Terroir

An Integrated Wine Science Publication

FOOD & WINE
finding the perfect match

OFF TO MARKET
who buys what?

LANGUAGE OF TASTE
making sense of it all

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the physics facts

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pour a glass of goodness

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irrigation for everyone

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An Integrated Wine Science Publication

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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 2016

Cover Image: A good image of the color of red. Wikimedia Commons. Francesco Pappalardo. 2010
Table of Contents Image: Barrel room. Wikimedia Commons. Michael Clarke. 2010.

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EDITOR: Russ Ellis

Perfect Pairings:

The Science of Food and Wine Matchmaking

Chimira Andres, Mary Kathryn Bohn, Paige Darville-O'Quinn, Aarani Mathialagan & Jennifer Hanuschak

The history of wine is rooted in not only viticulture, but also the regional food with which it has been enjoyed throughout the ages. Classic food pairings thus originated from what was available in the region – perhaps a Burgundy red wine with succulent lamb or an Italian Merlot with Parmesan cheese. As the culture and economic status of these countries evolved, so did the relationship between their food and wine. Their pairings developed from convenient to purposeful using the combination of specific flavour profiles. In the 1980s, food and wine pairings became a staple in high-end restaurants and rapidly became integrated into the dining experience. The current interest in the pairing experience has become so popular that the principle trickled down to the formation of strategic alliances along wine routes.

Although there is no controversy as to whether food and wine pairings work, there is still much debate as to why certain things pair together. *Is it purely chemical? Soil-based? Culture-based? Is there such thing as a chemically perfect pair?* These are the questions this article will explore.

WINE CHARACTERISTICS AND FLAVOUR CATEGORIES

A dinner party attendee holds up a glass of wine, letting the candlelight shine through, swirls the contents around, and makes some pronouncement that "It is soft and sensuous – quite an improvement over the 65s, which were dry and flaccid." A brief discussion may ensue on which descriptors best fit the wine. Despite the extensive literature on wines, minimal agreement occurs between wine-connoisseurs regarding the structure of the vocabulary (Lehrer, 1975).

The absence of a common understanding of descriptive terms can be, in part, attributed to the lack of knowledge of the average consumer regarding wine. Comprehensive research on wine has indicated that experts show superior wine discrimination on several properties including sweetness, acidity, and tannin levels (Lawless, 1984; Solomon, 1990; Harrington, 2008). Standardized terminology aids in the research and critical evaluation of food and wine pairings to provide valid and reliable conclusions.

The exploration of food and wine pairings begins with the identification of distinct characteristics including flavour, aroma, texture, and the interactions between them. Sensory properties of wine encompass multiple sensations of acidity, sweetness, bitterness, flavour, viscosity, warmth, and astringency (Gawel, Oberholster, and Francis, 2000). An expansive range of terms is used to describe wine acidity, ranging from flat, soft, and flaccid for low acidity to sharp, tart, and green for high acidity (Harrington, 2008). Wine sweetness ranges from bone dry, indicating imperceptible sweetness, to very sweet, indicating a high level of perceptibility. Sweetness levels in food follow the same principle, allowing wine experts to anticipate the level of match between pairings (see Table 1). An established pairing rule indicates that the acidity or sweetness level in food must be less than or equal to that in the wine (Harrington, 2008). For instance, a lemon tart can be paired with a Canadian ice wine, suppressing the tangy quality of the tart with sweetness of the wine.

The final aroma and flavour profile of a wine are strongly dependent on all aspects of viticultural practices. Seven major flavour categories are fruity, nutty, smoky, herbal, buttery, floral, and earthy (Lawless, 1984; Harrington, 2008). The relative success of a food and wine pairing relies upon the match using either similarity or contrast, as well as flavour intensity (Harrington, 2008). Dominant flavours present in food are distinct and require minimal evaluation.

Texture in wine encompasses body, astringency, and structure, with a range of mouthfeel characteristics. Mouthfeel is an important characteristic of wine evaluations; it is a concept employed by evaluators to assess the level of astringency in wine (Harrington, 2008). Tannin creates the sensory attribute of astringency in wine, often described as a puckery sensation in the mouth. Terminology used to describe astringency includes rich, parching, and aggressive (Gawel, Oberholster, and Francis, 2000). Alcohol in wine works in tandem with sweetness and tannin levels, remaining a key element in food and wine pairing considerations. During the wine-production process, oak barrels impart flavour, colour, aroma, and body to a finished wine. Tannins, alcohol, oak, and other elements work in tandem to provide perceptions of body and texture in wine. Levels of overall body in wine range from thin to heavy. Thin-bodied wine indicates a wine with low tannin, low alcohol, and minimal oak, while heavy body indicates high tannin, high alcohol, and heavy oak (Harrington, 2008).

TABLE 1: ANTICIPATED LEVEL OF FOOD & WINE MATCH. Different food items paired with suggested wines and anticipated level of match, based upon the synergistic interactions of food and wine characteristics (Harrington, 2008).

Food Item	Suggested Wine(s)	Anticipated Level of Match
Artichokes or asparagus	A crispy white – New Zealand Sauvignon Blanc or white Rioja; if served with melted butter, a young, crisp Chardonnay	Neutral to good
Caesar salad	A full-flavoured white such as cool/moderate-climate Chardonnay (New York or Washington)	Refreshment to neutral
Chicken curry with lime	Gewürztraminer or Riesling	Neutral
Ceviche	A tart Sauvignon Blanc from New Zealand, Sancerre	Neutral
Fruit salad	A sparkling wine such as Moscato d'Asti	Good
Gazpacho	Sauvignon Blanc or Manzanilla Sherry	Good
Lemon tart	Canadian ice wine, Riesling	Good to synergistic
Salads (general guidelines)	Sauvignon Blanc, Riesling, Pinot Grigio, dry rosé, or light reds such as Beaujolais, Dolcetto, or Gamay	Refreshment to neutral
Sauerkraut	Very crisp and dry white – Mosel Riesling, Canadian Riesling	Refreshment to neutral
Sorbets	Light sweet sparkling wine – Moscato d'Asti	Good

The perception of wine flavours, aroma, and texture is the result of a multitude of interactions between a large number of chemical compounds and sensory receptors (Styger, Prior, and Bauer, 2011). The perfect marriage of food and wine arises from the consideration of both synergistic and antagonistic interactions of compounds (Styger, Prior, and Bauer, 2011).

CAUSES OF PERCEIVED INTERACTION: *HOW DOES FOOD & WINE INTERACT?*

Food and wine pairings are often advertised as perfect matches whose tantalizing tastes promise to transcend all prior sensory experiences. Now that characteristics of food and wine have been separately defined, oenologists and **sommeliers** have recently started collaborating to chemically define a *perfect pair*. The majority of current literature regarding food and wine pairings is anecdotal and entirely based on trial and error - a sweet Riesling with decadent crab cakes or classic Champagne with caviar. The question still remains as to why these pairings work so effortlessly (Harrington, 2005).

> **Sommelier:** A person who specializes in all aspects of wine service and food and wine pairing.

One of the most common pairings worldwide is wine and cheese. It is thus the primary food pairing studied in literature. Studies that incorporate empirical sensory data from trained individuals have shown interesting results. A study conducted in 2006 had students completing their sommelier training evaluate flavour profiles of wine alone and wine with cheese on a calibrated scale. Researchers found that low intensity mixtures tend to result in enhancement, medium intensity in additivity, and high intensity in suppression (Madrigal-Galan & Heymann, 2006). For example, a strong blue cheese significantly suppressed the oak flavour of Chardonnay wine while fresh mozzarella showed no significant sensory effect on wine flavour. Sommeliers use this finding to pair food and wine based on the weights of their flavour profiles and what flavour they want to shine through.

The mechanism for the suppression of wine characteristics has been heavily hypothesized. As cheese is high in fat content, researchers have hypothesized that the formation of a fat coating in the oral cavity plays a critical role in pairing taste. Fat coating modifies the partitioning of specific compounds between the food, saliva, and taste receptors (Madrigal-Galan & Heymann, 2006.). This leads to a decrease in the amount of a given compound reaching the olfactory receptors. This is likely to delay the volatilization of aromatic substances and diffusion of attributes towards receptors. There have been no controlled studies to confirm this hypothesis but it is considered widely plausible in the oenology community (Nygren et. al., 2001). As a result, restaurants will often use astringent wines to remove after-tastes and fat coating in the mouth before the next course. Some oenologists also hypothesize that the suppression of wine attributes can occur due to protein interactions. Protein binding can also inhibit the volatization of compounds leading to taste suppression (Keast & Breslin, 2003). As most studies completed on wine and food interactions use cheese as the food component, more studies are needed regarding the interactions of foods with low fat and protein indices.

It is important to note that although there are many ways to chemically define food and wine taste profiles and their interactions, personal preference acts as an inherent bias for subjective outcomes. As research evolves, oenologists are finding it increasingly difficult to separate gastronomic identity from chemical taste. Many have come to the conclusion that there is no one global perfect pairing based on chemistry alone - it must come from a combination of cultural, personal, and chemical factors.

GASTRONOMIC IDENTITY

Sharing a meal is the focal point around which most social events are centred, and as such eating food and drinking wine is a universally shared experience. However, although wining and dining in general is seen around the world, the specifics vary greatly depending on the locale.

The affect of specific environmental factors influencing agriculture can be summed up by the term **terroir**. The interaction between soil type, topography, geology, and microclimate give distinctive qualities to food (Roullier-Gall et al., 2014). Terroir originated in France as a standard of quality, relating the product to its place of origin (Douglas, Cliff and Reynolds, 2001). Here in Ontario, the VQA (Vintners Quality Alliance), a quality regulatory system which labels wine making territories based on terroir, recognizes three different appellations - Lake Erie North Shore, Prince Edward County, and the Niagara Peninsula. The Niagara Peninsula is further divided into sub-appellations including "Beamsville Bench", "Lakeshore" and "Four Mile Creek" based on distinction between terroirs (Douglas, Cliff and Reynolds, 2001). Several studies were conducted between 2001 and 2005 to assess the differences between grapes grown and wines produced in each of those three sub-appellations (Douglas, Cliff and Reynolds, 2001; Kontkanen et al., 2005; Schlosser et al., 2005). All of these studies showed significant variation in chemical composition as well as flavour profiles between the wines of different terroirs.

> **Terroir:**
> Consists of the set of all environmental factors that affect a grapevine's epigenetic qualities, unique taste and farming practices.

Different cultures and geographic locations have specific standards and traditions regarding the food they eat, as well as the wine they pair it with (Ahn et al., 2011). This is a part of the culinary and **gastronomic identity**. A region's culinary identity is based on its history and the prevailing culture and ethnic diversity (Harrington, 2005). These factors dictate the dishes produced by influencing

> **Gastronomic Identity:**
> Combination of geographic region, topography and climate, and the prevailing culture, ethnic diversity and history, to influence the flavour profiles of food produced.

the ingredients, flavours, preparation techniques and recipes used. This combined with environmental factors, such as geographic location, climate, and terroir create the gastronomic identity (Harrington, 2005).

From philosophers in 200 AD Greece publishing works of *Gastronomia* to menus today suggesting what wines to order with one's dinner, gastronomy has provided guidance on what to eat and drink (Santich, 2004). Gastronomy dictates wine and food pairings through the cuisine common to the region, as well as the agricultural products available based on what can be grown and produced (Harrington, 2005). As such, meals prepared with locally sourced ingredients are often paired with wines from the same or similar terroir. Certain flavours are often shared between foods from the same terroir, so this kind of pairing can serve to enhance those similar characteristics. This trend, dubbed "what grows together goes together," has historical basis. Before globalization made it easy to acquire any ingredient for any type of cuisine at a supermarket, people relied on products immediately available from farms or nearby trade. Therefore, the food they ate and the wine they drank with it were a product of the region's terroir and gastronomic identity. This is seen today, but for reasons stemming more from the emphasis that health conscious individuals put on fresh grown food, and from local pride (Harrington, 2005).

In addition to sharing characteristics of the same terroir, food and wine pairings also differ regionally based on specific flavour profiles. Common ingredients in Mexican cuisine include tomatoes, chili, and lime. These flavours together often create warm and spicy foods, paired with sweet or refreshing wines for contrast. (Rozin, 1996). In California, buttery Chardonnays are paired with local Dungeness crabs dipped in butter to enhance the flavour (Harrington, 2005). Acidic Sancerre white wine from the Sancerre region of France cuts the richness of goat cheese from the same area. Finally, sweet ice wines from Niagara match well with desserts like tarts and pies made using locally grown fruit (Harrington, 2005).

One major application of food and wine pairings based on gastronomy is the culinary or gastronomic tourism industry. When traveling, many visitors' motivations for picking destinations are based on the unique food options available. In order to truly immerse themselves in new or different culture, many visitors tour local wineries and food producers. This is popular in France with "Ferme-auberges," where farmhouses are converted to inns, and guests can experience the preparation of all of their meals with ingredients produced on-site. Going to restaurants is already one of the most frequent leisure activities of travellers, and promoting regional specialties is a way to increase revenue. By suggesting wine to pair with food, consumers feel as though they are enhancing their experience. In Australia, since 1999 15% of visitors have booked winery tours and wine tastings, and this number has only increased. In Canada specifically, local cuisine has been a top factor motivating travel by Americans, according to the Canadian Tourism Commission.

Because food and wine pairings rely so heavily on gastronomy and terroir, in order to make pairing decisions it is helpful to be able to visualize the area. In particular, it would be useful to examine the terroir and wines being produced at vineyards along the Niagara Wine Route.

RELATIONSHIPS BETWEEN NIAGARA WINERIES USING GIS

It is important to have a concrete understanding of the various connections that food and wine pairings present between geographical areas. For the reinforcement of the overall concept of gastronomic identity, these different environmental and agricultural relationships are illustrated through a map of the Niagara Wine Route created with the geographic information system (GIS) as shown below in Figure 1.

This geographic map highlights the various agricultural land-use systems within the Niagara Peninsula, thereby making it easier for correlations to be made between the locations of farmed products (i.e. berries, corn, and fish) relative to the location of vineyards. As shown in Figure 1, Niagara is home to many important sport, commercial, recreational, and aboriginal fisheries that belong in the Fisheries Management Zone 20 (FMZ 20). FMZ 20 includes the Canadian waters of Lake Ontario, the Bay of Quinte, the Niagara River below Niagara Falls, Hamilton Harbour, and the St. Lawrence River (Ontario, 2014). In these waters, fisheries are able to harvest a variety of world class salmon, trout, bass, northern pike, walleye, yellow perch and muskellunge (Ontario, 2014). With this, pairing seafood and wine in Niagara has become quite the commodity. In fact, restaurants, such as the "Tide and Vine", have established themselves as exclusive wine and seafood experts in order to share their passion and provide a pairing experience to their customers. They are located at a prime spot, west of the Niagara River and their menu specialties include an 8oz lobster tail paired with Chardonnay, freshly shucked oysters paired with dry Champagne or Muscadet, and Niagara salmon paired with Sauvignon Blanc.

In addition, other popular harvests in the Niagara region are two distinct fruits, cherries and peaches. Interestingly, Niagara is home to the first fruit winery in Canada named "Sunnybrook Farm Estate Winery", which uses 100% Niagara Peninsula grown tree fruits and berries to create their wines. Located in the northern part of the region, Sunnybrook produces roughly 3, 500 cases of peaches, plums, apricots, pears, and berry wines as well as some of the most distinctive ice wine in the region (Sunnybrook Wine, 2014). This winery specializes in not only producing fruit wine but pairing classical wine with food as well. Fruit wines are great for accompanying dishes featuring fruit and great for livening up simple fish entrees. A fruit wine introduces an aromatic, vibrant kick to spice things up.

"It is encouraged for Ontarians to use the opportunity of matching their local food with local wines crafted from 100 per cent Ontario grapes.

What grows together, goes together."

— Hillary Dawson, President, Wine Council of Ontario

Similarly, with corn being a major product in the southern Niagara region, corn has been paired with many varietals of wine as well. Due to the very strong flavour of Chardonnay, a winery named, "Ravine Vineyard Estate Winery", has made it their set-up to specifically pair their 2013 Ravine Vidal Chardonnay with a buttery corn bread. Ravine Vineyard also introduces Chardonnay as the perfect pairing for sweet corn that is typically grown in the Niagara region. Chardonnay is one of the most well-known white wine varieties and since there are many different styles of Chardonnay, it is said that this wine generally works best with popcorn, sweet corn or corn chowder due to the subtle hints of butter, vanilla, and sweetness in its aroma that compliment corn-based entrees.

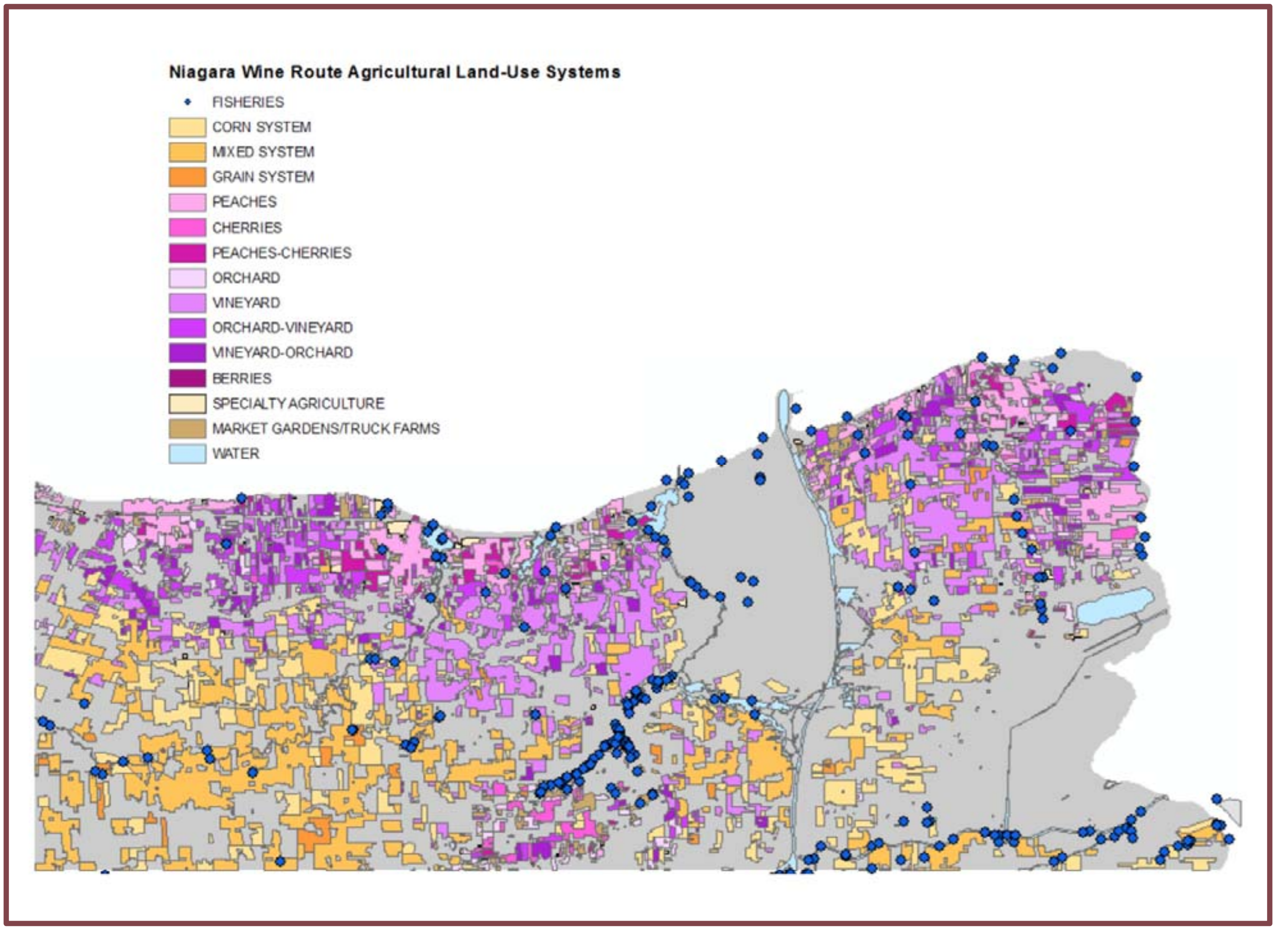

FIGURE 1: A SIMPLIFIED MAP OF THE NIAGARA PENINSULA that illustrates major vineyards and wineries and their spatial relation to surrounding agricultural land-use systems (Created by: Chimira Andres; ArcGIS and Scholars GeoPortal database).

