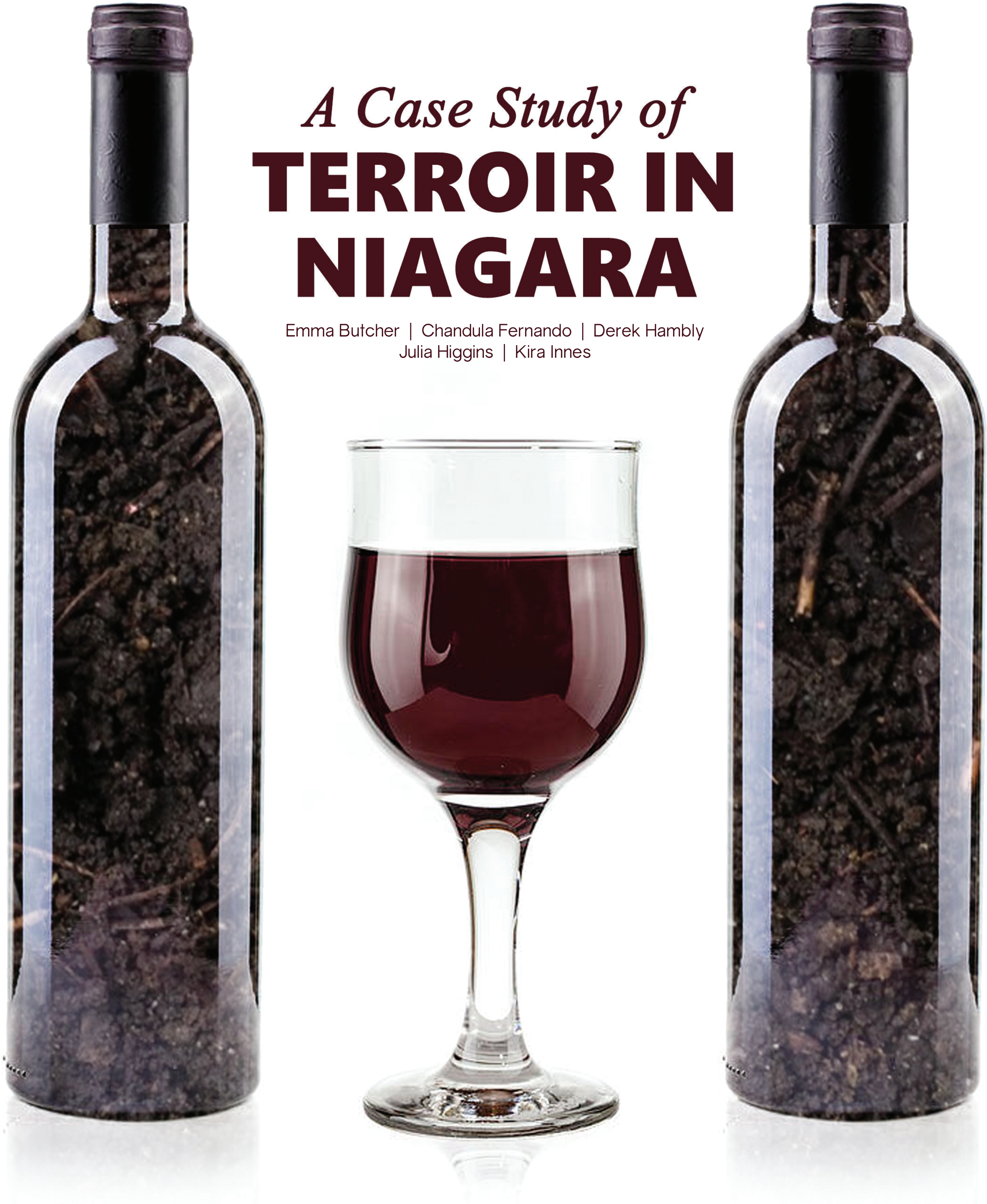
Figure 4: Wikipedia Commons. (2013). Para se sentir mais amado. Retrieved November 18, 2014, from < http://www.parideal.com.br/para-se-sentir-mais-amado/>.