However, despite the agricultural diversity that the Niagara Wine region has to offer, it still becomes quite hard to make the connection between which food and which wine must perfectly go together. To remedy this drawback, VQA wines are being put out to sell at Niagara farmers' markets to create another needed opportunity for Niagara's wineries to connect with consumers — closer to home side-by-side with Ontario farmers.

FOOD & WINE PAIRING APPLICATIONS

Food and wine pairings have a variety of applications in industry. For instance, food and wine pairing events can be popular tourist attractions. In addition, industries often work together, creating **strategic alliances** in order to increase business. Strategic alliances are a commonplace along the Niagara Wine Route (Figure 2; Telfer, 2001). For

FIGURE 2: THE NIAGARA EXCARPMENT OVERLOOKING A NIAGARA VINEYARD following the path of the Niagara Wine Route (Niagara Vineyard, n.d.).

example, "Taste the Season" is an event created by the Wineries of Niagara-on-the-Lake. This event features 25 Niagara wineries showcasing "locally inspired VQA wine and food pairings." The purchase of a ticket will give you access to all 25 wineries and the pairings they offer. Although transportation is not included in the purchase of a ticket, the Wineries of Niagara-on-the-Lake mention that it can be arranged with one of their official transportation partners. These partners include both tour operators and transport groups (Wineries of Niagara-on-the-Lake, 2016; Wineries of Niagara-on-the-Lake, n.d.).

This event attracts business to all 25 wineries, the food providers, and the transportation partners. "Taste the Season" involves strategic alliances between the wine, food, transportation, and tourism industries. Strategic alliances, such as "Taste the Season", are a commonplace along the Niagara Wine Route. Wineries, restaurants, tour operators, hotels, and food producers are just of a few of the parties engaging in these alliances (Telfer, 2001).

Strategic Alliances: Voluntary arrangements between parties that allow parties to work together to pursue their goals. Strategic alliances often involve the sharing of information and resources. They always involve teamwork.

Perceived Risk: The financial and social risk associated with the purchase of wine. This risk is a result of the variations between wine varieties which makes it practically impossible for an individual to be familiar will all wines.

In addition, food and wine pairings are an effective means of reducing the **perceived risk** involved with purchasing wine, and therefore, pairings can increase wine sales (Wansink et al., 2005). As well, in the restaurant industry, the proper food and wine pairings can results in higher customer satisfaction, which can lead to word-of-mouth advertising and more return business. Although the ultimate objective of pairing for many restaurants is to create a novel and superior gastronomic effect, a 'perfect' pairing does not guarantee a satisfied customer. This is because there is no pairing that will please everyone. Hence, there is no such thing as a universal perfect pairing (Harrington, 2005).

When trying suggested food and wine pairings, the average consumer should remember that universal perfect pairings do not exist. Pairing preferences are subjective. Perfect pairings can exist on an individual basis and can greatly enhance one's dining experience. The only way to discover which food and wine pairings are perfect for you is to experiment. Bonne chance!

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Market Segmentation in the Wine Industry

Aryan Pour-Bahreini, Joanna Krynski, Aidan Bullen, David Bowman, Brynley Hanson-Wright

Over the past fifty years consumers have become increasingly aware of advertising techniques and strategies. As a result of this public awareness, advertising has been made more difficult for marketers, as they must innovate to maneuver around what the public expects. Ironically, this increased awareness may aid marketers. It is a natural reaction to read about advertising strategies and balk at the suggestion that they may affect you. When looking at advertisements you should be asking yourself who the advertisement is targeted at? An advertisement could be targeted at you for an astoundingly long list of reasons including wealth, age, location, gender, and lifestyle.

Have you ever had a label catch your eye and been enticed to take a closer look? Have you ever seen a headline about an emerging brand or region in wine and decided to try it out with your next trip to the liquor store? Do you have an unchanging rule about dropping or rising around a specific price point with wine? If any of these statements sound familiar, you fall into a category that is being targeted by advertisers regarding wine. These categories are segmented, forming different groups that are specifically advertised to based on the qualities that advertisers have determined are characteristic of the group. The process in which they determine what characterizes these different groups is called market segmentation.

SEGMENTATION IN PRACTICE

Market segmentation is the marketing strategy of dividing the heterogeneous market into homogenous groups, based on their geographic, demographic, psychographic and behavioural characteristics (Goyat, 2011). These factors, either alone or in combination are used to divide consumers into subcategories for specific targeting. An example of geographic segmentation would be division by neighbourhood. Psychographic, demographic and behavioural segmentation use attributes of an individual person as can be seen in *Table 1*.

The wine industry uses market segmentation in order to identify the needs of the consumer, and then specialise a product to address or target those needs. Once the interests of the consumer are established, a segmentation profile can be conducted to ensure that the product is as attractive as possible (Thach and Olsen, 2006).

The earliest studies on segmenting the wine market were completed by McKinna (1987), which identified qualitative segments of the Australian wine market intended to both increase product sales yield, and decrease sales risk. Spawton (1991) further analysed the data that McKinna collected to produce four distinct segments of wine consumers - the connoisseur, the aspirational drinker, the beverage wine consumer, and the novice wine drinker. Each of these segments possessed certain characteristics in their consumption patterns, related to product expectation and attraction that could be capitalised on to maximise sales to a segment (Pickering and Thomas, 2003). However, in order to segment their market in a meaningful and successful manner, a producer must consider a number of factors and processes.

Riviezzo, De Nisco, and Garofano (2011) identified a series of steps involved in the wine purchase process that the consumer considers, whether they realise it or not. By understanding these steps, a universal segmentation process may be applied.

The perception of need. The consumer identifies their reason for purchasing a bottle of wine, such as social, cultural, or health-oriented motivations.

The search for information. The consumer considers information form either internal sources such as personal experiences with the product, or external sources, such as information from acquaintances, ads, or public commentary.

The evaluation of alternatives. The consumer considers characteristics of the wine itself as an umbrella approach – red versus white, domestic versus international.

The purchase decision. The consumer, decided on a certain wine archetype, now considers finer details, such as where to purchase their wine from, the price of the wine, its quality and origin and the history of the winemaker and region.

The use of the product. The consumer considers how the wine will be used. This may include characteristics such as the wine's pairing with a certain food, or the atmosphere of a social event they wish to bring the wine to.

The post-purchase behaviour. Finally, after the consumer has purchased their selection, satisfaction with the wine is likely to lead to recurring purchases of the same wine in the future.

Once the grounds for segmentation are established, a wine marketer weighs the upfront costs of research and conducting segmentation against the potential long-term return on investment garnered by the enhanced understanding of their market

Behavioural	Psychographic	Demographic
Benefit Sought	Interests	Age
Usage Rate	Activities	Gender
Brand Loyalty	Opinions	Family Size
User Status	Values	Income
Readiness to buy	Attitudes	Occupation
Occasions		Education
		Ethnicity

TABLE 1: COMMON SEGMENT TYPES

A summary of some aspects commonly used to segment markets separated into demographic, psychographic, and behavioural characteristics.

corner. A comprehensive understanding of the purchase process identified by Riviezzo et al. (2011) promises a more meaningful segmentation. A popular method of assessing the market's characteristics is the use of direct questioning to a significant sample size, practiced by a series of documented segmentation attempts (Matei, 2014; Pickering and Thomas, 2003; Thach and Olsen, 2006; Simpson, Bretherton, and de Vere, 2005; Riviezzo, De Nisco and Garofano, 2011). In this process, consumers are presented a questionnaire pertaining to the characteristics of purchased wine and their thoughts or opinions on certain features of the product. Interviewee attributes such as gender, age, socioeconomic and marital status, and other demographic data are also collected, either directly or indirectly.

One such study by Constellation Brands surveyed 4,000 wine consumers in the United States and nearly 3,000 in Canada. Using a survey of 100 questions, Constellation determined their sample to be formed six distinct behavioural segments: the enthusiast, the loyal consumer, the price-influenced consumer, the newcomer, and the image consumer. Each segment showed a preference towards certain price ranges of wine, consumed a certain number of glasses per month, and demonstrated varying degrees of knowledge of viticulture and the wine that they were purchasing. The behavioural segments correspond to demographic characteristics: gender, marital status, and average household income. Constellation could then use this information to create specifically-targeted ads. Greater emphasis could be placed on features more attractive to a given segment (*Figure 1*; Matei, 2014). This method of assessing a target market provides incredible insight into the

FIGURE 1: TARGETED ADVERTISING

A Hardy's wine advertisement (John Short, 2014). This campaign used the imposing fonts and dark colour schemes, as well as staged meals on tabletops. The advertisement is meant for older businessmen and women, since there is a business-like air about both ads, as well as a moment of reflection over a day's hard work and spending celebratory moments with your colleagues and friends.

purchasing patterns of a select population. Having this understanding allows the wine producer to focus their product marketing to maximise sales across any given target demographic.

SOCIAL MEDIA AND VIRTUAL SEGMENTATION

While the findings from decades of research have demonstrated techniques and uses for traditional market segmentation, the past few years have opened a new window for the segmentation of virtual customers. Social networking sites (SNS) provide a new platform for companies to consolidate their brand and share advertisements, as well as present a venue to learn more about their customers. The general category of social media includes any web-based venue allowing users to create and exchange information while SNS are specifically websites where people create profiles and lists of the people with whom they interact and share content. It is important for any business to remember that the segments they appeal to may change when using different forms of media for branding and advertising. Marketers who have had trouble exploiting benefits of SNS likely made the mistake of considering their online users as one segment. New research indicates that users of social media can be segmented based on their motivations on social media and reactions to branded content. The main implication for winery managers is to understand and effectively target the heterogeneity of social media users.

Alonso et al. (2013) questioned winery owners about their usage of websites and social media and the perceived benefits. 71.9% of respondents believed a winery's online presence was useful for promoting their wines. Besides promotion, the wineries were not fully exploiting what the Internet had to offer businesses, failing to make use of website functions and especially social media tools. Carson (2005) proposed that the Internet can be used by businesses for five main functions: promotion, communication, management, product distribution, and research. Social media provides the opportunity to research the market, segment the market, and advertise more effectively. Compared to other alcohols, wines do not get nearly the same attention on social media. The wine with the largest Facebook fan base, Frizzé has just 2,462,303 likes compared to Heineken's 21,731,440 likes and Jack Daniel's 14,554,612 likes. One wine within the top five bestsellers in the US, Franzia, does not even have a Facebook page (sales data from Statista, 2016 and Facebook likes as of October 5, 2016). The biographical and locational data available about the specific consumer groups who like your Facebook page can be instrumental for segmentation.

Shao et al. (2015) were the first to detail motivational segmentation strategies of Facebook users. They created four segments: *Devotee*, *Agnostic*, *Socializer*, and *Finder*. Motivations involved in the choice to use Facebook are categorized into socializing, entertainment, self-status seeking, and information seeking. *Devotees* (17%) scored higher than any other segment on socializing, entertainment, and status-seeking motivations as well as above average on information seeking. It was found that *Devotees* went on Facebook often and for a long time to fulfill all four motivations. *Agnostic* (21%) had the lowest scores of all segments on each of the four motivations. Their use of Facebook was limited; these individuals engaged for short periods of time and predominantly with the purpose of socializing. *Socializers* (37%) were driven by socializing and entertainment motivations and used Facebook in short bursts, as "light users." *Finders* (25%) were moderate to heavy Facebook users and formed the segment most motivated by information seeking. One important consideration was for marketers to be aware of the audience who were unreachable through SNS publicity. 27% of males and 17% of females were classified as *Agnostic* and were not responsive to Facebook as a marketing channel. If wineries know what type of person belongs to this segment, they can make sure ads in other venues put emphasis on targeting the *Agnostics*. In contrast, targeting *Socializers* requires getting their attention quickly, providing instant gratification, and inducing pleasure (Shao et al., 2015).

To augment the research about what made people go on SNS, Campbell et al. (2014) studied users' reactions to brand marketing online to gauge receptivity to marketing messages. The segmentation bases were based on three behavioural outcomes in response to marketing: brand engagement, purchase intention, and word-of-mouth (WOM) intentions. The segments were denoted as *Passive, Talkers, Hesitant, Active*, and *Averse*. The *Passive* segment (29%) were all relatively indifferent to the marketing as it fails on all three behavioural outcomes. They had high entertainment motivation with low convenience motivation and were more often male. *Talkers* (28%) had a strong rating on brand engagement and WOM, and were highly motivated by information. *Hesitant* (24%) had low levels on all outcomes. They were defined by low information motivation and were not interested in engaging or responding to SNS for brands. *Actives* (10%) had the highest rating on every outcome. Their interactions online were very important for their offline shopping decisions. This segment included people, often young females, with high information motivation, who enjoyed shopping, and valued convenience. They were most open to interacting with the brands online, most likely to make future purchases because of exposure to the marketing on SNS, and most likely to tell others about it. *Averse* segment (9%) received no impact from the marketing on their behaviours at all.

FIGURE 2: SOCIAL MEDIA ADVERTISING
Four brand posts to target the active segment with entertaining images (Girls Night Out Facebook, 2016).

When adding the *Talkers* and *Actives*, 38% of the market is positively affected through SNS marketing. It is likely that these two segments will grow as general Internet usage becomes more central to society. The best predictors of segment membership are information motivation, entertainment motivation and age. If a winery wants to spread WOM about their product and increase brand engagement, it is most effective to target the *Talkers*, and can do so by posting content that fulfills an information motivation. They may want to post about the process for making their wines, facts about their vineyard, descriptions of products, etc. If the winery is more concerned with attracting the *Actives* to directly influence purchasing, then entertainment has increased importance in the posts. This usually involves humorous pictures, interactive campaigns, short videos about food-wine pairings, etc. (see *Figure 2*). It is important to note that education, income, and smartphone ownership had no relationship to the five segments. Wineries using social networking to market their products may want to put more time into researching the consumer motivations and reactions to their Facebook page as opposed to the typical demographic research of their target market.

WINE TOURISM AND SEGMENTATION

Wine tourism is a relatively recent yet fast growing aspect of the wine industry. The act of touring a vineyard or winery, or frequenting a wine festival, became popular in the 1990s (Charters and Carlsen, 2006). Excursions to vineyards were educational and relaxing; one had the benefit of tasting wines and learning about viticulture, the science of growing grapes, as well as enjoying temperate climates and beautiful landscapes. Wine tourism research is useful to both the vineyards attempting to attract tourists and to prospective tourists who want to maximize the pleasure of their trip. In 2008, the Government of Ontario predicted that there would be overall growth in tourism in the Niagara Region over the next two decades, including a sizeable growth of 28% in the wine tourism sector by 2025 (Government of Ontario, 2008). However, this growth does not occur organically. The wine tourism sector must invest time to understand their customers and motivate them to purchase their product. This is most easily obtained by segmentation of the tourist market.

Dividing the large tourist market into smaller subgroups has many benefits for vineyards. Understanding what a tourist aspires to experience during his or her trip can maximize a vineyard's profits and create a loyal customer base (Cho, Bonn and Brymer, 2014). Wine tourist markets can be segmented via traditional product marketing, such as by the gender, age, income or education level of the targeted customer, or by more recent methods of psychographic marketing (Famularo, Bruwer and Li, 2010; Cho, Bonn and Brymer, 2014). Psychographic marketing investigates a consumer's behaviour in relation to their lifestyle, activities, interests and opinions. This is more useful than the traditional method because wine tourism tends to be sold as an experience, not a product (Cho, Bonn and Brymer, 2014).

FIGURE 3: ADVERTISING FOR REGIONAL WINE TOURISM

A screenshot of a wine tourism website. The website portrays visiting a winery as an educational adventure. The variety of media available purposefully appeals to a wide number of segmented market groups (California Wine Tourism, 2016)

Vineyards can use the psychographics aspects of an aspiring tourist to learn of customers' motivations. Cho et al. (2014) found that tourists that participate in wine region activities do so to relax, explore the region, socialize, and learn about wine. These internal motivations can be used to market a wine region to have a "tourist terroir": a place with unique combinations of physical, cultural and natural environment that appeal to distinct tourist desires (*Figure 3*; Alebaki and Iakovidou, 2011).

It is also important to know why consumers *don't* become wine tourists. The constraints in individuals' lives are deciding factors in wine tourism, and can be used to segment the market as well. For example, the segments can be individuals with insufficient money, lack of time, lack of information, or lack of interest (Cho, Bonn and Brymer, 2014). Targeting these non-tourists can help a vineyard create new customers that would have otherwise not chosen to become wine tourists. An example of such targeting is the promotion of off-peak tours to those who cannot afford high season visits, including some unique activity of this season.

Understanding the motivation and constraints of the wine tourist is key in the growth of the industry. Segmentation of the market through these methods aids vineyards and wineries with the creation of new customers and the retention of loyal patrons.

APPLICATION TO THE NIAGARA WINE MARKET

The Niagara Region continues to be one of the most promising regions for wine growth in the world. With over 100 wineries within the Niagara Peninsula, the market for Niagara wines attracts a vast diversity of customers (Wine Country Ontario, 2015). In addition to customers who purchase Niagara wines, the Niagara Region also boasts an impressive wine tourism industry which attracts customers from all over the world. In order to effectively address market demands and ensure continued profitability, wineries within the region must develop comprehensive market strategies.

To begin, it is important to consider market strategies for the wine tourism industry in the Niagara Region. The Niagara Region receives an estimated 1.8 million tourists per year who have come to the region specifically for the purpose of wine tourism. Of these 1.8 million, a majority are from the province of Ontario, and approximately 300,000 arrive from the United States and other international locations (Ministry of Tourism, 2015). As previously mentioned, the division of tourist groups into market segments can have numerous benefits for a winery. Through a comprehensive understanding of consumers, wineries are able to target tourists on a more specific basis (*Figure 4*).

FIGURE 4: HEALTHY ACTIVE TOURISM
A group of people participating in a bike-centered tour of a winery. This is an example of people who may be attending a wine tour for social aspects, physical activities, and exploration (Baquia, 2009).

Within the Niagara Region, wineries have taken a collaborative approach towards developing effective market segmentation. Dozens of wineries within the area have formed formal and informal alliances to market each other's wines to tourists. A representative was quoted as saying that wineries in the area "market collectively and promote together however sell competitively between each other" (Telfer, 2001). This includes promoting wines by word-of-mouth to tourists as well as developing tourist routes with other wineries so that tourists are encouraged to visit all wineries in the alliance. Such partnerships are often carried out with tour providers as well. For example, the Inniskillin Wines winery has developed strong links with Japanese tourists who have shown to be one of the largest consumers of icewine. The winery has a close partnership with the Japanese Tourist Board (JTB) and offers discounted icewine tasting packages to the JTB in hopes of further utilizing this market (Telfer, 2001).

Studies of the Niagara tourism industry have also shown that wine tourism is not commonly the principal reason for visiting the Niagara Region. The most common reason cited is visiting the Falls or visiting the casinos (Ministry of Tourism,

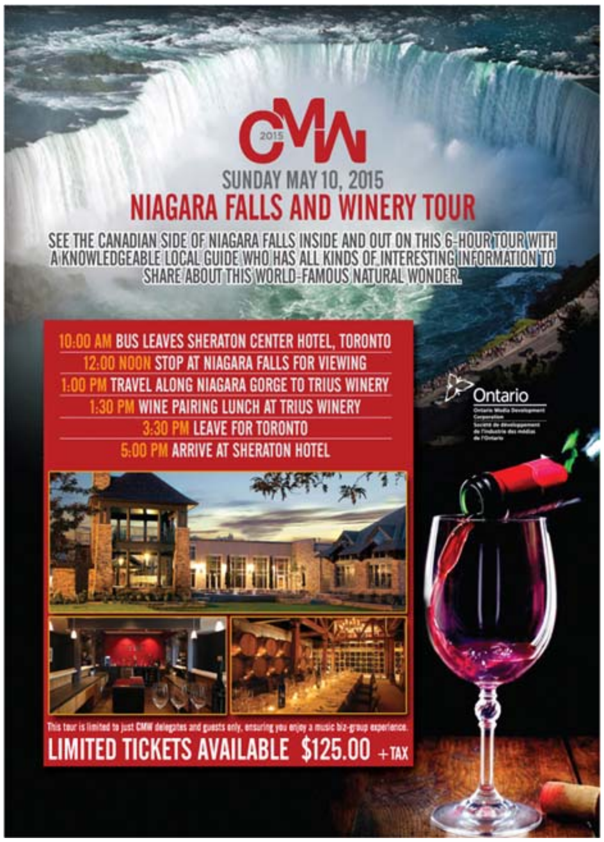

FIGURE 5: CANADIAN MUSIC WEEK TOURISM PACKAGE

An advertisement showcasing the Falls and the local Trius Winery (Canadian Music Week, 2016). Bundling two of the region's highlights creates an exciting opportunity for tourists.