Figure 5: Adapted from; Haynes, S.J., 2000. Geology and Wine 2. A geological foundation for terroirs and potential sub-appellations of Niagara Peninsula wines, Ontario, Canada. Geoscience Canada, 27(2), pp.67-87. Available at: <http://journals.hil.unb.ca/index.php/gc/article/view/2712/3155>.

A Case Study of

TERROIR IN NIAGARA

Emma Butcher | Chandula Fernando | Derek Hambly
Julia Higgins | Kira Innes



Every avid wine drinker should be aware of *terroir* and the role it plays in wine characteristics. *Terroir* is the idea that subtle aromas and flavours in wine are derived from the physical growing environment of the grapes. Soil composition, climate, and water availability alter the wine's chemical composition, resulting in complex flavours that are unique to the vineyard location. The Niagara Peninsula is an up-and-coming wine region that has gathered a lot of attention over the last decade. Recently, Niagara has been divided into sub-regions, or sub-appellations, based on subtle differences in *terroir*. However, these divisions are somewhat arbitrary and have not been extensively tested. We propose that a comparison of Pinot Noir produced by the same winemaker but grown in neighbouring sub-appellations will help determine the validity of unique *terroir* in each region. We will investigate whether sub-appellations should determine what wine is served at your next soiree.

THE HISTORY OF *TERROIR* AND APPELLATIONS

Terroir is a concept that originated in France, the motherland of wine. *Terroir* is the belief that environmental factors, such as soil composition and climate, are expressed as unique flavours and aromas in the final product (Haynes, 1999; Leeuwen & Seguin, 2007). Wines grown in distinct regions of France have specific tastes and qualities that are associated with their *terroir*. While the influence of winemakers is appreciated, *terroir* addresses the role of the natural world in wine production (Leeuwen & Seguin, 2007). The French believe that the soil of the vineyard is highly influential on the quality of the grapes and therefore the quality of the wine. Soil, however, is only one of a long list of environmental factors that are considered a part of *terroir*. These include, but are not limited to, soil, precipitation, slope aspect, gradient, hydrological characteristics, temperature, and sunlight (Haynes, 1999).

Appellations in France

Another concept of interest in the world of wine is the idea of appellations. Appellations are regions that are separated based on their *terroir* (VQA Ontario, 2014a). Appellations were first defined in France in order to classify wine, protect and represent the origin of each wine, and set guidelines for winemakers to follow. The boundaries of an appellation depend only on the *terroir* of the region and thus the size of the appellation can vary greatly (Haynes, 2000). For example, the Champagne appellation of France is known for its high quality sparkling wines. While similar wines can be grown in other appellations, they will not have the same characteristics as those from Champagne.

After dividing regions into appellations, they can be separated further into what are known as sub-appellations. These sub-appellations also have unique environmental conditions thought to affect wine (VQA Ontario, 2014a). While sub-appellations are well established in France and other regions that have been producing wine for centuries, integrating this idea into Canada, specifically the Niagara Region, has caused debate (Haynes, 2000).

Appellations in the Niagara Region

In Canada, the Vintners Quality Alliance, or VQA, has identified appellations. One example is the Niagara Peninsula, an especially productive appellation located in Southern Ontario. Sub-appellations in the Niagara Region were a recent addition met with opposition (Haynes, 2000; Kontkanen, et al., 2005). After much research, focused on sensory and chemical differences in wines from specific locations within the Niagara Region, sub-appellations were defined by the VQA (Szabo and Szabo, 2006).

With the idea of *terroir* in mind, we can say that wines of a certain varietal grown in one sub-appellation should have different characteristics than the same varietal grown in another. To test the validity of *terroir* in these sub-appellations, wines of the same varietal from different sub-appellations can be compared. If variations exists, it should be possible to attribute them to specific differences in the local environment. In this case, we will be comparing Pinot Noir grown in neighboring sub-appellations: Niagara River and Four Mile Creek.

FIGURE 1: Sub-Appellations of the Niagara Region
The Four Mile Creek (pink) and Niagara River (green) sub-appellations (Adapted from VQA Ontario, 2014b; VQA Ontario, 2014c)

PINOT NOIR: A CASE STUDY OF *TERROIR*

The Pinot Noir grape is known for expressing different flavours based on its local growing environment, which makes it an excellent choice for testing the validity of *terroir*. The Pinot Noir grape is difficult to grow due to its delicate skin, which decreases its ability to withstand pests and unfavourable climatic conditions (Haeger, 2004). Thus, Pinot Noir is the most expensive North American wine to produce, with crushed grapes sometimes priced at double the cost of other varieties (Haeger and Storchmann, 2006). Although cultivating such a grape has inherent difficulties, these challenges give Pinot Noir its unique character. The mild flesh of the berry allows subtle tastes and aromas to stand out, and the thin skin lets the local climate influence the grapes' flavour and content more than other varieties. As a result, Pinot Noir is said to be an expressive grape, with its tastes and aromas imparting a sense of place and time (Haeger, 2004). If *terroir* exists in the Niagara region, there is no better grape with which to measure its influence than Pinot Noir.

The character of Pinot Noir is reliant not only on the local growing conditions, but on the decisions of the winemaker as well. Thus, comparing two Pinot Noirs from different vintners and sub-appellations is moot as differences may be caused by the winemaking process rather than *terroir*. However, in 2012, two Pinot Noirs from different sub-appellations were created by the same vintner from Inniskillin Wines, allowing for fair comparison (Nicholson, 2014a). The Reserve Pinot Noir was grown on vineyards in the Four Mile Creek sub-appellation, while the Montague Vineyard Pinot Noir was grown on a single vineyard in the Niagara River sub-appellation (Nicholson, 2014a).

Both wines were harvested in late summer, destemmed, and left to cold soak for 48 hours. They were fermented to dryness, the Reserve Pinot Noir at an average of 25 °C and the Montague Vineyard Pinot Noir at an average of 24 °C. Both wines were aged in French oak barrels, 15 months for the Reverse Pinot Noir, and 18 months for the Montague Vineyard Pinot Noir (Nicholson, 2014a; Nicholson, 2014b). Although the processes were not identical, they are exceedingly similar and remove variables associated with the types of barrels and yeast used. Despite these similarities, the Reserve wine is valued at $24.95 CAD, while the Montague vineyard is $29.95 CAD (Inniskillin Wines, 2014a; Inniskillin Wines, 2014b). If there is noticeable *terroir* in Niagara it should be expressed in these Pinot Noirs and attributable to the climate, topography, soil type, and hydrology of each sub-appellation.

The Four Mile Creek Sub-Appellation

The Four Mile Creek sub-appellation encompasses central Niagara-on-the-Lake below the bench of the Niagara Escarpment. It lies between the Welland Canal and the Niagara River sub-appellation, covering an area of 68 km^2. The Four Mile Creek sub-appellation is the largest in the Niagara Peninsula with 13 wineries producing about 148 500L of 45 different wine varietals (VQA Ontario, 2014b).

Excluding the buried former valley of the Niagara River, the sub-appellation is almost completely flat with gentle slopes facing all directions (Ledderhof, 2010). The lack of major topographical features means that the vast span of this sub-appellation receives generous sunlight throughout the day. The soil of this sub-appellation is rich in Halton Till clay loam and red shale with high silt and clay content (Haynes, 2000). This combination of soil and topographical profile leads to high water retention within the sub-appellation. The lack of slope can be problematic during nights as air can flow through this sub-appellation without retention, thereby having little to no effect on moderating temperature (VQA Ontario, 2014b).

> "The French believe that the soil of the vineyard is highly influential on the quality of the grapes and therefore the quality of the wine."