2008). This provides an excellent opportunity for wineries to target specific markets (*Figure 5*). Luxury "boutique" wineries can advertise within casinos to attract more affluent consumers. Overall, the development of an effective market strategy for Niagara wineries is essential to their success. Many wineries in the area reported that over half of their sales came from on-site visits. Some smaller wineries reported that close to all their sales came from on-site visits (Telfer, 2015).

In addition to segmentation of the tourist market, it is important to consider how a winery may develop a market strategy for the retail world. In the digital world that we live in, many Niagara wineries have focused much of their retail marketing on social media and other digital avenues. Within their online pages, the Niagara wineries often feature a consistent motif or aesthetic that is meant to further its appeal towards a certain market segment. As an example, many wineries have now begun targeting the market of wine consumers looking for food-wine pairings. Fielding Estates Winery features an extensive online catalogue of foods which are best suited to their wines (Fielding Estate Winery, 2016).

In recent years many Niagara wineries have focused their retail attention on younger consumers as a market group. This "millennial" generation of consumers consistently displays strong purchasing power and is one of the most promising groups to market towards (Thach and Olsen, 2006). Within the Niagara Region, these young consumers often fall into the group of "pleasure seekers" of wine. These individuals are more concerned with the experiential satisfaction of drinking the wine and less so with the cultural image of wine. As a result, much of the marketing surrounding this group emphasizes the experiences associated with drinking wine - laughing with friends, enjoying a good meal, or spending time with family.

"We market collectively and promote together however we sell competitively between each other"

Additionally, wineries in the Niagara Region have also shown a vested interest in engaging youth in the world of viticulture itself. Wineries in the Niagara Region have developed partnerships with Brock University in St. Catharines to help support its undergraduate degree in Oenology and Viticulture (Brock University, 2016). This support comes in the form of offering work-integrated learning opportunities as well as financial support to help develop the program.

CONCLUSION

The marketing strategies adopted by the wine industry must adapt and evolve so as to meet the demands of an unpredictable market. Market segmentation is useful to wineries to focus advertising efforts on target groups of consumers. Although initial research into understanding one's market may be costly, the benefits are evident in current literature. Additionally, the recent developments in social networking sites are already showing promise with respect to market segmentation. The Niagara Region can make use of market segmentation to integrate the growing wine industry with the well-established industries.

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Translating Wine Tasting Terminology into Science

Raisa Ahmed, Julia Bandura, Angela Gupta, Jasleen Pahwa, Veronica van der Vliet

What's the difference between a smooth, dry, full-bodied, fruit-forward Cabernet Sauvignon and a spicy, sweet, medium-bodied, fruity Riesling? Though a wine novice might say, "the colour", a wine expert will likely disagree, giving any number of descriptors to describe the wine. Wine tasting, using a variety of descriptors, seeks to differentiate and describe the complex nature of this most divine of alcohol beverages. However, what quantifiable components of wine gives it these characteristics?

INTRODUCTION

The word 'wine' comes from the Latin word *vinum* and is the product of grape juice fermented by yeast (Clarke and Bakker, 2004). Today, 98% of total grape wine production comes from a single species of grapevine, *Vitis vinifera* (Clarke and Bakker, 2004). The chemical profile of wine is directly influenced by the grape variety used, their growth and harvesting conditions, the treatment of the must (grape juice), the fermentation process, and the maturation of the wine (Styger, Prior and Bauer, 2011). From sweet to dry, and still to sparkling, the individual chemical profile of each wine determines its flavours and aromas.

FIGURE 1: NIAGARAN SUB-APPELLATIONS. There are sixteen wine appellations in the Niagara Peninsula, varying in soil type, climate, precipitation, and topography. This allows the Niagara region to produce a variety of wine types (VQA Ontario, 2016).

With the large increase in popularity for wine tourism in the Niagara region (Figure 1), wine tasting has become a significant area of study in viticulture (Carmichael, 2005). Wine tasting allows us to determine the nature of wine, which is a product of the four taste senses (sweet, salt, bitter, sour) and aroma or smell. Taste is detected by the tongue from non-volatile substances, and smell is a product of volatile substances reaching the nose (Styger, Prior and Bauer, 2011). The flavour and aroma of wine is a direct result of a multitude of interactions between numerous chemical compounds and sensory receptors. Both synergistic (enhancing the perception of other compounds) and antagonistic (suppressing the perception of other compounds) interactions can occur. Thus, the multitude of flavour- and aroma-active compounds cause the sensory perception of wine to be highly complex. For example, the presence of sugar, polyol, salt, polyphenol, and flavonoid components account for, respectively, the floral, fruity, peppery, and woody tastes that are often described in wine (Styger, Prior and Bauer, 2011).

The complex composition of wine makes wine tasting and perception largely subjective to individual experiences. Physical and environmental aspects, such as the temperature and shape of the wine glass, can affect the perception of its aroma and flavour (Styger, Prior and Bauer, 2011). Furthermore, since individual consumers' tastes vary, and since peer consumption and marketing can also influence wine enjoyment, what defines the quality of a wine is difficult to understand (Goldstein et al., 2008). Nevertheless, it is important for winemakers and consumers alike to understand the biochemical processes that occur during a wine tasting and the extrinsic cultural factors that influence wine appreciation. As such, this review will examine the cultural history of wine, and conduct an in-depth analysis of the biochemical basis of perceiving and tasting wine, in terms of sweetness, texture, body, and fruit level. In doing so, this article will attempt to translate the language of wine tasting into scientific terminology.

THE DRINK OF THE ELITE

Wine is an interesting beverage, in that it not only appeals to the senses, but also symbolizes wealth and class (Valentin, 2001). Few other foods or drinks have been described in such detail, or their taste so thoroughly researched. Some of the earliest wine taste research dates back to 1535, from a Veronesi physician named Giovanni Confalonieri (Holt, 2006). Confalonieri published on the differences of opinion on the taste of wine: whether it was hot or cool, moist or dry. He found 'tannic' wines were 'drier' and that the location of the vineyard, its exposure to the sun, and the properties of the soil were important factors in determining flavour. Confalonieri refused, however, to make bold, general statements about all wines, deeming such an attempt futile given wine's incredible diversity. It is likely that many of today's wine tasters would agree with him (Holt, 2006). But where did wine tasting begin? Why does it have such a strong connection to class structure?

Europe in the 16th century had a Roman Catholic, largely wine-drinking culture in the south. This connection of geography, religion, and drink preference can be understood through the relationship between wine and the Catholic church. The doctrine of the Eucharist states that the wine of the Mass turns into the blood of Christ when consecrated by an ordained priest. Wine was thus considered so holy that 'common folk' were not allowed to drink it (Holt, 2006). In fact, many spaces in which wine was sold were not accessible for lower class citizens, as the powerful elite (the church, the bourgeoisie, and the nobility) made wine cheapest and attainable only to themselves (Holt, 2006; Crawford, 1977). This was done through the establishment of laws allowing the ruling class to buy wine cheaper wholesale, sold by vintners, while the poorer classes bought wine retail from taverners, when it was affordable (Crawford, 1977). For example, Henry II of England, reigning from 1154 to 1189, established the right of 'prisage', entitling the king to a certain amount of all imported wine. He could also purchase any additional wines at a reduced, fixed price. Through this, and a host of other regulations throughout history, the elite classes monopolized the market, associating wine with wealth and superiority (Crawford, 1977). As wine became easier to make with new techniques, the quantity of wine available increased, and the price became more accessible to the middle and lower classes. This removed the upper-class monopoly on wine, and it was no longer an automatic indication of wealth. Because of this, modern wine tasting may have arisen as a way for the upper class to maintain a niche market. This emphasized the importance of having expensive wine from specific regions, prized for taste characteristics (Crawford, 1977).

Wine tasting is also connected to insuring bottles have not been poisoned or gone bad, as some could turn to vinegar, or potentially dissolve a rotting cork (Loubere, 1978). The various phases of inspection used in wine tasting may have come from simply assuring oneself that the wine was fit to drink. Taverners who wanted to prove they weren't swindling their customers might also have adopted this practice. There is certainly 'initial tasting' done in restaurants today to ensure drinkability (Loubere, 1978). The more recent rituals of wine tasting could also have been driven by the growth of high-end commercial wineries in California (Holt, 2006). By the late 1800's, California vineyards realized they had to cultivate a sense of connoisseurship to establish a sizable American market for themselves. They started aggressively promoting how 'real' vintners taste tested, and how to become a wine tasting 'expert', effectively tying their names to large European wineries (Holt, 2006).

The historical precedent for the current cultural practices surrounding wine tasting is complex. Due to the push for wine to remain sophisticated and refined, there is now an intricate means of classifying taste in wine. But, what does it mean when we say that a wine is smooth, spicy, sweet, dry or any number of other terminologies?

A SWEET NECTAR

Perhaps the most ubiquitously identifiable component of a wine's taste is its sugar content, or sweetness. In wine tasting terminology, the sweetness of a wine is described on a scale of dryness, ranging from bone dry to sweet, with comprised of glucose and fructose. The residual sugar level in dry wines is 0.2-0.8 g/L of glucose and 1.2 g/L of fructose, while the residual sugar level in sweet wines is 30 g/L and 60 g/L of glucose and fructose, respectively (Stevenson, 1999).

FIGURE 2: NOBLE ROT ON RIESLING GRAPES. The rot can be seen on the grapes pictured, where some have already shriveled due to loss of water (Maack, 2005).

The high residual sugar level in sweet wines usually comes from the sugar that is not consumed by the yeast during the fermentation process (Clarke and Bakker, 2004). Therefore, to produce a sweeter wine, the fermentation process can be stopped early. Drier wines can also be sweetened with specially prepared sweetening wine. For example, Süssreserve (unfermented grape must) is used as a sweetener in various German wines.

Wine can also be sweetened using sun-dried grapes or late-harvest grapes infected with *Botrytis cinerea*, a mould which attacks grapes, causing 'noble rot' (Figure 2). *Botrytis* creates a desirable grape rot in areas near river valleys, where mist develops at night, lingers in the morning, and clears up by the sunny afternoons. The mould causes a drying effect, removing water from the grape. This results in concentrated sugars creating juice that will have a sugar content of 30-40% sugar weight per volume. The drying effect also makes the grapes less susceptible to a second invasion by bacteria and fungi. Late ripening grapes have thick skins and are also susceptible to noble rot. Riesling and Semillon are the main varieties used, but Furmit, Chenin Blanc and often Gewürztraminer are used as they are also susceptible to a 'noble rot'. When used properly, the Botrytis cinerea can create some of the most remarkable sweet wines (Clarke and Bakker, 2004).

The sweetness of wine can also influence other characteristics of the wine. For example, high levels of sugar have been associated with reduced bitterness of wine (McRae and Kennedy, 2011). Sweeter wines also tend to suppress wine acidity. In fact, when compared to other fermented drinks such as beer, the high acidity of wine is tolerable as it counterbalanced by the high residual sugar levels (Stevenson, 1999).

IT GOES DOWN SMOOTH

The sense or perception of wine after swallowing, referred to as the texture or finish of wine, is another term frequently used when assessing the taste of wine. Various chemical factors can affect the unique finish of each wine produced. The presence of tannins and polysaccharides, ethanol concentrations, and the acidity level are the greatest contributors to the finish of wine (Jones et al., 2008).

Tannins (Figure 3), a naturally occurring compound extracted from the seeds and skin of grapes, are one of the most significant factors pertaining to the mouthfeel and texture of wine (Vidal et al., 2004). Tannins interact with salivary proteins, causing the formation of tannin-protein complexes, which increase friction in the oral cavity (McRae and Kennedy, 2011). These complexes influence the astringency of wine, a tactile sensation on the palate, resulting in loss of lubrication in the mouth (Vidal et al., 2004). This can be described as a dry or rough sensation in the mouth, and is commonly associated with an undesirable wine (Vidal et al., 2004). Tannin compounds alone are structurally very stable, and thus create a grittier taste in the wine. This further influences tactile sensation and increases the astringent effect on the finish of wine. The effects of tannins on astringency levels in wine are directly correlated, and dependent on the concentration of tannin compounds in the wine. Therefore, an understanding of tannin interactions is significant in controlling the texture of wine. Methods such as micro-oxygenation or fining techniques are commonly used to control the finish and texture of wine. Micro-oxygenation adds oxygen to wine, which improves aroma while changing the structure of tannins to more structurally flexible compounds, thus reducing astringency (McRae and Kennedy, 2011).

Higher ethanol levels of wine (11% – 20%) can alternatively result in a smooth texture and finish to wine (McRae and Kennedy, 2011). This is primarily due to the structural changes that result from decreased protein-tannin binding as well as changes in the solubility of protein-tannin complexes in the presence of higher ethanol concentrations. Furthermore, increased ethanol may also reduce the roughness in texture perceived, due to the onset of increased lubricity in the mouth (McRae and Kennedy, 2011).

FIGURE 3: TANNIN POWDER. A mixture of various tannic compounds, this component of wine gives it its bitterness (Eugster, 2009).

The pH levels of wines typically range from 3.2 to 3.8 (McRae and Kennedy, 2011). The slightest change in pH can affect the astringency and therefore texture of wine. A lower pH has been shown to increase the tannin-protein association resulting in an increase in astringency of wine (McRae and Kennedy, 2011).

A SENSATION OF WEIGHT

Unlike other descriptors for wine, body is a more imprecise term, and the specific characteristics that contribute to it are difficult to define. In wine tasting, body is a function of the tactile weight or richness of the wine in the mouth (Jackson, 2009). A high amount of body makes a wine "full-bodied", and an absence of body makes a wine "watery" or "light-bodied". But what does this actually mean? What quantifiable characteristics of wine give it its body? The answer comes from the products of fermentation by yeast, and their effect on wine viscosity.

Perceived viscosity of a wine has been found to be the most significant factor influencing wine body (Runnebaum, Boulton, Powell and Heymann, 2011). One study, conducted on the properties of white wines and their composition in relation to body sensation, found that typically light-bodied wines like Sauvignon blanc were found to have lower viscosities, and full-bodied wines such as Chardonnay tended to have higher viscosities (Runnebaum et al., 2011).

The components of wine that influence viscosity are mostly produced by yeast. *Saccharomyces cerevisiae* converts the sugars in grape juice to ethanol and carbon dioxide, and produces many secondary metabolites, including various acids, alcohols, carbonyls, esters, and sulfur compounds (Pretorius, Curtin and Chambers, 2012). Ethanol is thought to have the greatest effect on perceived viscosity, and has also been found to increase other subjective mouthfeel sensations, such as intensity and harshness of taste (Demiglio and Pickering, 2008; Yanniotis, Kotseridis, Orfanidou and Petraki, 2007). A potential explanation for these effects of ethanol may be its inhibition of salivary protein binding to polyphenolic constituents of the wines (Demiglio and Pickering, 2008). Glycerol, a major by-product of yeast fermentation, has also been found to have a positive effect on the viscosity of wine, but it is generally present in a very low concentration, rendering its effect negligible (Yanniotis et al., 2007).

FIGURE 4: RED AND WHITE WINE. Red wine is generally more full-bodied, whereas white wine is lighter. However, light-bodied reds like Pinot Noirs can be lighter than full-bodied whites like Chardonnays (Public domain).

A secondary type of fermentation, malolactic fermentation, is catalyzed by the lactic acid bacterium *Leuconostoc oenos* (Versari, Parpinello and Cattaneo, 1999). Lactate, the major product of malolactic fermentation, has also been shown to increase perceived viscous mouthfeel, and is associated with viscosity and thus wine body (Runnebaum et al., 2011).

However, products of fermentative processes in wine are not the only components which influence wine body. In both red and white wine, dry extract (defined as the total content of a wine that is not water or alcohol) has been found to positively correlate with viscosity (and therefore body) (Yanniotis et al., 2007). It has been found that dry white wines have the lowest viscosity, followed by dry red wines, and finally sweet wines (red or white) with the highest viscosity (Figure 4) (Yanniotis et al., 2007). Finally, the most abundant amino acid found in grapes, proline, is unused by yeast in fermentative processes (unlike arginine, alanine, glutamate, and glutamine), and has also been positively correlated with wine body (Skogerson et al., 2009).

FRUITY AND AROMATIC WINE

When individuals refer to the fruitiness of wine, terms such as 'savoury' or 'fruit-forward' arise. These terms are more indicative of the aroma of wine rather than its actual taste. Why is it that some wines tend to be fruitier, and others herbaceous? Many important processes and compounds play a role in the aroma of wine, and work together to result in multiple different odours.

Yeast metabolism is very important when it comes to the aroma of wine, as various volatile compounds, including esters, co-exist to create complex aromas individual to each wine (Pretorius and Lambrechts, 2000). Volatile fatty acids are some of the aroma compounds that contribute greatly to the smell of the wine

(Pretorius and Lambrechts, 2000; Styger et al., 2011).

Long-chain fatty acids and medium-chain fatty acids contribute to the aroma of each wine (Pretorius and Lambrechts, 2000; Swiegers et al., 2005). Long-chain fatty acids, particularly those with 16 and 18 carbon atoms (C16 and C18), are commonly found in esters and are precursors for lipids that are found in the yeast used for fermentation, including phospholipids, glycolipids, and acylglycerols (Pretorius and Lambrechts, 2000). These long-chain fatty acids, found in the yeast plasma membrane, allow for the regulation and movement of molecules into and out of yeast cells during fermentation (Pretorius and Lambrechts, 2000). Medium-chain fatty acids, such as C8, C10, and C12, are produced as intermediates during the synthesis pathway of long-chain fatty acids (Pretorius and Lambrechts, 2000). Both long-chain and medium-chain fatty acids determine the aroma of the wine (Pretorius and Lambrechts, 2000; Styger et al., 2011). For example, the presence of fatty acids such as acetic acid, propionic acid, butyric acid, and valeric acid result in an unpleasant, pungent smell; tridecanoic acid and decanoic acid give a citrus smell; while acids such as hexanoic acid and isovaleric acid give almost a cheesy aroma to wine (refer to table 1; Pretorius and Lambrechts, 2000).

Along with fatty acids, higher alcohols, known as fusel alcohols, also affect the aroma of wine (Swiegers et al., 2005). Higher alcohols consist of alcohols at a higher boiling point and molecular weight than ethanol, and these give wine an unpleasant, pungent smell when present between the concentrations of 300-400 mg/L (Pretorius and Lambrechts, 2000). Amino acids found in the grape juice, most commonly valine, leucine, and isoleucine, greatly influence the yield of higher alcohol formation (Styger et al., 2011). The concentrations of these high alcohols in wine are dependent on the presence of the aforementioned amino acids, therefore affecting the intensity of unpleasant aromas of the wine (Pretorius and Lambrechts, 2000; Styger et al., 2011).