Four Mile Creek is too far from Lake Ontario to receive the temperature moderating effects, resulting in colder winters and higher risk of vine damage. Over the years, growers in the area have managed to mitigate these climate risks by using fans to artificially circulate air among the vines. The Four Mile Creek sub-appellation sustains a growing season of about 158 days, which is slightly below the average for the Niagara region (VQA Ontario, 2014b). During the growing season there is full sunlight exposure, which causes soils to give off heat and produce large convection currents. As a result there is a relatively large difference between daytime maximum and nighttime minimum temperatures, averaging 12ºC (Ledderhof, 2010). This instills distinct deep colours, strong flavours, and aromas into the region's red grapes. In addition to Pinot Noir, this region is also renowned for its Pinot Gris and Chardonnay (VQA Ontario, 2014b).

The Niagara River Sub-Appellation

The Niagara River is the easternmost sub-appellation in southern Ontario's wine country. This geographic designation includes the 10 km^2 that span from Niagara-on-the-Lake, southwards to Queenstown Heights Park, following a one kilometer inland contour of the Niagara River (VQA Ontario, 2014c). There are many characteristics that distinguish the Niagara River sub-appellation from others in the surrounding Niagara Region. These discernible characteristics pertain to topography, soil, and climate.

Topographic features of the Niagara River region include extensive gradual slopes that receive a significant degree of sunlight. These slopes are predominantly eastern-facing, which promotes a heightened degree of sunlight in the spring. Furthermore, eastern slopes yield warmer growing conditions as they shield against westerly winds and act as a basin for warm southern fronts and moderated winds off of Lake Ontario (VQA Ontario, 2014c; Ledderhof, 2010).

"The Niagara River sub-appellation supports six wineries that yield 244 300 litres of wine per year."

The soil of the Niagara River sub-appellation promotes the growth of healthy varietals. This sub-appellation sits upon the Queenston Formation, which is composed of red shale with high silt and clay content. As a result of this, and the proximity to the Niagara River, there is a significant longitudinal variation in the grain size and soil type along the sub-appellation (VQA Ontario, 2014c). The predominant soil type in the northern half of the region is clay loam till, whereas the southern portion of the region is largely lacustrine very fine sand loam, loamy sand, and sand (Haynes, 2000). Clay loam till is considered an aquitard, while the loamy sand and sand of the south, which are notorious aquifers, facilitate more drainage (McCarthy, 1977). In general, the southern soils are considered more advantageous as they prevent over-watering of the vines. This is due to the reduced water retention capacity of the soil and the increased thickness of the top horizons of the soil profiles. Correspondingly, in seasons of limited precipitation, the northern soils are preferable due to their capacity for heightened water retention.

Climate also plays an important role in the cultivation of grapes in this region. Convection currents off of the Niagara River moderate air temperatures and reroute cold eastern winds away from the vineyards (VQA Ontario, 2014c). These currents are of particular advantage to the vineyards closest to the shoreline, as close proximity to the river has a moderating effect that offers protection against spring and autumn frosts. The other significant body of water that dictates the climate of the Niagara River sub-appellation is Lake Ontario. The magnitude of the lake makes it an influential moderator of both cold winter temperatures and warm summer temperatures (Haynes, 2000). Lake Ontario is arguably the chief factor allowing for the existence of an Ontario wine region and facilitates an average 161 day growing season for the Niagara River terrain (VQA Ontario, 2014c).

The Niagara River sub-appellation supports six wineries that yield 244 300 litres of wine per year (VQA Ontario, 2014c). There are 56 VQA approved wines in this sub-appellation, of which the predominating varietals are Riesling, Cabernet Franc, and Chardonnay. The Niagara River is a unique sub-appellation in the sense that it supports some of Canada's most popular wineries and is the most protected grape growing environment in Ontario (VQA Ontario, 2014c). Further research into each aspect of the territorial traits and climatic qualities of this area will serve to explain the unique qualities that this land imparts on its world class wines.