Unlike fatty acids and fusel alcohols, esters are volatile compounds that give a pleasant aroma to wine (Lilly et al., 2000; Pretorius and Lambrechts, 2000). The mixture of esters produced during fermentation gives a fruity, floral aroma to wine, where the most prominent are acetate esters, which are classified as fermentation compounds (Lilly et al., 2000; Pretorius and Lambrechts, 2000). Table 1 shows some of the aromatic acetate esters formed during fermentation that produce various smells, from different fruits, to honey and flowery aromas (Pretorius and Lambrechts, 2000). Carbonyl aldehydes, specifically volatile aldehydes, are also important compounds in the production of higher alcohols from amino acids (Liu and Pilone, 2000). These aldehydes, when interacting with keto-acids, also contribute a fruity aroma to wine that varies from fruit-forward, to herbaceous and coffee-like (refer to Table 1; Liu and Pilone, 2000).

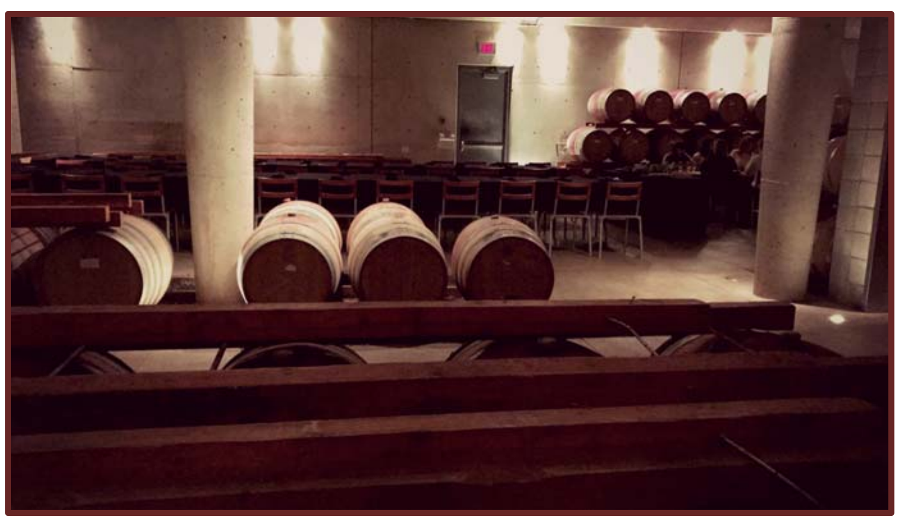

FIGURE 5: OAK BARRELS. Wine undergoes further malolactic fermentation in oak barrels, pictured here in the cellar of Jackson Triggs Winery (Raisa Ahmed, 2016)

TABLE 1: VARIOUS COMPOUNDS AND THEIR SIGNIFICANCE TO WINE AROMA. (Pretorius and Lambrechts, 2000).

Classification of Compound	Compound	Odour
Fatty Acids	Acetic Acid	Vinegar, pungent
	Hexonic acid	Sour, vinegar, cheese, sweaty, rancid, fatty, pungent
	Octanic acid	Oily, soapy, sweet, faint fruity, butter
	Tridecanoic acid	Fatty, citrus, unpleasant
Higher Alcohols	Tyrosol	Bees wax, honey-like
	Phenethyl alcohol	Floral, rose
Esters	Ethyl acetate	Varnish, nail polish, fruity
	Isoamyl acetate	Banana, pear
	2-Phenethyl acetate	Rose, honey, fruity, flowery
Aldehydes	Isobutanal	Slightly apple like
	Pentanal	Cocoa, coffee-like, slightly fruity
	Isovaleraldehyde	Warm, herbaceous, slightly fruity, nut-like

Not all compounds affecting aroma are produced during yeast fermentation. Some wines tend to undergo malolactic fermentation, as previously mentioned (Styger et al., 2011). Since many malolactic fermentation steps occur within oak barrels (Figure 5), the lactic acid bacteria that is involved in this process chemically reacts with the oak and produces oak-derived compounds (Styger et al., 2011). These compounds give off a vanilla aroma as lactic acid bacteria modify a vanillin precursor within the oak barrels, releasing vanillin into the wine (Styger et al., 2011).

The aroma of wine is affected by many factors, including the types of fermentation, as well as which metabolic compounds are found in the grape juice and used in the fermentative process. However, the aroma of wine is also more dynamic than it is static, as the ageing of wine and its means of storage could result in an altered taste in the designated wine (Styger et al., 2011). As such, the aroma of wine is a result of complex interactions between many volatile compounds, and gives specific wines their fruit profile.

THE NIAGARAN TERROIR

Over the past centuries, the Niagara Peninsula has rapidly grown into the New World Wine Route, an area where the favourable microclimate and proximity to the Niagara Falls has led to the development of one of Ontario's major tourist destinations (Hakimi, Rezaei, and Reynolds, 2010). The unique environmental aspects of the Niagara region vastly influence the characteristics and quality of the wines produced there. In fact, the Niagara region is known to be the Fruit Belt of Canada due to its adequate temperature and soil types to produce high quality wine and fruit (Telfer, 2000). Due to this ideal location, irrigation in the Niagara region tends to increase the acidity of must in the process of producing wine, which increases the overall quality of these wines (Reynolds, Lowrey, and De Savigny, 2005). Nutrient uptake, a factor associated with the quality of wine, is highly efficient in these wineries as the Niagara Peninsula provides ideal conditions for transpiration, metabolic activity and warming temperatures (Reynolds, Lowrey, and De Savigny, 2005).

Wines produced in the Niagara river and lakeshore area are identified to have a higher green bean and bell pepper aroma, due to the cool temperatures associated with the presence of large water bodies nearby, an environmental influence referred to as Buis (Rezaei et al., 2010). Studies conducted in the Niagara Peninsula have further identified increased red fruit, black currant, black cherry and black pepper aromas, specifically in the Henry of Pelham and Château de Charmes sites. Similarly, this is due to a close proximity to Lake Ontario. Overall, the various aspects of each wine produced, the hue, colour intensity, and ethanol content vary from site to site as the chemical and sensory components of wine are affected by a vineyard's proximity to large bodies of water and growing conditions (Rezaei et al., 2010).

CONCLUSION

From historical wine to wine in modern society, it is fascinating to see how wine tasting has changed throughout the years and how the focus has shifted from the taste of a wine to the reasoning behind its taste. Factors ranging from wine texture, to sweetness, to its aroma and body profile, all work together to produce their own unique taste for every individual wine. However, despite attempts by the scientific community to chemically analyze wine components, the quality of a wine will always be defined by each individual's tastes. The interaction between the various components of wine and the outcome of this interaction is such a delicate, intricate process that it should not be considered just a science, but also an art.

MORE TO EXPLORE

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Title page: <https://pixabay.com/en/wineglass-wine-glass-wine-tasting-553467/>

Figure 4: <https://pixabay.com/en/wine-red-wine-alcohol-wine-glass-1585337/>

Bubble Fizzics

Using Science to Enhance the Sparkling Wine Experience

Will Farmer, Laura Green, Matthew Nugent, Jonathan Panuelos, Simon Zhang

Sparkling wine has become synonymous with celebration and pleasure, and so it stands to reason that one should have an interest in making the drinking experience as enjoyable as possible. This article identifies the most notable qualities of sparkling wine, and methods by which these qualities can be improved upon. The ideal conditions for serving and drinking sparkling wine are deduced according to popular opinion on what makes a good sparkling wine.

INTRODUCTION

Noted for its effervescence – the characteristic rise of bubbles – sparkling wine is the quintessential drink for celebrating a special occasion. Much more than an elegant display, however, effervescence also contributes to the aroma and taste of sparkling wine. From vineyard to celebratory toast, numerous factors in the wine-making process will affect the properties of the end product.

Like many food and drink products, what makes a good sparkling wine is open to – often fierce – debate. However, consensus agrees that certain attributes are currently more desirable than others. Foam generated upon pouring is visually appealing, and effervescence of small bubbles is expected to last the entire drinking period.

Ontarian winemakers are starting to make inroads into the sparkling wine market. Of the 132 registered wine producers in Ontario, approximately 26 are producers of sparkling wine (Vintners Quality Alliance, from here on denoted as VQA, 2013). Annual production of Ontarian sparkling wine is approximately 500,000 litres, which equates to around 55,000 cases of product.

This article will explore how different factors can be altered to provide the consumer with the most enjoyable sparkling wine experience possible, and where relevant, will note the methods and techniques used within the Ontarian Sparkling Wine Industry.

AT THE VINEYARD

Growing Grapes

With such a pristine end product, it is easy to see how many regulations and steps are required to differentiate sparkling wine. Since sparkling wines benefit from a high acidity and low soluble sugars, their grapes are picked early in the harvesting season (Jones et al., 2014). This leads to a very clear base wine that will eventually be fermented into sparkling wine. The three grape varieties that are mainly associated with sparkling wines are Chardonnay, Pinot noir, and Pinot meunier with less common varietals including Sauvignon blanc, Pinot blanc and Riesling (Jones et al., 2014). Each grape variety adds its own individual attributes to the finished product. For example, Chardonnay adds elegance to the wine, Pinot noir increases the body, while Pinot meunier rounds out the flavour of the wine with fruitiness. Therefore, specific wineries will add these three grapes in different proportions to design their wine's flavour (Jones et al., 2014). Since these grapes have different maturation periods, wine-makers are challenged into carefully planning their growing season to create a base wine that is ready for fermentation.

The most common grape varieties used in Ontario are Chardonnay, Pinot noir and Riesling. These varieties are chosen due to their suitability to the clay loam soils often found in the greater Ontario area (VQA, 2013).

Fermentation

The defining feature of a glass of sparkling wine is the carbon dioxide (CO_2) bubbles that delight the palate upon consumption. Unlike the CO_2 injections used in carbonated sodas, the high CO_2 content leading to the carbonation of sparkling wine is traditionally introduced via fermentation (Grainger and Tattersall, 2005). Although the injection method is used in the creation of some sparkling wines, these wines are often cheaper and considered inferior to those which have CO_2 introduced via fermentation. It is also generally accepted in the wine community that sparkling wine contains small, lingering bubbles which do not occur in any artificially carbonated drinks.

In the traditional method of sparkling wine fermentation, yeast is added into the base wine along with some sugar, then sealed into bottles. These bottles are carefully monitored for 14 to 90 days, with the fermentation being considered done once the pressure inside the wine is about 5 times atmospheric pressure (Grainger and Tattersall, 2005). After the wine has time to mature, the bottles are placed into wooden easels with slanted holes which invert the bottle gradually over time. Initially, a wine-maker places a bottle almost horizontally neck first into these holes. In a process called riddling, shown in Figure 1, the bottles are given a slight twist and occasionally moved to a more vertical hole every day for the next six weeks (Grainger and Tattersall, 2005). This coaxes the dead yeast to the neck of the bottle, which now must be removed in a process called disgorging. This involves freezing the neck of the bottle along with the yeast sediment and removing the small frozen yeast pellet without disrupting the pressure inside the bottle (Grainger and Tattersall, 2005, Pozo-Bayón et al., 2009). The removed ice pellet is replaced with some of the original base wine, known as a dosage, then recorked and labelled.

There are two methods other than traditional and artificial carbonation – the transfer and the Charmat methods. The transfer method is very similar to the traditional method but involves filtering the wine instead of disgorging (Grainger and Tattersall, 2005; Pozo-Bayón et al., 2009). The Charmat method is like the transfer method but involves fermentation in a pressurized tank instead of in the bottle. Second to artificial carbonation, this method is the cheapest in making sparkling wine (Grainger and Tattersall, 2005).

In Ontario, 65% (~325,000 litres) of sparkling wine is produced utilizing the traditional method, while the remaining 35% (175,000 litres) is produced through the Charmat method (VQA). Interestingly, the method of fermentation affects the choice of grape varietals used. Wines produced traditionally are composed of approximately 84% Chardonnay and Pinot noir, whereas those produced through Charmat feature a lower percentage of Pinot noir and an introduction of Riesling to the blend. One exception to the above is sparkling ice wine; a product unique to Ontario created by topping up a traditionally produced sparkling wine with a dosage of ice wine.

FIGURE 1: A bottle of sparkling wine currently undergoing the early stages of riddling. The dead yeast cells, known as lees, have sank to the side of the bottle where it will eventually end up in the neck to be removed by disgorging (Bernt, 2005).

INTO THE GLASS

Bubble Formation

The product of the careful fermentation process is the millions of bubbles arising from a freshly poured glass. Few people think any more about how and why these bubbles form, but the process is remarkable in itself.

After uncorking, the pressure of CO_2 gas inside the bottle lowers to atmospheric pressure. This disrupts the equilibrium of CO_2 gas dissolved in the sparkling wine that is formed when the bottle is sealed. As the CO_2 gas is allowed to dissolve in the sparkling wine, its dissolved concentration becomes proportional to the pressure of the air surrounding the liquid; consequently, the sparkling wine becomes supersaturated with CO_2 as the pressure of the gas in the bottle lowers

(Liger-Belair, Parmentier and Cilindre, 2012). If there is a sufficient disturbance, such as the violent opening of a bottle of sparkling wine, the supersaturated CO_2 will be released. This release can be done through bubbling or direct exchange with the open air in contact with the liquid. Bubbling is the more noticeable of the two, but gas exchange directly from the open surface accounts for most of the CO_2 loss – 80% compared to bubbling's 20% (Liger-Belair, 2005). It is, however, more important to understand the quality of sparkling wine from a visual perspective in order to observe it more effectively. For example, its bubble properties can be seen and appreciated simply by the naked eye.

Upon pouring a glass of sparkling wine, bubble trains immediately start to form from the walls of the glass. Contrary to popular belief of consumers, these trains do not arise from imperfections or scratches in the glass (Liger-Belair, Marchal and Jeandet, 2002). These scratches are rarely large enough to have the required radius needed to form a bubble. Sparkling wine has a relatively low supersaturation, meaning there is not a lot of excess CO_2 dissolved in the wine. As such, it takes a lot of energy for the CO_2 to gather in one location and form a bubble, unless there is already a sufficiently large pocket of air in the wine that gas can enter (Jones, Evans and Galvin, 1999). It has been shown that gas bubbles originate from pockets of air trapped in cellulose fibres in the sparkling wine (Liger-Belair, Marchal and Jeandet, 2002).

The cellulose fibres allow for CO_2 to gather more freely as their radii can provide the necessary air pocket size for bubble production. The radius required to form CO_2 bubbles increases as the dissolved concentration of CO_2 gas decreases over time, meaning the thinnest fibres will become inactive first, followed by the widest fibres as the champagne begins to settle (Liger-Belair, 2005).

As a CO_2 gas pocket forms and expands inside a cellulose fibre, it will eventually reach a size where it meets the end of the fibre. The gas bubble will expand outwards until the upward buoyant force outweighs the capillary force keeping it attached to the fibre. At this point, a bubble detaches from the rest of the air pocket. This leaves space for more CO_2 to gather in the fibre and grow into another bubble. By this process, bubbles are released with slightly imperfect consistency until there is no longer a sufficient supply of CO_2 (Liger-Belair, 2005). Thus, it is the cellulose fibres in the bottle that give rise to the characteristic and beloved bubble trains of sparkling wine.

Flows

After bubble generation, known as nucleation, the pattern of rising and swirling bubbles in sparkling wine is often noted for its aesthetic appeal. However, its presence adds much more to the drinking experience than just visual engagement. In particular, the rise of these bubbles has a significant effect on the fluid dynamics in the glass, and by extension, the release of aromas on the liquid surface (Liger-Belair, Polidori and Jeandet, 2008).

It has been shown via laser tomography, a method where minute particles are suspended in the fluid and illuminated by a laser, that the movement of bubbles toward the surface induces a flow on the surrounding fluid due to turbulence generated behind the bubble (Polidori, Beaumont, Jeandet and Liger-Belair, 2009). The flow around objects can be characterized by the Reynolds number, which is the ratio of inertial to viscous forces. Low Reynolds numbers represent laminar, or smooth, flows while higher values represent turbulent flows (Magnaudet and Eames, 2000; Chorin and Marsden, 2000). Compare dropping a marble in water and in honey – in water, the marble causes a splash, falls very quickly, and mixes the water as it falls. Honey has a much higher viscosity, slowing the marble and preventing any turbulent mixing. Wine has a low enough viscosity that the rising movement of the bubble is able to create the same mixing effect as the falling marble in water. In fact, bubbles will have this turbulence-generating property in any low viscosity fluid, such as water and carbonated soda (Duineveld, 1995).

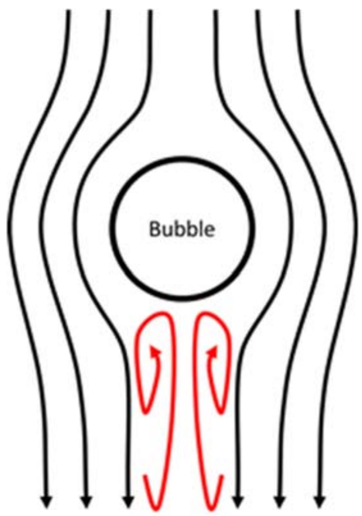

FIGURE 2: Flow around a bubble in low-viscosity fluid. As the bubble rises, it displaces the fluid in front of it, which follows the curvature of the bubble to produce laminar, or smooth, flow as shown by the black arrows. At some point at the back of the bubble, the bubble's inertial forces due to its upward momentum exceeds the viscous forces keeping the fluid at the boundary, causing the laminar flow to separate from the bubble boundary. This creates a low-pressure zone behind the bubble, which pulls fluid back towards it, shown with the red arrows. Note that this is the reverse of the rest of the fluid flow, producing turbulent mixing. This type of flow is typical for high Reynolds numbers (Chorin and Marsden, 2000).

Turbulent mixing occurs at the wake of the bubble. As the bubble rises, wine flows down relative to the bubble on the front and sides, but separates on the back as is typical for high Reynolds number flows. This causes a low-pressure zone behind the bubble, pulling fluid back towards it, as shown in Figure 2 (Chorin and Marsden, 2000). This not only causes the mixing, but moreover, causes more aromatic compounds to be entrapped in the bubble surface, which are then released at the surface of the wine upon popping (Liger-Belair, Polidori and Jeandet, 2008).

In natural effervescence – that which arises solely from nucleation in the cellulose fibres – the overall flows produced are random and constantly changing, as the nucleation sites drift about the fluid. In the case of artificial effervescence, generated by laser etchings in the bottom the glass, nucleation is constant and vigorous enough to produce a steady flow (Liger-Belair, Polidori and Jeandet, 2008). It is with this case that a large difference arises between the two traditional champagne glasses – the coupe and the flute, as shown in Figure 3. The coupe's wide and flat shape results in non-mixing dead zones at the edge of the glass, since the rising bubbles do not have enough velocity to reach the edge of the wide glass. In comparison, the deeper flute gives the bubbles more distance to gain velocity, in addition to the shorter travel distance to the edge of the glass (Polidori et al., 2009). Thus, the flute is better mixed than a coupe when under artificial effervescence, though both behave similarly under natural bubbling.

Temperature Dependence

The major influencing variables on the rate of bubble release are temperature, pressure, viscosity, and CO_2 concentration. Considering that viscosity and CO_2 concentration are inherent to the wine-making process, and pressure is fairly constant aside from at extreme altitudes, the only variable relevant to the consumer is temperature. Liger-Belair *et al.* show both experimentally and theoretically that CO_2 release is proportional to temperature (Liger-Belair, Polidori and Jeandet, 2008). Thus, it is advantageous to drink sparkling wine chilled, as this slows bubbling, preventing

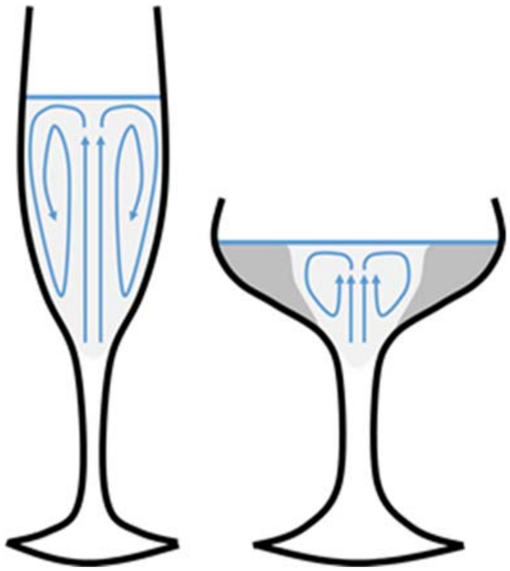

FIGURE 3: Flow differences between a flute (left) and a coupe (right), subject to artificial effervescence. Flow lines are represented in blue, with the mixed regions in light grey and non-mixing regions in dark grey. Bubbles are generated at an engraving at the bottom of the cups, and accelerate due to buoyant force upwards. Note that the distance travelled by the bubble is much shorter in the case of the coupe, and therefore in addition to requiring a further distance to travel the edge of the cup, bubbles have a slower velocity upon reaching the surface. Non-mixing dead zones are thus present in the coupe. Image adapted from Polidori *et al.*, 2009.

excessive fizz formation, therefore allowing the effervescence to last longer. Fortunately, people expect wines to be served cold, and prefer the taste of colder wines as well (Zellner, Stewart, Rozin, & Brown, 1988).

To investigate the effect of chilling the glass before pouring, a model was developed in the C programming language, whose results are shown in Figures 4 and 5. This model uses the theoretical equations derived by Liger-Belair *et al.*, coupled with heat diffusion to analyze its effect (Liger-Belair, Polidori and Jeandet, 2008). It shows that the timescale for heat to transfer between the glass and the liquid is much longer than that of CO_2 release. Thus, although there is a slight improvement from chilling the glass, it is not nearly as significant as chilling the wine itself. Additionally, it shows that the flute has more CO_2 release through bubbling, mostly due to the deeper glass shape allowing bubbles to absorb CO_2 for longer. Therefore, the glass shapes both have advantages and disadvantages – on one hand, the flute experiences more thorough mixing but suffers from high CO_2 release, while on the other, the coupe contains dead zones but slower carbonation.

SPARKLING WINE ENJOYMENT

The Sensory Experience

Overall, the subtleties within each step of the sparkling wine-making process ensure that every bottle is unique in sight, taste, and smell. As bubbles burst from the surface of the sparkling wine, they release droplets into the air. This creates a constantly renewing aerosol of sparkling wine above the surface of the liquid, seen in Figure 6. Dispersed throughout the aerosol are compounds that bubbles pick up as they rise through the liquid bulk. These compounds, restricted to the liquid bulk in non-sparkling wines, are largely responsible for the aroma. This is because many of them are amphiphilic, meaning they contain a water-soluble region and a non-soluble region. This property allows the compounds to remain soluble in wine, which is mostly water, and still be able to bind to olfactory receptors in the nose, which preferentially bind to non-soluble molecules. Overall, the release of surfactants in the aerosol leads to increased aromatics above a sparkling wine as compared to a non-sparkling wine (Liger-Belair et al., 2009).

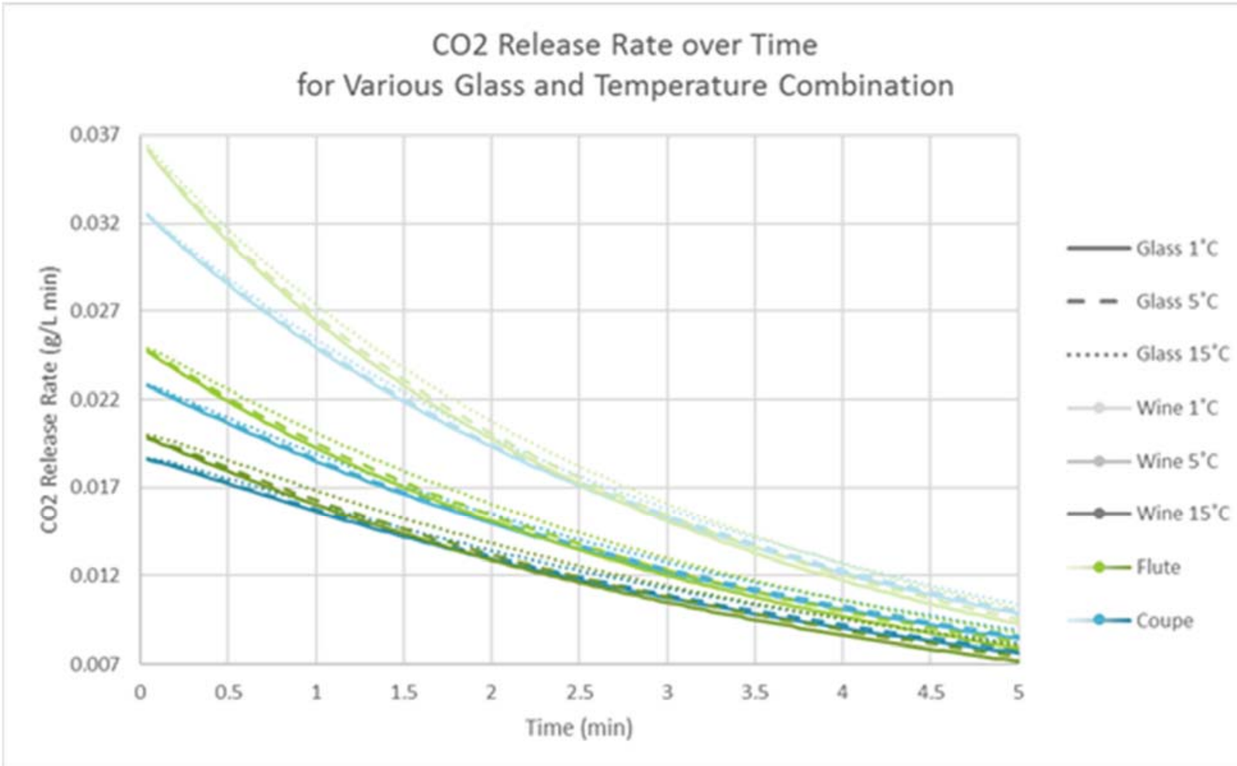

FIGURE 4: Results for a CO_2 release coupled with heat diffusion model. Main results found were that heat transfer between the glass and the liquid yielded little effect, as shown by differences between solid, dashed, and dotted lines. Additionally, it was found that the flute has higher CO_2 release rate than the coupe due to its greater depth.

Further, the various surfactants in the aerosol are in slightly different concentrations than those that remain in the bulk liquid. A study by Liger-Belair *et al.* shows that the aerosol contains more organic compounds than the liquid below (Liger-Belair, Villaume, Cilindre, Polidori and Jeandet, 2009). These include decanoic acid, which exhibits acidic and toasty aromas in sparkling wines, and dodecanoic acid, which is responsible for dry and metallic notes. As well, there are monounsaturated fatty acids, which are markers of foam quality in sparkling wine and precursors to herbaceous aromas. A family of odorant compounds, norisoprenoids, in sparkling wine aerosols contribute to a fruity aroma found in several grape varietals. Finally, the aerosol also contains ricinoleic acid, which leads to a peachy aroma.

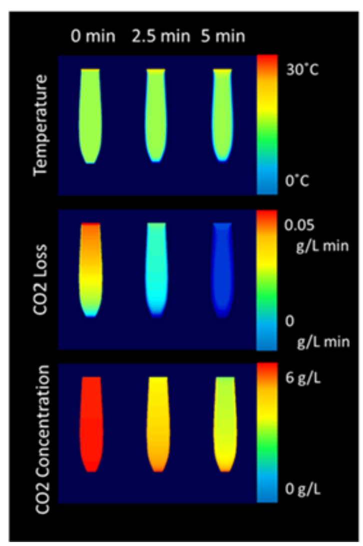

FIGURE 5: Simulation results for a flute with 0˚C glass and 15˚C wine. Results over time is shown between columns, and the rows represent temperature, CO_2 loss rate, and CO_2 concentration from top to bottom respectively. As can be seen in the differences over time, CO_2 concentrations – and therefore rate – fall very dramatically over time. By comparison, changes in temperature due to heat diffusion barely occur. This suggests that the timescale for temperature change is much slower than CO_2 loss and therefore gives very little effect.

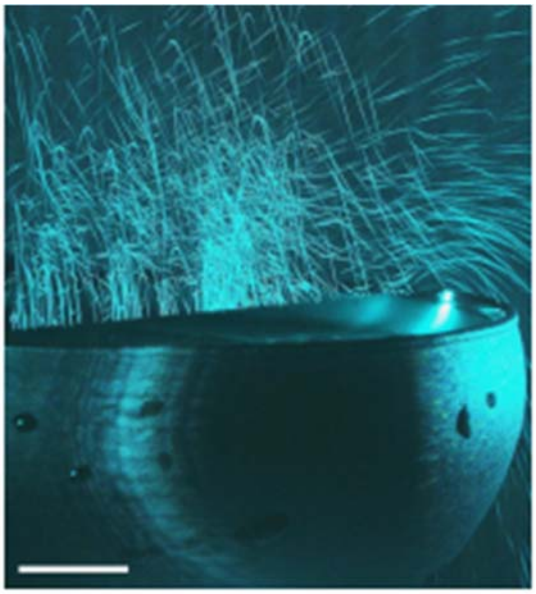

FIGURE 6: Aerosol above a champagne glass, as seen through laser tomography. The drops' trajectories are seen as streaks of blue light, shown through a 1 s exposure time of a digital camera (Scale bar, 1 cm) (Liger-Belair, Polidori, & Jeandet, 2008).

Serving

As mentioned above, the two most common shapes of champagne glasses are the flute and the coupe. Each style has purported benefits, and as such each is more suitable for some types of sparkling wine over others.

Currently, the most popular choice of champagne glass is the flute. It is believed that this tall design brings about the biggest advantage to a sparkling wine's effervescence, by emphasizing the rise of the bubbles. However, there is a lack of air space, meaning that there is not much room in which the aromatic compounds released from the bubbles can gather. Some wine experts argue that this hinders the development of the wine's aroma and flavour.

Despite having lost its crown to the flute in recent years, the champagne coupe still remains a popular choice for sparkling wine consumers. Its design stirs up imagery of the early 1900's, evoking Gatsby-esque allusions and luxurious connotations. Whereas the flute promotes a wine's carbonation, the coupe instead focusses on the aromas of the wine. The large surface area and shallow depth mean that many small bubbles are released in a short amount of time (Liger-Belair et al., 2009). Although bubbling is not as emphasized, the area above the coupe becomes thick with aromatic particles, allowing the wine's aroma to develop.

Reviewing a timeline of wine glass use, it appears the reason that the coupe has fallen out of favour is due to change in taste. Modern sparkling wine is much fizzier and less aromatic than older, more complex sparkling wines, and so the receptacle used has adapted to accommodate the change in market demand (Polidori, Jeandet, and Liger-Belair, 2009).

It also pays to keep note of the age of a sparkling wine. At 18 months after bottling, the sparkling wine's foam will be at its best, due to increased stabilizing proteins and polysaccharides from yeast breakdown. However, after too long, fructose sugars will start to increase as well (Pueyo, Martin-Alvarez, & Polo, 1995). Furthermore, CO_2 can diffuse across the cork, which can decrease CO_2 concentration from 11g/L to 8 g/L over ten years (Liger-Belair et al., 2012). It appears that sparkling wines and their accompanying celebrations were never meant to wait long.

Finally, presentation is of the utmost importance. Traditionally, champagne is poured directly into an upright champagne flute, which creates a thick foam due to turbulence out of the bottle neck and diffusion of dissolved CO_2. The foam settles into a raft of bubbles, which then bursts and results in a ring of bubbles around the edge of the glass, with a few bubbles streaming up from nucleation sites around the glass, as shown in Figure 7 (Vignes-Adler, 2013). At this point, most people are ready to enjoy their sparkling wine. Afterwards, however, it is a matter of opinion as to how long a sparkling wine should remain effervescent. A rule of thumb is that bubbling should remain as long as the celebratory conversation continues. To produce a more consistent and pleasing bubbling, it may help to reduce the temperature and serve the wine in a champagne flute, as discussed above. However, it can also help to pour in the 'beer style', which consists of pouring the sparkling wine into a tilted champagne flute, gradually righting the glass as it fills. This results in a less turbulent flow, so that there is less foam at first, but effervescence lasts longer overall (Liger-Belair et al., 2012).

FIGURE 7: Traditional filling of a champagne glass. The glass on the right was filled first, while the glass on the left has just been filled (Vignes-Adler, 2013).

CONCLUSION

Common consensus between sparkling wine experts is that sparkling wine is best enjoyed when carbonation is conserved, releasing a prolonged stream of small, numerous bubbles instead of all CO_2 being released at once. As such, these qualities can be maximized by cooling the wine, pouring the wine much like a beer and using a champagne flute. However, ultimately it is the responsibility of the consumer to decide on their own sparkling wine preferences. Though science can point out how to manipulate certain variables, the consumer must decide for themselves how they most enjoy sparkling wine.

MORE TO EXPLORE

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The Application of Precision Viticulture Techniques to the Niagara Region

Alex Wilson, Jordan Aharoni, Aurora Basinski-Ferris, Anjali Narayanan, Julia Pantaleo

When the practice of winemaking was in its infancy, vineyards were treated uniformly despite heterogeneities across the vineyard in soil composition and vine growth. Since then, viticulturists have discovered the importance of precision viticulture, or the site-specific management of unique areas within a vineyard. Given the impact soil and grape composition has on wine quality, it is no surprise wineries have adopted the practice of precision viticulture to combat variability and gain high quality products. Traditionally, sampling and testing of soil and grapes is performed by hand, which is usually an inefficient process. However, as time progressed so did technology, and new sampling techniques were developed. A majority of these techniques use sensors to obtain information about soil and vine properties, which can be mapped out across the vineyard and used to develop efficient management plans. Although precision viticulture is still a new field, it holds much promise for wineries everywhere, especially in regions with high soil variability, such as the Niagara Peninsula region of Ontario, Canada.

INTRODUCTION

One of the most interesting emerging technologies for the production of wine is the use of precision viticulture (PV) at the grape growing stage. PV is a recent application of the older field of precision agriculture (PA) to the operation of vineyards (Bramley, 2001); thus, to get a complete picture of the history of PV, it is necessary to start by examining the history of PA.

PA is based around the idea of site-specific management – this entails treating areas of land differently according to varying properties such as soil composition. This idea originated in Germany and Denmark in 1988 when technology that allowed for the variable rate application of fertilizers was demonstrated. Although in this same year, Global Positioning Systems (GPS) for civilian purposes became available, GPS systems weren't generally used due to a very high cost and a very low performance quality. Thus, for quite a while, the decision of how to apply the variable rate of agrochemicals was based on a concept termed 'dead reckoning' which entailed making educated guesses based on the labour intensive process of topographical survey in fields (Haneklaus et al., n.d.).

The use of GPS to assist with field variation data collection began in the early 1990s (Haneklaus et al., n.d.). The first agriculture resource map based on GPS collection was a yield map of a canola crop in 1991 (Bramley and Trengove, 2013). In the next few years, the term 'precision agriculture' would be coined and brought forth into the scientific community (Haneklaus et al., n.d.).

Over time, PA has spread from traditional applications, primarily grain, into other aspects of cultivation. The application of PA to viticulture occurred quite recently; in 1999, research on 'precision viticulture' came out of Australia and the USA when yield sensors and monitors specific to vineyards became available on the market. In past years, there has been some research conducted in countries such as Chile and South Africa; however, most of the prominent research on PV has been conducted by Australian researchers (Arnó et al., 2009).

Through a pure definition and technology lens, there is not a large difference between PA and PV. The distinction appears when recognizing the differences in use and application that may occur due to different desired outcomes. Winemakers attach a much larger importance to the quality of their crop, meaning the main difference between PV and PA is that targeted management decisions will differ in order to maximize quality rather than just yield (Bramley, 2001).

THEORY OF PRECISION VITICULTURE

In the past, viticulture maintenance has been performed uniformly such that practices like pruning or application of fertilizers are done evenly in all areas of the vineyard (Arnó et al., 2009). Despite this traditional practice, the yield of grapes is quite spatially variable across a vineyard when this is done (Arnó et al., 2009; Bramley, 2001). The idea behind PV is that treating areas with different attributes, such as soil or topography, in different ways can help minimize cost and environmental impact. Limiting fertilizer and pesticides to only necessary areas results in overall less fertilizer and pesticide use, and treating areas differently can optimize yield and yield quality in all areas of the vineyard. This idea of defining different zones by different management is referred to as 'differential treatment' or 'site-specific management' (Arnó et al., 2009).

The process of PV starts with sampling data deemed relevant; in most cases, soil and crop sampling are used. The types of common data taken in these categories include weight of yield, soil moisture, and soil conductivity; this type of data can often be taken 'on the go' when attached to other machinery moving through fields such as tractors. In many cases, remote sensing is also used to obtain spatially referenced crop vigour data over areas; crop vigour is measured using a variety of indices, most of which compare the spectral reflectances at various wavelengths with certain physiological characteristics of the vine (Marciniak et al., 2015; Arnó et al., 2009).

management, the spatial variation of vineyard attributes must be consistent from year to year so a management plan from previous data will still be relevant (Bramley, 2001). The final translation in PV is to apply the spatially variable management strategy on the vineyard; this is done using variable rate technology for maintenance (Matese and Gennaro, 2015).

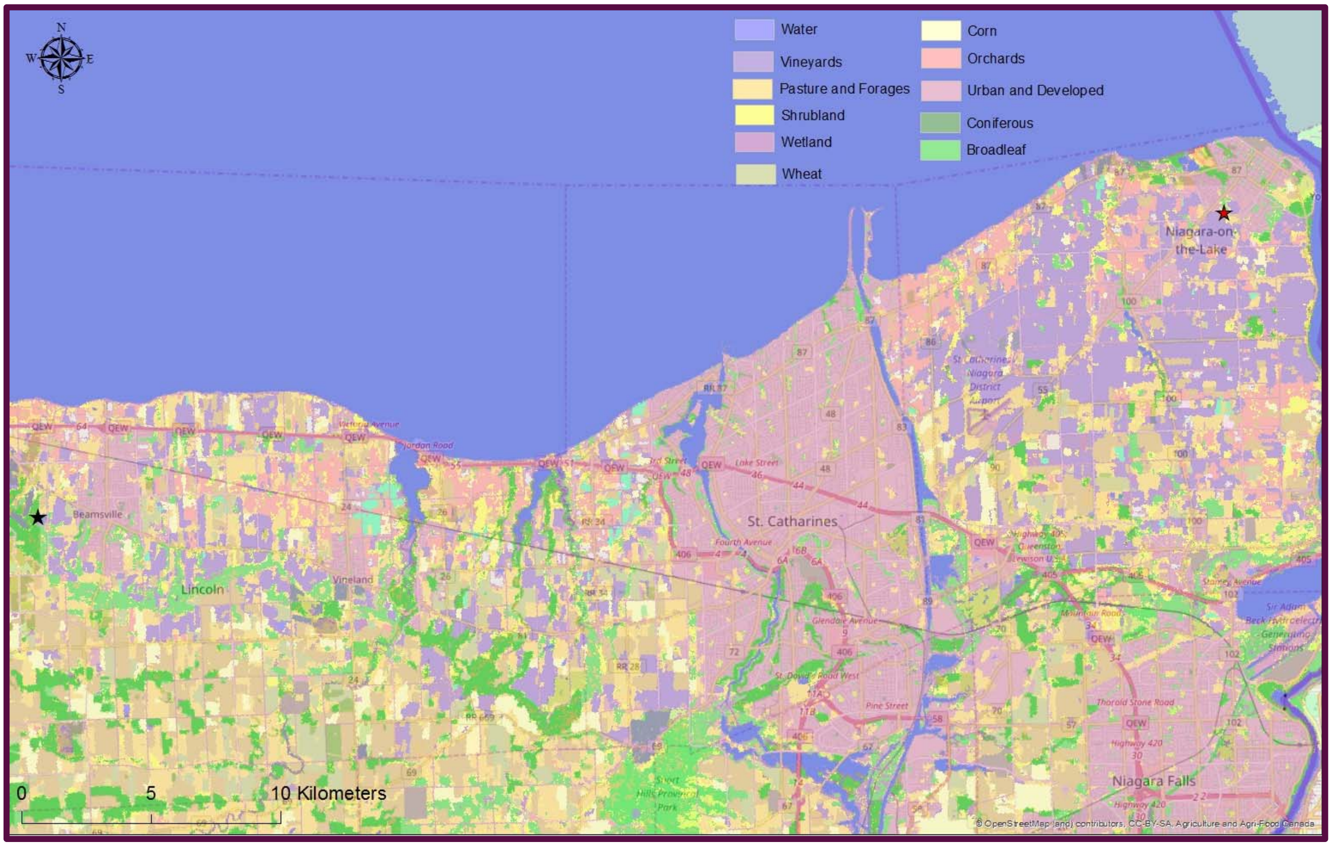

FIGURE 1: GIS MAP OF CROP LAND USE IN NIAGARA, ONTARIO. GIS is often used to analyze data and construct maps to visually represent the data collected. For PV use, this is usually done on the field scale; however, for clarity, this image includes all of the Niagara winemaking regions. Raster analysis (i.e. pixel or cell-based) is often chosen because precision viticulture operates on a smaller scale or resolution than a whole vineyard (usually an individual field). In addition to remote sensing, aerial photographs are used in various land-use planning and environmental projects (ArcMap 10.4.1, 2016).