Pinot Noir	Residual Sugars	Acidity	Main Flavours
Reserve (Niagara River)	5.1 g/L	6.34g/L	leather, spice, plum, chocolate
Montague Vineyard (Four Mile Creek)	5.5 g/L	6.45 g/L	leather, spice, plum, chocolate, black cherry, earth

TABLE 2: Comparison of the two Inniskillin Wines (Inniskillin Wines, 2014a; Inniskillin Wines, 2014b; Nicholson, 2014b)

How do Sub-Appellations Affect the Characteristics of Pinot Noir?

The main differences between the Montague Vineyard and Reserve Pinot Noirs can be attributed to the amount of sunlight the grapes receive, the soil type, and hydrology of the sub-appellations. It is clear that grapes in the Four Mile Creek and Niagara River sub-appellations receive different amounts of sun exposure. The east-facing slopes of the Niagara River are advantageous in the early spring when the sun is lower in the sky. Increased sunlight in the spring causes early bud break, allowing for a longer growing season. The extra sunlight received by grapes in the Niagara River region allows delicate varietals, such as Pinot Noir, grow well (VQA Ontario, 2014c). Direct sunlight also warms the east-facing slopes, resulting in slightly higher temperatures than slopes in other directions. This is important as late spring frosts can put stress on the vines and compromise berry maturation (Nicholas, et al., 2011). Both the Niagara River and Four Mile Creek sub-appellations have a similar number of sunny days (VQA Ontario, 2014c). Thus, slope direction and subsequent exposure to sunlight in the early spring are the most influential factors on sun exposure.

The effects of additional sunlight in the Niagara Region are reflected in the wines we investigated. The Montague Vineyard has both higher sugar concentration and higher acidity (See Table 1). As both wines were fermented to dryness, we can assume that much of the acid in the final product began as sugars that were converted during the fermentation process. Thus, the Montague Vineyard grapes must have had higher sugar concentrations at the time of harvest. This can be attributed to the amount of sunlight; the earlier bud break in the Niagara River sub-appellation results in a slightly longer growing season that allows the vine to create more carbohydrates. Sugars are stored mainly in the berry, and thus the final wine contains more sugar (Nicholas, et al., 2011).

Sunlight and warm weather are also associated with higher levels of tannins in grapes (Nicholas, et al., 2011). The skin and seeds of the berry hold the majority of the tannins, but some are also present in the flesh. Both the Reserve and Montague Vineyard Pinot Noir are reported to have firm tannins (Inniskillin Wines, 2014a; Inniskillin Wines, 2014b). Tannins can be a desirable aspect of wine, but too much can cause bitterness and an unpleasant mouth-feel. Tannins are softened by aging in French oak barrels, which is precisely what the Inniskillin winemaker chose to do (Nicholson, 2014a). Although both wines had similar amounts of tannins in the final product, the Montague Vineyard Pinot Noir was aged for three months longer than the Reserve Pinot Noir (Inniskillin Wines, 2014a; Inniskillin Wines, 2014b). All other aspects of the winemaking process were essentially identical, and so the original Montague Vineyard grapes must have had higher tannic content at the time of harvest. Again, we see that the amount of sun exposure creates a notable difference in the *terrior* of the Niagara River and Four Mile Creek sub-appellations.

Sunlight can also affect the amount of other phenols contained in Pinot Noir. Concentrations of anthocyanins and quercetin are directly correlated to sunlight exposure (Price, et al., 1995). Both phenols are associated with deep red colours that are generally desired in Pinot Noir. Anthocyanin and quercetin can both be found in monomer and polymer conformations. Sunlight causes polymerization of both compounds and so we would expect to see higher levels in the Montague Vineyard Pinot Noir, due to the increased sun exposure. The levels of polymerized anthocyanin in grapes exposed to high sunlight can be more than 40% greater than in grapes exposed to moderate amounts of sunlight (Price, et al., 1995). Phenolic polymerization increases the chemical stability of wine and is associated with high quality products (Price, et al., 1995). Although the pricing of wine is complex, the levels of polymerized phenols may play a part in the higher pricing of the Montague Vineyard wine.