Once data collection is completed, the results are analyzed using Geographic Information Systems (GIS) – which often includes the mapping of various variables (Figure 1). Ultimately, the results are employed by an analyst to make decisions regarding how to best treat different areas of the vineyard (Arnó et al., 2009). In order to effectively implement site-specific

THE IMPORTANCE OF TERROIR AND SOIL PROPERTIES TO SITE-SPECIFIC MANAGEMENT

While it can be difficult to determine the exact variables that make an area unique for site specific management, the most prevalent sources of differences in microclimates are climate and soil composition (De Andrés Prado et al., 2007; Van

Leeuwen et al., 2006). Variations within these over an area can create sections of plots, called parcels, which have unique needs, and thus could benefit from site-specific management.

The climate of the Niagara region varies during the growing season. This is because air from Lake Ontario in the northern portion of the region cools the area, while higher heat accumulation in the southern portion of the region adjacent to the escarpment warms the area (Wiebe and Anderson, 1977; Kontkanen et al., 2005). The Great Lakes have a very large moderating effect on both the diurnal and seasonal temperatures of adjacent vineyards because of air currents produced. Compared to further inland sites, these adjacent vineyards will have cooler days and warmer nights. Without the moderating effects of the lakes, these inland sites accumulate heat to a greater extent during the day and to lose it more quickly at night. Research has demonstrated that heat accumulation during fruit maturation has an impact on fruit composition and wine quality, as the grapes will produce higher levels of monoterpenes, molecules in grapes which are associated with wine character (Reynolds, Wardle, Hall, & Dever, 1995; Reynolds et al., 1996; Kontkanen et al., 2005).

Soil itself is very complex, and the levels of composites like nitrogen, magnesium, potassium, organic carbon, organic matter, and water present affect its properties (De Andrés Prado et al., 2007). These variables can affect measurable properties within the grapes produced. For example, soil type has significant impacts on berry weight, sugar concentration, and anthocyanin concentration, molecules affecting the colour and taste of the wine produced, as well as the total acidity and pH of the juice produced (Van Leeuwen et al., 2004).

Globally, the effect of soil type on viticulture and wine quality has geologic, pedologic, and agronomic considerations (Van Leeuwen et al., 2006). Geologic approaches examine the geology of a region and its sedimentary strata, which affects topography. While there are some areas, such as Chablis France, where all the famous vineyards are planted on Kimmeridgian limestone and marl, most areas in the world, including the Niagara Region, have less clear links between geology and wine quality (Van Leeuwen et al., 2006). Pedologic approaches involve mapping the soil types in order to improve wine quality in an area (Figure 2). Although internationally high quality wines are grown on a wide variety of soils, it is unclear the extent to which soil type affects wine quality in the Niagara region. Agronomic approaches examine the interaction between the vine and soil properties and are influenced by both geologic and pedologic factors. Agronomic approaches examine initial vine growth, vigour, mineral content, and water availability.

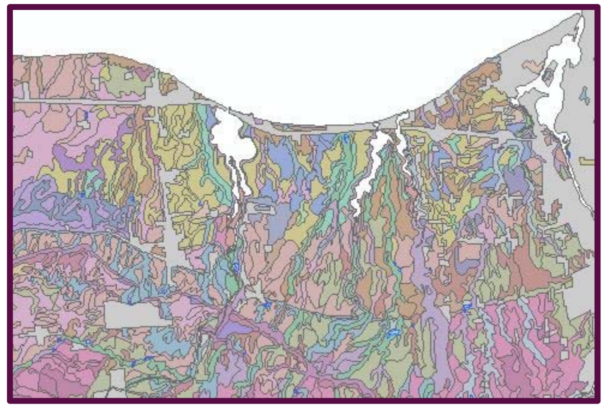

FIGURE 2: SOIL PROFILE OF THE NIAGARA REGION. Each colour marks a distinct soil profile. Within these regions there can still be large variations in properties affecting vine quality (Agriculture and Agri-food Canada, 1990). See Agriculture and Agri-food Canada, 1990 for a legend to this image.

Initial vine growth, especially at budbreak, is related to soil temperature in the root zone (Coulon-Leroy et al., 2012). Soil temperature in the root zone is high in dry, shallow soils and low in deep, humid soils. Initial vine growth is related to vine vigour, which in turn, is inversely related to wine quality (Van Leeuwen et al., 2006).

Soil may influence vine development and fruit ripening through mineral supply. For example, magnesium, potassium, and nitrogen content in the vine petiole (leaf stem) are highly dependent on soil type (Van Leeuwen et al., 2004). Soil nitrogen levels are determined by the turnover of organic matter, which is influenced by soil temperature, aeration, pH, and moisture content (Van Leeuwen et al., 2006). As a result, nitrogen is being constantly supplied from the soil to the vine roots. The levels of this supply can be considered a component of terroir and it is highly variable depending on the soil type. Nitrogen uptake is directly related to wine quality, particularly in red grapes, where limited nitrogen supply to the vines due to soil parameters increases quality in red wine production. This is because it reduces vine vigour and increases berry and wine phenolic content (a compound that adds flavour to wine) (Van Leeuwen et al., 2006).

Lastly, water uptake as influenced by soil water holding capacity (WHC) can have very significant effects on wine quality. Although water and fertile elements are necessary for good vine development, excessive quantities can be detrimental for grape composition, as they increase vine vigour and production, increase the production of rot, and reduce harvest quality (De Andrés Prado et al., 2007). For higher yield, the best results in terms of quality are obtained when water deficit is mild (Van Leeuwen et al., 2004). Sandy loam soils have moderate to high levels of organic matter and minerals; and the higher sand component allows for better drainage and therefore lower vine vigour. As a result, sandy loam soils are used predominantly as wine growing soils in the Niagara Region.

Pedoclimatic factors, such as soil type and climate, all affect vine vigour and wine quality through soil temperature, mineral supply, and water availability (De Andrés Prado et al., 2007; Choné et al., 2001). Climate and soil type can create unique zones for specific vine cultivars that, if maintained over many years, can create distinct areas that could lend themselves to site-specific management. This high variability of soil type as well as the unique climate from the Great Lakes makes the Niagara Region a prime candidate for the implementation of PV.

THE USE OF TECHNOLOGY IN PRECISION VITICULTURE

Given the role soil composition and vine growth has on fruit and wine quality, it is no surprise viticulturists have taken an interest in the site-specific management of vineyards. Traditional methods for determining soil and suit composition are labour intensive, time consuming, and destructive to the sample. PV offers new sampling methods which employ the use of sensors, and can be grouped into one of two categories: proximal sensing, which involves ground-based data collection usually relating to soil composition, and remote sensing, which involves aerial-based data collection usually relating to vine growth. Both methods play an important role in developing targeted management plans across a vineyard.

PROXIMAL SENSING

Proximal sensing is carried out primarily by means of electromagnetic sensors. These sensors are used to collect information regarding the electrical conductance (EC) of the soil, which correlates with multiple soil properties such as salinity, ion content, water content, and soil type (Tisseyre, Ojeda and Taylor, 2007; Priori et al., 2013; Rodríguez-Pérez et al., 2011). Currently, there are three main types of sensors: electrical resistivity (ER) sensors, electromagnetic induction (EM) sensors, and time domain reflectometry sensors, with ER and EM sensors being the most commercially popular (Tisseyre, Ojeda and Taylor, 2007). These methods of

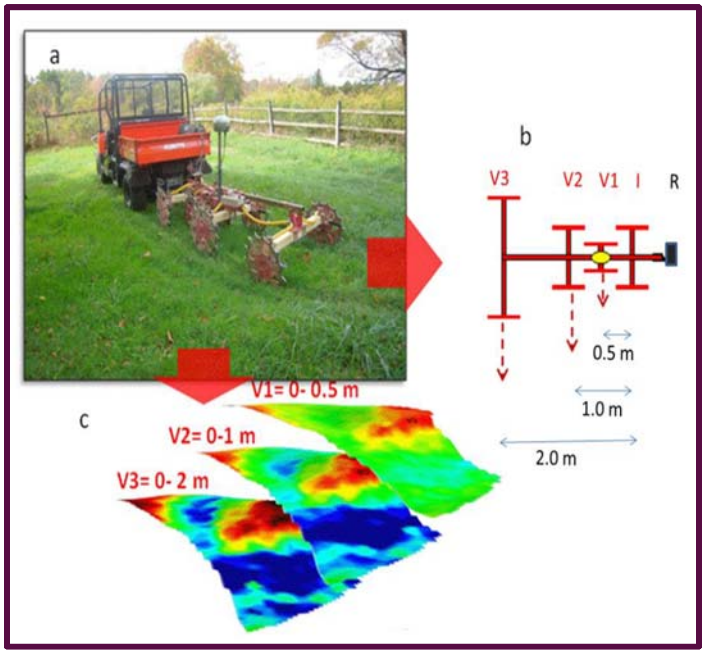

FIGURE 3: AN ER SENSOR. a) A photograph of a common ER sensor, the Automatic Resistivity Profiler (ARP), which is being towed across the vineyard by a small vehicle; b) An overhead schematic diagram of the ARP, where I is the injection wheel, V1, V2, and V3 are the receiver wheels each at a different distance from the injection wheel, and R is the ER sensor. In this particular model, there are three receiver wheels opposed to one, but the sensor functions in the same manner; c) A map of soil EC at each depth of the area surveyed in the study, with red areas indicating regions of low EC and blue representing areas of high EC (Rossi et al., 2013).

determining soil composition have a direct benefit over traditional soil sampling methods as they allow for data collection from more sampling sites, providing a more accurate picture of soil composition within a given region (Rossi et al., 2013).

ER sensors function by applying direct electric currents to a given soil volume and measuring the resultant potential difference. The data collected can be used to construct pattern maps, which allows for the identification of soil properties and heterogeneities (Tisseyre, Ojeda and Taylor, 2007). The equipment itself, which is towed around the vineyard, consists of two wheels: an injection wheel, containing electrodes that supply currents to the soil, and a receiver wheel, containing electrodes that measure the potential difference (Figure 3) (Rossi et al., 2013). The distance between the two wheels can be altered to gain EC information at different soil depths (Rossi et al., 2013; Tisseyre, Ojeda and Taylor, 2007). One disadvantage to this method is the need for the electrodes to be in direct contact with the soil, which reduces the sampling rate of the system (Tisseyre, Ojeda and Taylor, 2007).

EM sensors function by generating a magnetic field, which creates small electric currents within a given soil volume. This generates a secondary magnetic field, which is measured by the sensor (Figure 4) (Tisseyre, Ojeda and Taylor, 2007). This information is used to map out soil EC, thus allowing for the determination of soil properties and heterogeneities, as with ER sensors. EM sensors have an advantage over ER sensors as they generally have higher resolutions, and are non-invasive as they do not require direct contact with the soil. As such, the speed at which data can be collected is increased compared to ER methods (Rodríguez-Pérez et al., 2011). One downfall, however, is that EM sensors are sensitive to the presence of metals, which can be troublesome due to the use of metal trellises or

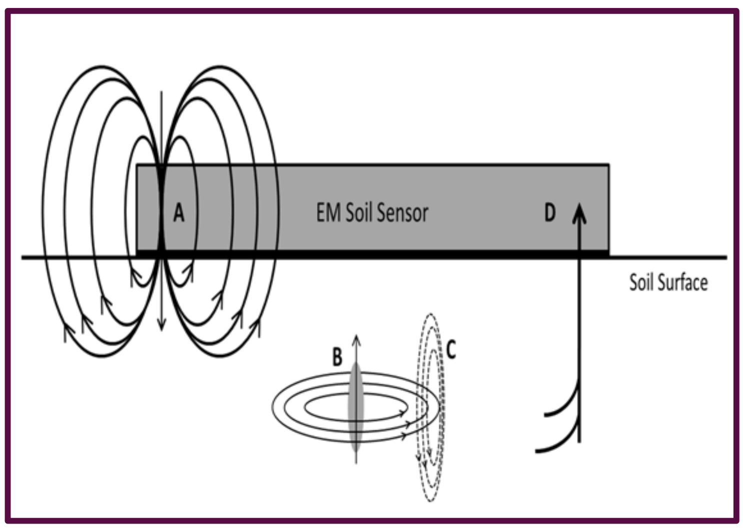

FIGURE 4: DIAGRAM OF AN EM SENSOR. The EM sensor contains two coils, a transmitting coil (A) which generates the primary magnetic field, and a receiving coil (D), which measures the input from the primary and secondary magnetic fields. Within the soil, there are components which respond to the primary magnetic field by generating eddy currents within the soil (B). This causes the production of a secondary magnetic field (C) in response. Adapted from Visconti and de Paz, 2016.

irrigation systems in vineyards (Tisseyre, Ojeda and Taylor, 2007; Rossi et al., 2013).

Regardless of the sensor used to obtain measurements, general trends between soil properties and EC can be found. The two largest contributors to soil EC are the electrolyte concentration and water holding capacity of the soil (Priori et al., 2013; Rodríguez-Pérez et al., 2011). Generally, high electrolyte concentrations, namely in sodium, magnesium, and calcium, causes increased soil EC. Identification of these areas could be beneficial to viticulturists as each of these ions plays an important role in plant growth and photosynthesis (Rodríguez-Pérez et al., 2011). Similarly, soil with a high water holding capacity leads to high EC values. Therefore, identification of these areas could also be beneficial as water plays an integral part in sustaining plant and fruit growth (Priori et al., 2013; Rossi et al., 2013).

REMOTE SENSING

The primary function of remote sensing is to use the amount of sunlight reflected off object surfaces as a means to quantify the properties of those objects on the ground (Hall et al., 2002). In order for the sensor to be able to discriminate changes in ground objects, it must have sufficient spatial and spectral resolution. Spatial resolution is the ability of the sensor to identify individual objects on the ground. This resolution is described by pixel size, with the size of the pixel being the size of the smallest object the sensor is able to identify on the ground. For viticulture, the ideal pixel size matches the length of the inter-row spacing. Spectral resolution is defined as the number of different wavelengths measured within each pixel of the image. Since sunlight contains a number of different wavelengths within the electromagnetic spectrum (Figure 5), it is necessary to define which wavelengths will be measured during data collection. Generally speaking, the more wavelengths measured, the more detailed the reflectance profile of the object becomes. In viticulture, a sufficient amount of resolution is provided by four wavelengths: green, blue, red, and near-infrared (NIR) (Hall et al., 2002).

In order to obtain meaningful information from the spectral data collected, it is summarized into a vegetation index, which is a numerical value describing a specific property of a given area of vegetation. The most commonly used index is the Normalized Difference Vegetation Index (NDVI), which describes vegetation vigour (Hall et al., 2002; Tisseyre, Ojeda and Taylor, 2007; Priori et al., 2013). An NDVI value close to one identifies highly vegetative areas while values close to zero indicate areas of low vegetation. NDVI is calculated as the difference between reflectance in the NIR band and the red band normalized against all of the light reflected in both bands (equation 1) (Hall et al., 2002; Priori et al., 2013). Since the NDVI is a normalized value, the total amount of light reflected has no impact on the value obtained, which is beneficial as cloud cover and shadows will not skew the results (Hall et al., 2002).

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (1)$$

Usually, spectral images are obtained using special sensors, which are mounted onto aircraft and flown over the vineyard (Hall et al., 2002; Tisseyre, Ojeda and Taylor, 2007). Once the images are obtained, NDVI values can be calculated and vine vigour across the vineyard can be assessed. In viticulture, vigour refers only to the growth of vine shoots opposed to growth of the entire vine, and thus remote sensing cannot be used to determine vine vigour directly (Hall et al., 2002). NDVI provides information about the amount of photosynthetically-active biomass (PAB) present in a given area, which is used to indirectly assess vine vigor. The amount of PAB

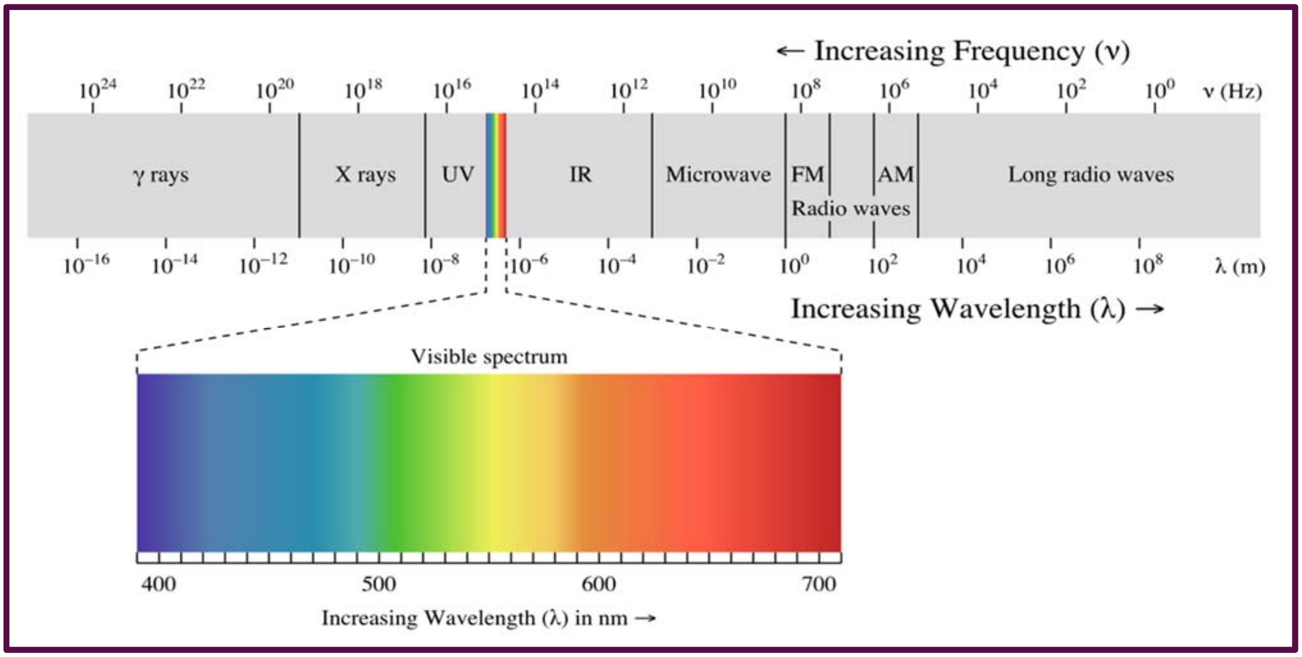

FIGURE 5: A DIAGRAM OF THE ELECTROMAGNETIC SPECTRUM. Sunlight contains many of these wavelengths, namely X-rays, ultraviolet rays, visible light rays, and IR waves. For this reason, it is important to select a few individual wavelengths to measure when using remote sensing (Ronan, 2007).

influences the amount of NIR and red light reflected, thus allowing NDVI to accurately describe the amount of PAB in a given area. Generally, areas of high vigour require larger amounts of PAB in order to keep up with the photosynthetic demands of the plant, resulting in higher NDVI values (Hall et al., 2002).