Water availability also makes significant contributions to *terrior*. The amount of water the vines receive depends largely on precipitation and drainage. As the Niagara River and Four Mile Creek are adjacent sub-appellations, precipitation rates are quite similar (VQA Ontario, 2014b; VQA Ontario, 2014c). However, different soil types causes varied drainage patterns. The Halton Till clay loam and red shale that underlie Four Mile Creek are much less permeable than the sand loams and loamy sands seen in the Niagara River sub-appellation (Haynes, 2000). Slope gradients are similar in both regions, and so soil has the largest influence on differences in water retention. Grapes are very susceptible to small changes in water availability and exhibit different root activity under different hydrologic conditions (Chaves, et al., 2010). High water retention in soil can be detrimental, and is associated with lower lateral shoot growth, leaf size, and berry weight (Renyolds and Naylor, 1994). Well drained soils are generally preferred as they encourage vines to grow deeper roots and draw up more water than vines in saturated soils (Chaves, et al., 2010). In fact, water deficits in the early season are actually beneficial to Pinot Noir vines as it causes faster fruit maturation (Renyolds and Naylor, 2004). During times of drought the vine will grow deeper roots in an attempt to locate water. The efficiency and efficacy of water collection, known as the root hydraulic conductance, is also improved by water deficits and the effects remain after water has become more readily available (Chaves, et al., 2010). The Niagara River sub-appellation has more permeable soils, and so we would expect to see higher quality grapes.

Phenolic composition of the grapes is also influenced by water deficit. Lower water levels results in higher sugar content in grapes and cause the expression of various biosynthetic pathways (Renyolds and Naylor, 2004). This results in slightly higher levels of phenols, specifically flavonols and anthocyanins. Although the overall level of flavonols does not change greatly, the phenolic profile of the wine becomes more diverse. This can increase the complexity of the wine, and so imposed water deficits in the early growing season is becoming an increasingly common practice (Chaves, et al., 2010). The flavour profiles of the wines we investigated were fairly similar (See Table 1). Both the Reserve and Montague Vineyard Pinot Noirs had hints of leather, spice, chocolate, and plum (Inniskillin Wines, 2014a; Inniskillin Wines, 2014b). However, the Montague Vineyard also had notes of black cherry and an overall earthy flavour (Inniskillin Wines, 2014a) implying that a more diverse range of biosynthetic pathways were activated. This aligns with what we know about water availability in the Niagara River sub-appellation. The soils in this area are more permeable than those in Four Mile Creek, and thus drain water more quickly, reducing the chances of over-watering and increasing water deficit. This would improve the berry maturation and create additional flavour compounds in the wine.

DOES *TERROIR* EXIST IN NIAGARA?

The differences in the two Pinot Noirs can clearly be linked to environmental factors. The climate and strong sun exposure in the Niagara River sub-appellation account for the higher sugar and tannin content in the Montague Vineyard wine. Water availability influences the grapes ability to make flavour compounds, and so soil type influences the flavours of each wine. Overall, we have to agree that the characteristics of each Pinot Noir is directly influenced by subtle differences in its growing environment. Thus we conclude that *terroir* does exist in the Niagara Peninsula, and the division between the Four Mile Creek and Niagara River sub-appellations is justified. However, it is important to note that although there are differences between the Reserve and Montague Vineyard Pinot Noirs, they are subtle and will likely be undetectable by the average consumer. In essence, *terroir* does exist for the elite wine taster, but for the majority of people sub-appellations in the Niagara Peninsula may be indistinguishable. So when deciding on what wine to serve at your soiree, keep in mind that the effects of *terroir* may be lost on guests with less-developed palates. Your focus should be selecting the best varietal to pair with your meal and *terroir* should be less of a priority as its effects will be subtler.

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