Naturally, the presence of photosynthetic pigments, such as chlorophyll, causes leaves to absorb a majority of visible wavelengths, including red light (Hall et al., 2002; Priori et al., 2013). Due to the structure of plant cell walls and the presence of water, plants also reflect a majority of NIR light. Together, this means areas of high PAB, and thus high vigour, reflect large amounts of NIR light while absorbing large amounts of red light, leading to an NDVI value close to one. Inversely, areas of low vigour will have low NDVI values (Hall et al., 2002; Priori et al., 2013). Using NDVI as a guide, vigour can be mapped across the vineyard.

Vine vigour alone does not provide much valuable information to viticulturists. However, research has shown a strong link between vine vigour and grape yield, and yield is known to directly influence grape and wine quality (Hall et al., 2002; Arnó et al., 2009). Highly vigorous vines have high fruit yields, which leads to delayed fruit maturation and decreased fruit quality, often due to increased shading of the grape bunches by the dense leaf canopy (Lamb, Weedon and Bramley, 2008). Flavonoids, which are compounds present primarily in grape skins, contribute to wine colour and flavour, meaning higher flavonoid concentrations are desirable. Sunlight is needed to promote the production and accumulation of these compounds within the grapes, and thus highly vigorous vines likely hinder the production of these compounds, decreasing the overall fruit and wine quality (Lamb, Weedon and Bramley, 2008). For this reason, viticulturists aim for vines of moderate vigour to ensure sufficient grape quality. By mapping out vigour using remote sensing, viticulturists have the opportunity to increase fruit quality in the vineyard by identifying highly vigorous blocks and reducing the growth by pruning these areas.

THE CURRENT USE OF PRECISION VITICULTURE

Precision viticulture is currently well established in winemaking regions within Australia, New Zealand, and the United States (Arnó et al., 2009). These regions gained interest in PV back in 1999 as a method of protection and prevention against Phylloxera, a deadly grapevine pest (Brown, 2012; Arnó et al, 2009). Thus, PV is generally more researched and used in regions where the technology originated and was necessary. However, the usage of PV as a vineyard management technique is growing in interest, impacting winemaking sectors in various countries such as Chile, Brazil, South Africa, Spain, and some European regions (especially France and Portugal) over the past decade (Arnó et al., 2009). In fact, in countries with a progressive wine industry, installation and servicing of PV is often commercially offered to vineyards (Santesteban et al., 2013).

Winemaking in more established, foreign regions have the benefit of knowing exactly what processes, technologies, and viticulture management techniques work best – a benefit that has yet to reach the Niagara winemaking region (Dixon, 2012). Thus, the implementation of new technologies and management practices may not be as seamless in the Niagara region as they are in foreign regions. This isn't to say, however, that implementation of PV is unwarranted in Niagara's winemaking region. Brown (2012) justifies utilizing PV in Niagara by alluding to the high variability within winemaking regions due to the geological history and terroir of the region. Additionally, properties of grapes such as berry vigour, nutrient and water availability, fruit quality, and others can differ greatly among and in fields of a vineyard (Brown, 2012). The inconsistencies in Niagara's winemaking region explicitly confirm that it is a great contender to implement PV to help adapt and manage vineyards.

COST AND APPEAL OF PRECISION VITICULTURE

Another incentive to implement PV in vineyards is its cost. Overall, PV is a relatively inexpensive method of acquiring valuable variability information about a vineyard (Bramley, 2001). Interestingly, despite the fact that PV costs are equivalent to the order of 0.5-1% of the value of crop produced (Bramley, 2001), it has been observed that larger, corporate winemakers have more of an affinity to implement such technologies in their vineyards than smaller, or boutique winemakers, who are still rather apprehensive to the idea given traditional practices (Maynard, 2016). Surprisingly, the increase of emerging research on the benefits of PV still leaves a level of mistrust or a gap in knowledge between boutique winemakers and researchers (Maynard, 2016). This suggests winemakers with smaller vineyards are hesitant to implement PV. This confirms that the integration of PV in a vineyard is purely the winemakers' preference, and not necessarily related to how well the technology performs (Maynard, 2016).

Indeed, PV can be quite beneficial from a practical standpoint, however, a cost-benefit analysis is yet to be conducted (Maynard, 2016). Overall, considering the potential of PV to summarize mapped vineyard variability from different surveying devices and data management technologies, PV appears to be a reliable method to analyze trends on both the field and whole-vineyard scale (Santesteban et al., 2013).

FUTURE DIRECTIONS OF PRECISION VITICULTURE

As mentioned earlier, not all winemakers are immediately responsive to precision viticulture. Future directions taken by PV may provide reason for this to change. In general, the focus of PV improvement is technological, which means developing better monitoring tools and protocols to better vineyard sampling (Bramley, 2001). This includes producing efficient, wireless PV technologies designed to remotely monitor and collect vineyard information, allowing for flexibility in planning and installation (Matese et al., 2009). Applications of decision support systems to PV are also being researched, which can help winemakers make decisions regarding input applications, irrigation practices, and pest control (Tardio and Rosado, 2012). In addition to these technological progressions, some research is being directed towards making data acquisition easier for winemakers by lessening the complexity of current PV devices and service costs (Irie and Woodhead, 2014). This includes being able to apply PV to smaller than corporate vineyards and making such technology accessible to boutique winemakers, which may change the way PV is currently perceived by such winemakers (Irie and Woodhead, 2014).

Finally, the potential of PV at the whole-vineyard scale is also being investigated, paralleling current research in PA. Given the success of PV in smaller parcels (where it is primarily being used now), the usage of PV on a larger scale may be just as beneficial, if not more. Optimal PV technologies would work at both the field and whole-vineyard scale, which encompasses all fields managed. Most winemakers work on a multi-field scale anyway, thus it would be ideal if one technology or method (i.e. PV) is applicable at the whole-vineyard scale so that the winemaker need not go through individual fields to make whole-vineyard decisions (Santesteban et al., 2013). These advances in PV may change the face of the technology in the near future. Given emerging research in the area, it may not be long before PV is widely used in vineyards of all sizes and production scales.

CONCLUSION

The founding idea of precision viticulture is to help winemakers maximize their vineyard's potential by giving each area of land the management that will optimize the vines' yield and quality. The reasons behind different areas of land requiring different management can be broad, but generally the variation is associated with climate and soil. In the Niagara region specifically, the application of differential management using precision viticulture would be greatly beneficial due to significant variation in microclimates - especially soil variation. Currently, PV utilizes a myriad of on-site sampling equipment that employs the use of proximal or remote sensors. To address various issues with sampling equipment, the technology of PV continues to develop to make data collection and analysis wireless and seamless on the vineyard. Further, applications of PV to larger production scales have also been researched, increasing the appeal of this technology to winemakers; multi-field winemakers, such as the winemakers in the Niagara region, can benefit greatly from this application. The current technological progress and marketing to boutique winemakers will likely result in better management techniques in the Niagara region via the adoption of precision viticulture techniques.

MORE TO EXPLORE

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The Changing Climate of Viticulture in Niagara

Rama Al-Atout, Michael Chong, Ross Edwards, Adam Marr, and Connor Nelson

From the grapevine to the glass, winemaking is a complex process, with seemingly countless variables that could potentially affect the taste of the final product. Viticulturists and vintners are meticulous when controlling these factors; however, one of the most important things to consider when making wine is one that cannot be directly controlled - the climate. While grapes are known to grow in a wide range of conditions worldwide, climatic variables such as temperature and precipitation can have a dramatic effect on grape crop quality and yield. The following review investigates the relevant climate projections for the Niagara winemaking region of Ontario, Canada. Based on the changes of temperature and rainfall within local environments, the potential challenges that may arise are summarized. Though winemaking is dependent on a vast number of variables that are entangled with climate, an understanding of the microclimates of Niagara allows for scientists and winemakers to predict the impact and create potential mitigation strategies.

THE NIAGARA VITICULTURE REGION

Boasting over 13,600 acres worth of vineyards and over 46 grape varietals, Niagara is the largest winemaking region in Canada (VQA Ontario, 2016a). There are two predominant species of grapes grown in this region - *Vitis labrusca* and *Vitis vinifera*. While the French-American hybrid *V. labrusca* was the first commercially grown grape in Niagara, *V. vinifera* slowly began to replace it in the early 20th century. Today, the Canadian wine regulatory body, the Vintner's Quality Alliance (VQA), allows only *V. vinifera* wines to be produced under its label (VQA Ontario, 2016a). Despite being a less cold-tolerant species, *V. vinifera* has traditionally been the most widely used grape variety in winemaking. Therefore, a major challenge to winemaking in Canada's relatively cold, continental climate is the possibility of frost damage.

FIGURE 1: A MAP OF THE NIAGARA REGION. The Niagara region is bordered by Lake Ontario to the North and Lake Erie to the South (Google Earth, 2016).

Given the geographic location of the area, one might expect a cool continental climate in Canada with hot summers and cold winters similar to other mid-latitude climates. However, the presence of the Great Lakes to the north and south of the region (Figure 1), and the Niagara River to the east create a unique microclimate. Due to these factors, the Niagara region has a milder, maritime-like climate instead of a continental climate (Haynes, 2000).

Perhaps the most significant contributor to this unexpected climate is Lake Ontario, just north of the region. Though it has the smallest surface area, it is the second deepest of the Great Lakes (Environment and Climate Change Canada, 2014). The low surface area to volume ratio causes the lake's temperature to react slowly to winter cooling, which often results in the water being much warmer than the surrounding air and landmass during the winter. In turn, the lake acts as a source of heat and warms cold winds arriving from the north, and can delay the onset of frost during the winter. The opposite effect occurs in the summer, as the lake acts as a heat sink for the surrounding region. In addition, during calm evenings, a convection current is formed by the temperature difference between the warm air mass over the lake and the cool air mass over the land. This causes warm air to be drawn inland, and raises the overnight minimum temperature. Adding to this temperature moderating effect, a band of consistent cloud cover also develops over the lake, which reflects sunlight during the day and acts as a thermal insulator at night. This helps keep daytime temperatures cool while also raising nighttime lows. Like Lake Ontario, Lake Erie, which is larger in surface area, provides similar benefits from the south of the region. These effects, when compounded, greatly moderate winter temperatures above what would typically be expected at this latitude, helping extend the growing season by delaying the onset of frost (Shaw, 2005).

In Niagara, there are also three geographically distinct regions: the Lake Iroquois Plain, the Niagara Escarpment, and the Haldimand Plain. The Iroquois Plain experiences a slightly milder climate and lower wind speeds due to shelter from southerly winds from the escarpment and closer proximity to Lake Ontario. In addition, the escarpment tends to trap warm air from the lake over the plain (Kontkanen et al., 2005). In contrast, the Haldimand Plain, which lies on the top of the escarpment to the south, tends to have more extreme temperatures and higher wind speeds due to lack of shelter from the escarpment (Shaw, 2002).

Even though the Haldimand Plain covers most of the Niagara region, the vast majority of vineyard sites exist in the Lake Iroquois Plain because of its soil. Unlike the Haldimand Plain, which consists of clay loams, the Lake Iroquois plain consists of mostly sandy loam with good drainage. Past cases in vineyards have shown that excess groundwater and rainfall can lead to fungal diseases such as botrytis, as well as the dilution of sugars in the berries (Cyr et al., 2010). Since this drainage promotes healthy vines that avoid the problems of fungal rot, the Lake Iroquois Plain - sometimes referred to as the 'Tender Fruit Belt' - attracts many winemakers (Shaw, 2005).

UNDERSTANDING CLIMATE CHANGE MODELS

Currently, the most widely accepted climate change models are made under the Coupled Model Intercomparison Project (CMIP5) design. This experiment framework was established in 2008 to provide climate simulations to inform policymakers as part of the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5). While there is a substantial body of work under the CMIP5 framework, individual results from global climate models (GCMs) vary. As of now, there is no scientific consensus on methods of assessing the likelihood of climate projections, making it difficult to draw substantial conclusions (IPCC, 2013). Furthermore, regional climate models (RCMs), which extend individual GCMs to more precise spatial and temporal resolutions, do not agree. There can therefore be disagreement in expected regional climate changes.

Generally, climate models loosely agree on an increase in temperature in all seasons in the Niagara region, although the extent of this

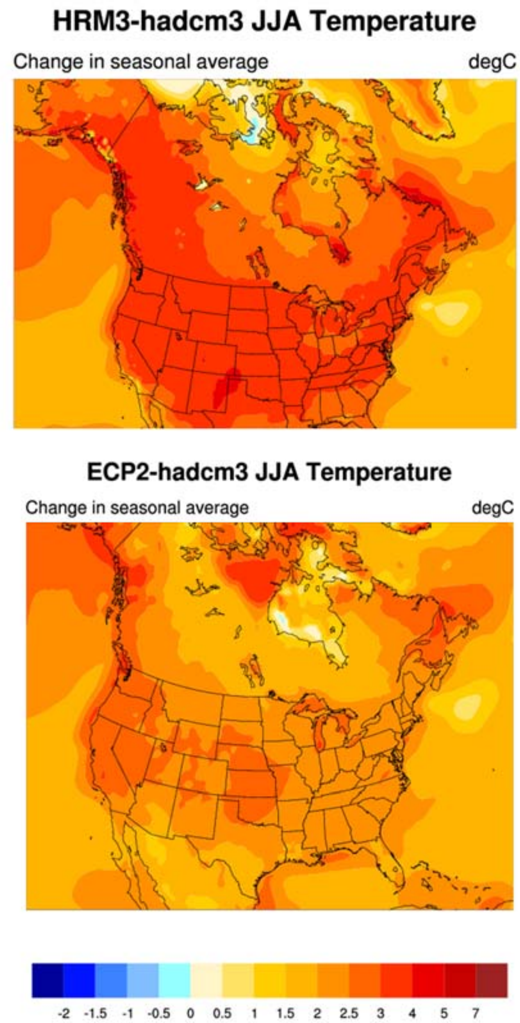

FIGURE 2: COMPARISON OF TEMPERATURE PROJECTIONS Projected average summer temperature change in 2041-2070 North America relative to 1971-2000 by two RCMs derived from the 'hadcm3' GCM. The extent of the projected warming in the Niagara region varies (+ 3/4°C vs. +2°C) (Mearns, 2014).

projected warming varies (Figure 2). Most RCMs derived from the IPCC median emissions scenario predict a 2-4°C increase in mean temperature across southern Ontario in all seasons by around 2050 (Chiotti & Lavender, 2008; Mearns et al., 2014). This bodes well for grape growing in the context of freeze damage, as a higher temperature would delay the onset of winter injury.

In contrast, there is substantial disagreement among RCMs in predicting future changes in average precipitation in Niagara and around the

Great Lakes (Figure 3). While there is are slightly more simulations that suggest an increase in average precipitation year-round, the magnitude of this proposed change varies greatly between models. Furthermore, a number of models disagree with an increase in precipitation entirely (Mearns et al., 2014).

In the context of frost, a slight increase in precipitation during the spring is beneficial for viticulturists. With greater humidity and precipitation, the minimum temperature is significantly raised due to the energy barrier associated with condensation of vapour and freezing of liquid water. Furthermore, the additional water content increases the heat capacity of the air, ground, and grapes, and provides somewhat of a buffering effect for changes in temperature. In turn, this prevents spring frost damage to vulnerable buds. Similar effects have been seen in other winemaking regions such as California, where climate changes in the late 1900s resulted in a 65-day increase in the frost-free growing period, despite only a small increase in surface temperature (Nemani et al., 2001).

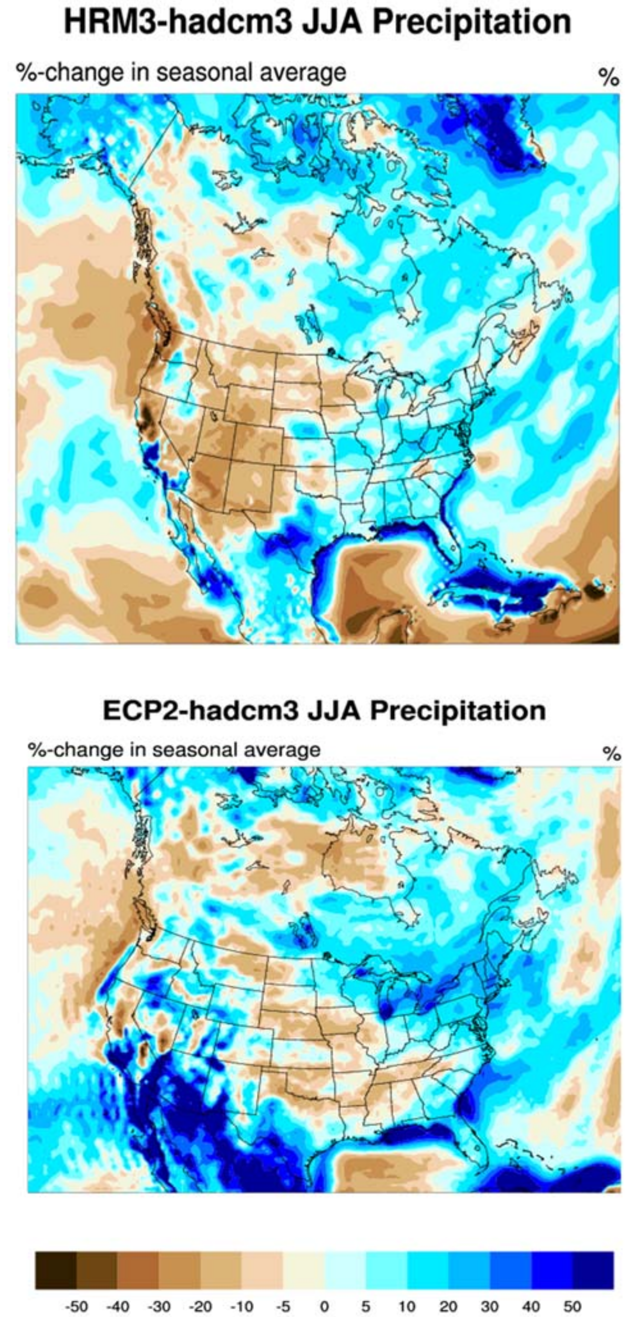

FIGURE 3: COMPARISON OF PRECIPITATION PROJECTIONS Projected percent change in average summer precipitation in 2041-2070 North America relative to 1971-2000 by two RCMs derived from the 'hadcm3' GCM. There is a significant difference in the results in the region surrounding the Great Lakes (no change vs. + 30%) (Mearns, 2014).

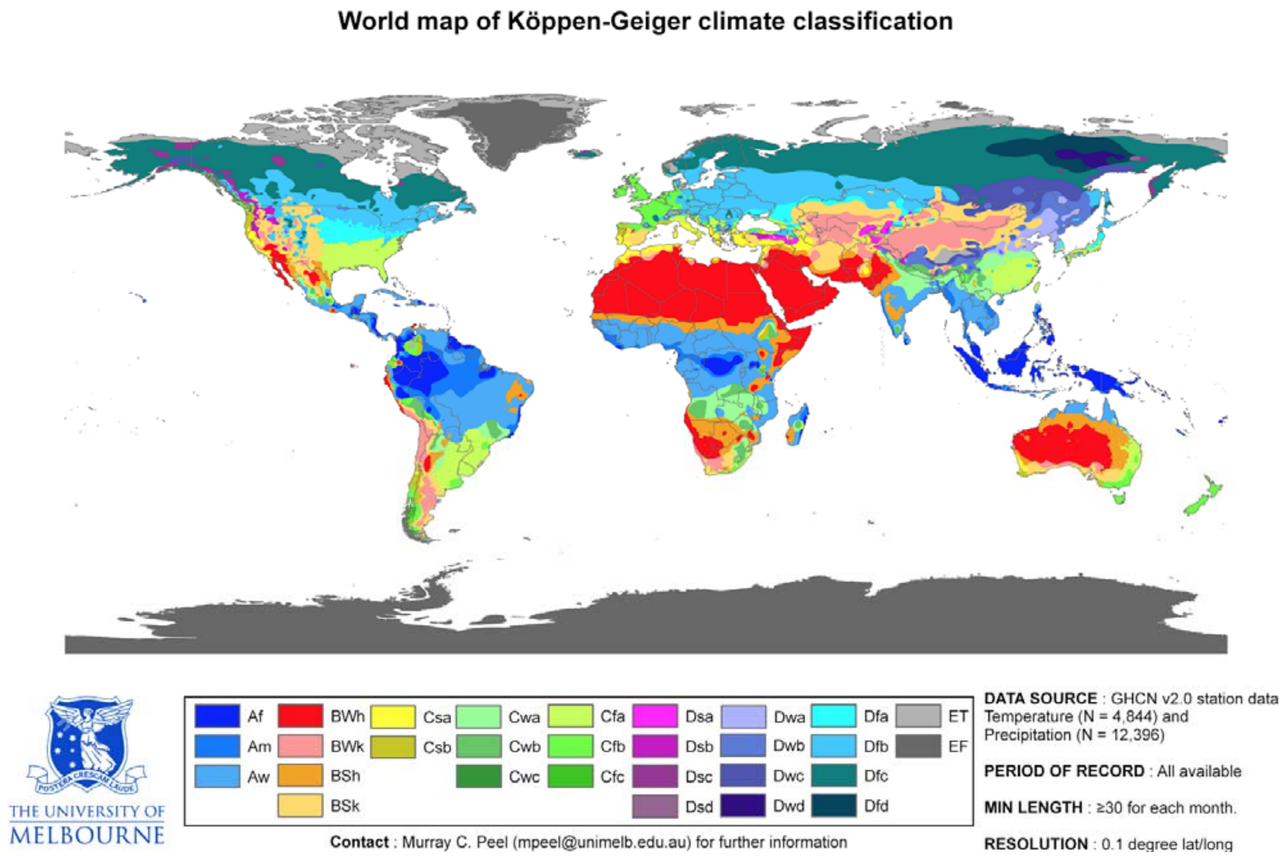

FIGURE 4: WORLD MAP OF KOPPEN-GEISHER CLIMATE CLASSIFICATIONS TODAY. Note the diversity of climate classifications in winemaking regions, including Cfb for Bordeaux, Csb for Napa Valley, and Dfa/Dfb for the Niagara region. In general, A is an equatorial zone, B is an arid zone, C is a warm temperature zone, D is a snow zone, and E is a polar zone. The second and third letters describe varying precipitation and air temperature within each subcategory, respectively (Peel et al., 2007).

COMPARISONS TO OTHER REGIONS

At times, it can be useful to consider the climate of winemaking regions on a macroscale level through the use of climate classification systems, which allow for broad comparisons between different areas. For instance, the Köppen-Geisher classification system assigns a three-letter code to regions based on distinct vegetative groups (e.g. equatorial, arid, polar), the amount of precipitation, and air temperature (Rubel & Kotek, 2010) as seen in Figure 4.

The Bordeaux region of France, which has historically been known for producing high quality wine, is commonly classified as 'Cfb' under the Köppen-Geisher system, indicating a maritime temperate climate. This can be attributed to the region's proximity to the Atlantic Ocean and its temperature moderating effects (Spellman 1999; Jones et al., 2012). On the other hand, California's Napa Valley features drier conditions than French vineyards. Akin to Mediterranean climates, it shares a 'Csb' classification, indicating a warm temperate climate with a dry summer. In contrast, the Niagara region and the surrounding area is referred to as humid continental, with significant quantities of snow during the winter. Given that summers can fluctuate between hot, 'a', or warm, 'b', this region is typically described as a mixture of 'Dfa' or 'Dfb' conditions (Jones et al., 2012).

There are limits to this form of macro-comparisons, as specific, local conditions can play a larger role in determining wine quality. As mentioned prior, the expected yield of vineyards in the Niagara region can vary tremendously as a result of distance from the moderating effects of Lake Ontario and Lake Erie. Another example can be seen in Bordeaux. In this region, Merlot cultivar grafted onto Fercal rootstock (*V. berlandieri* × *V. vinifera*) produced berries with higher concentrations of sugars and flavonoids when grown in sunny conditions as opposed to shady environments (Pereira et al., 2006). Extreme temperature conditions also play a significant role. Specifically, temperatures less than -2.5˚°C during the onset of growth, or >35°C during the growing or ripening season have been shown to result in poorer fruit yields (Jones et al., 2012).

Current projections suggest that in the next 30-50 years, the Niagara region and the surrounding area will see a gradual conversion to 'Cfb', with overall conditions similar to present-day Bordeaux and much of Western Europe (Rubel & Kotek, 2010). However, there is a high degree of variability in these projections on a local level. In particular, while precipitation is expected to increase on an annual basis, much of this is expected to fall as rain during a less snow-prone winter (Penney, 2012). Isolated rainstorms during the spring will contribute to this increase in annual precipitation as well, with additional dry spells during the summer.

IMPACT OF TEMPERATURE CHANGES

Changes in temperature are known to have a significant impact on vegetative cycles, vine phenology, and grape quality (Jackson & Lombard, 1993). Because of this, it is important to consider what new conditions vineyards should prepare for as a result of temperature increases in the coming years. Evidence suggests that the Niagara region will face both benefits and challenges from warming conditions, such as changes in overall wine quality due to change in the chemical composition of the berries.

For temperatures above 25□C, net photosynthesis in plants decreases, resulting in the replacement of lipids by starch in leaf chloroplasts, and a reduction in berry size and weight (Hale & Buttrose, 1974). At even higher temperatures malic acid concentration decreases, lowering the acidity and negatively impacting wine colour, aroma, and taste, due to an increase in oxidative reactions (Baumes, 2009). High pH is also known to favour a reaction that forms hemiketal anthocyanin, a chemical known to reduce the color of young red wines.

Temperature also affects the concentration of flavonoids and other phenolic compounds which are crucial to grape colour and aroma. For example, the formation of anthocyanins is inhibited at high temperatures, causing a reduction in grape colour. Temperature changes are also thought to reduce the amount of isoprenoids and pyrazines in white wines, causing a reduction in aromatic intensity. Warmer temperatures also increase the formation of a compound known as TDN (1, 1, 6-trimethyl-1,2-dihydronapthalene) in Riesling grapes, resulting in an aroma similar to gasoline (Marais, 1993). Similarly, the concentration of methoxypyrazines (known for its bell-pepper like aromas) are expected to increase. Although favorable for some specialty wines, these phenolic compounds may be perceived negatively at high concentrations.

Changes to ethanol and sugar concentration in grape resulting from increased temperatures can lead to several microbiological, technological, and financial challenges in the winemaking industry. At higher temperatures, sugar concentrations increase slightly due to evaporative loss of some aromatic compounds (Coulter et al., 2008). The increased sugar can inhibit the growth of microorganisms, which in turn may result in suppressed yeast activity, and therefore lower alcohol content in the final product (Santos et al., 2008).

Although little is known about how well vineyards and wineries will adapt, possible solutions could involve implementing new cooling techniques, such as a chamber-free system, where cooled air can be blown across the grape bunches. Winemakers may also consider or even using different yeast strains (Vink et al., 2009; Mozell & Thach, 2014).

PEST RELATED CHALLENGES

Another major concern that relates to climate is the risk of infection by microorganisms and fungi. Comparative studies show that higher temperatures are correlated with higher prevalence of microorganisms and fungi on the grape vine (Mira de Orduña, 2010). Fungi are known to affect the flavour of wine through a variety of processes, a notable example being the release of mycotoxins, a secondary metabolite. Almost all mycotoxins have some negative effect on grape chemistry, but a specific type known as Ochratoxin A (OTA) is classified as a possible carcinogen (Mira de Orduña, 2010). In a study of 942 wines from various vineyards, it was shown that OTA exists in higher concentrations in warmer regions of Europe (Mira de Orduña, 2010). If Niagara does eventually transition into an environment closer to that of Western Europe, OTA and other mycotoxins may become a greater concern. Insects pose yet another threat to the grapevine, which winemakers control by using insecticides, netting that surrounds the rootstock, and occasionally, natural predators. With dramatic changes in insect distribution caused by temperature changes, however, these control methods may become less effective.

Though bacteria, fungi, and insects can be mediated by pesticides, the removal of these harmful chemicals from the wine requires procedures like microfiltration techniques. Such processes can be costly for small-scale vineyards and are not completely effective, meaning a winemaker can never be confident that all pesticides are removed (Doulia et al., 2016). In fact, the multinational Pesticide Action Network (PAN) reported pesticides present in wines tested from eight different countries, with an average of four different types present per bottle (Guo et al., 2016). Of the pesticides found, around half were known to be a carcinogen or toxic in some form (Guo et al., 2016). Unfortunately, with the change in pest distribution in the Niagara region, avoiding pesticide use will become even more of a challenge as foreign organisms begin to impact the vines.

There are several ways viticulturists can adapt to these issues. Varieties of genetically modified grapevines have been created known as fungus resistant grapes (FRG), which may be used as a replacement for many existing vines grown currently (Pedneault and Provost, 2016). The advantages of FGR are staggering. Studies have shown that they reduce the need for pesticides and secure the yield of grape production, all while controlling for devastating fungal diseases often seen in *V. vinifera.* Additionally, in a blind tasting in Europe, the taste between regular grapes and their associated FGR could not be distinguished, meaning wine quality will likely not be impacted by the introduction of these grapes (Pedneault and Provost, 2016). FGR could be an important part of preventing future pest-related crop damage in the wine industry.

PROSPECTIVE RAINFALL

The uncertainty of rainfall events due to climate change raises issues such as bacterial infection and changing sugar concentration of the grapevine. In Niagara, an annual precipitation level around 700-800 mm yields high quality wines, especially if there are dry conditions during the period of ripening (Cyr et al., 2010). Any unusual rainfall events that could disrupt these ideal conditions may have detrimental impacts on the wine industry. Varieties especially susceptible to fungus, such as Pinot Noir, may be riskier to produce in the near future since rainfall events may be more common in the fall around the time of grape harvest. Ice wines, which are a product largely unique to Niagara, may also be at risk, since frost events could be delayed by rainfall and the general increase in temperature, making it difficult to timely achieve the minimum temperature of -8°C (VQA Ontario, 2016b) (Figure 5).

FIGURE 5: A NIAGARA REGION VINEYARD. Wineries of the Niagara Region such as the Jackson Triggs estate (pictured above) pride themselves on the production of ice wine, but with rainfall and temperature changes in the coming years, this practice will become increasingly difficult (Edwards, 2016).

Some economists believe that with increasingly unpredictable rainfall events, winemakers will have to implement weather derivatives - contracts between an agency and a firm that reduce the financial risk associated with growing grapes. Unlike insurance, weather derivatives compensate based on less destructive events that still pose a risk to crop yield. Such events, which include droughts or extreme temperatures, are expected to become more common with climate change (Cyr et al., 2010).

POTENITAL BENEFITS OF CLIMATE CHANGE

Despite the potential challenges, there is also evidence that suggests viticulture Niagara will benefit from climate change. Since increased temperatures will reduce the winter injury of grapevines, certain costly practices currently used to mitigate freeze damage might not be needed. For example, wind machines are currently used to reduce the impact of frosts that may occur in May at the beginning of the season, or in October at the end of the season. These machines work by circulating air in the vineyard to prevent the settling of cool air (Shaw, 2002). Studies have found that such machines protect the vine from about 90% of frost events, which benefits crop yield, but are also expensive to maintain (Shaw, 2002). Lower frost incidence would reduce the cost of running these wind machines without risking the destruction of grapevines.

Research indicates that the grape berries themselves may benefit as well, experiencing a longer ripening and maturation period which results in fruit with bolder flavors, more sugar, and more alcohol. Furthermore, higher temperatures and a longer frost-free season means grape-growers will have greater control over the time of harvest. However, if the upper temperature limit for growing certain varieties is reached, grape quality will begin to decline as described prior (Mozell & Thach, 2014). Ultimately, the greatest challenge does not come directly from warmer temperatures, but rather, the unpredictability of weather in the harvest season in the years to come.

CONCLUSION

Over the coming decades, climate in the Niagara region is expected to change dramatically. While climate models remain somewhat divided in their overall temperature and precipitation projections, the wine industry should be prepared for new and changing conditions. In particular, the risks associated with grapevine pests, changes to the chemical composition of grapes, and unpredictable weather will likely be concerns in the years to come. Yet, there remains a silver lining for viticulturists. Warming conditions in Niagara are expected to yield longer, more fruitful growing seasons and a reduction in frost damage. Although an exact picture of late 21st century Niagara remains elusive, a clear understanding of climate change and its effects on viticulture is critical to protect what has become a vital Ontario industry.

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Bottle Aging

The Effects of Chemical and Physical Factors on Wine Maturation

Dalton Budhram, Rouvin Kurian, Dhanyasri Maddiboina, David Martin, Tyler Or

How can Vintage Port evolve fragrant flavours after a decade in the cellar, while Riesling becomes discoloured after only a few years? There is a multiplexed answer for this complex question. During bottle aging, the molecules within a wine interact in various ways to produce new aromas and pigments. The degree to which a wine interacts with its environment is affected by the type of packaging and closure method used. Indeed, identical wines that are bottled differently evolve separate flavours. The taste of a mature vintage wine is sought after, and there have even been attempts at artificial aging methods. As well, although bottle aging is an important process for all wines, consumers often misunderstand the extent to which it is required.

INTRODUCTION

The aging of wine is a poorly understood process that significantly influences its flavour and value. The process occurs after fermentation and is separated into two phases: maturation and bottle aging. Maturation typically involves the storage of wine in oak barrels for several months to years, while bottle aging occurs afterwards. It is a common misconception that all bottled wines improve over time. In fact, most wines do not age well and should be consumed within a few years of purchase (Jackson, 2008). When wines have good aging potential, their fresh, fruity, and astringent character diminishes over time, but is compensated by the development of a subtler, smoother texture known as an aged bouquet (Robinson, 1999). Eventually, the wine will peak in taste before undergoing irreversible loss of quality. Interestingly, most consumers actually prefer the character of younger wines, as the subtle flavours in aged wine can be difficult to detect (Robinson, 1999).

Bottle aging is the result of many chemical changes, and an increasing number of studies on the subject are emerging due to recent developments in analytical techniques (Tao, García and Sun, 2014). However, it is difficult to understand their impacts on taste, as many of these changes may occur below the human sensory threshold. It should also be noted that the results of many studies may only be representative to the specific variety of wine tested (Ebeler, 2001). At present, more is known about wine spoilage than is known about the development of an aged bouquet.

Bottle aging is often associated with red wines, as they have a higher concentration of phenolic compounds that are extracted from the skin and seed of grapes. These compounds, responsible for taste, colour, and aroma of wine, are known to evolve over time after bottling (Tao, García and Sun, 2014). Red wine varieties that are known to have good aging potential include Cabernet Sauvignon, Shiraz, Tempranillo, Nebbiolo, and Pinot noir. There are also a few white wines that can be aged, including Riesling, Chardonnay, Sauvignon blanc, and Viura (Jackson, 2008). Factors that accelerate bottle aging or cause spoilage include the degree of phenolic extraction, oxygenation, storage temperature, and irradiation (Ghidossi et al., 2012). Hence, vintners must consider the effects of the manufacturing process, bottle characteristics, and sealing methods.

EVOLUTION OF PHENOLIC PROFILES IN RED AND WHITE WINES

Interactions between many molecules are responsible for the complex hues and almost indescribable aroma of a glass of wine. These molecules harmonize with the glass and the air to create the sensation of taste experienced with each sip. A very important class of molecules swirling around inside wine are phenols (Cordova and Sumpio, 2009).

Phenols are a broad class of plant-derived molecules largely found in the pulp, skin, and seeds of grapes (Waterhouse, 2002). When they combine to form larger complexes, they are known as polyphenols (Figure 1). It is the differing levels of a specific phenol, anthocyanin, that allows for distinctive reds and whites to be made from the same grape.

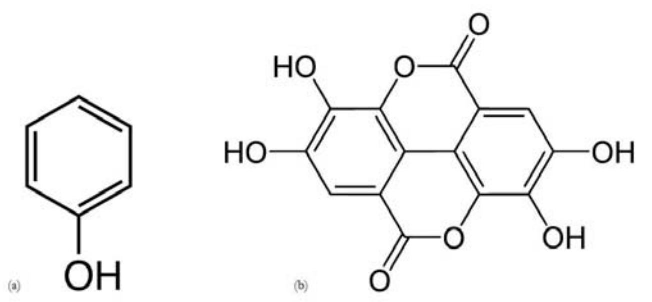

FIGURE 1: PHENOLS AND POLYPHENOLS. (a) Phenols are chemical compounds with a benzene ring and hydroxyl. (b) Polyphenols are complexes of phenols (Chemsketch, 2016).

During red wine production, the grape skins and seeds are soaked in the crushed grape juice for a period of time in a process called maceration. A large class of phenols known as anthocyanins leach out into the juice, giving rise to the vibrant colours that are absent in white wines (Cordova and Sumpio, 2009). In addition to impacting colour, phenols are the most important flavour compounds. They originate not only from wine grapes, but also from the yeast used for fermentation and the oak used in barrel aging. For example, when a wine has a creamy aroma and smooth mouthfeel, this is due to a phenol called vanillin that is released from oak barrels (Zhang et al., 2015). On the other hand, astringency, a feeling of dryness from wine, can be attributed to polyphenolic tannins. There are also many phenols that exist below the taste threshold, and instead contribute more subtly to the complex aroma and to pigment evolution during aging (Harbertson, 2016).

After phenolic compounds infuse into wine during maceration and barrel aging, the wine is bottled and usually stored at the winery for about one year. Most wines are expected to be consumed within 24 hours of purchase and therefore are not meant to be aged by consumers (Gaiter and Brecher, 2003). However, there are select wines that are produced with bottle aging in mind. These wines evolve over time to produce an even more complex phenolic profile. Some of the biggest factors in how well a wine ages are tannins. They are found in grape skins and seeds, meaning a high level of tannins is conferred to red wines over white, potentially allowing them to age well. Red wines often have the highest aging potential. They have significant levels of tannins at the start of bottle aging, giving them a very dry and rough mouthfeel (Cordova and Sumpio, 2009). As time progresses, the tannins form complexes with anthocyanins (red wine pigment molecules), which can lead to brown and yellow pigmented or colourless molecular products. This reduces the astringency and lightens ruby reds into tawny hues (Cheynier, 2006). Reacted tannins instil a smooth and supple feel to the aged bouquet, in stark contrast to the dry, chalky aftertaste accompanying their younger counterparts.

A series of reactions critical for the colour stability of red wines involves the complexation of anthocyanins with a class of colourless polyphenols called catechins. The association between the pigmented anthocyanins and catechins results in a greater colour intensity than the anthocyanins would exhibit on their own (Boulton, 2001). The loss of pigmentation intensity due to the formation of anthocyanin-tannin complexes is balanced by this copigmentation process. Consequently, while the hues are altered through bottle aging, the colour of intensity of red wines does not appear to be affected (Puértolas et al., 2010).

While the colour of red wines lightens over time, white wines tend to lose their clarity and develop darker colours as they bottle age. The main reason for this unstable colouration in white wine is a compound known as hydroxycinnamate. This compound reacts with oxygen to form a brown pigmented quinone molecule. Quinones join together and give off a yellow-brown hue which does not affect bitterness or astringency, but instead reduces the aesthetic properties and makes white wines unfavourable for aging (Recamales, Sayago, González-Miret and Hernanz, 2006).

After a period of bottle aging, the total phenolic content in red and white wines shows an overall decrease (Puértolas et al., 2010). One reason for this is that the formation of long-chained complexes among phenols eventually solidifies and sinks to the bottom of the bottle. This lowers the number of phenolics floating around in the wine (Cordova and Sumpio, 2009).

TABLE 1: THE EFFECTS OF VARIOUS PHENOLS AND POLYPHENOLS IN WINE. There are various molecules that affect the aging potential and taste of wine.

Molecule	Role in Wine
Anthocyanins	Red pigmentations
Vanillin	Creamy, vanilla flavour
Tannins	Astringency, aging potential
Catechins	Associate with anthocyanins to increase colour intensity
Hydroxycinnamate	Oxidize to form quinones
Quinones	Yellow-brown pigment molecules

WINEMAKING METHODS AND PHENOLIC COMPOUNDS

Previously, it was established that the phenolic content in wine dictates its amenability to aging. Hence, many efforts have been undertaken during the maceration and fermentation processes to control the extraction of these compounds (Sacchi, Bisson and Adams, 2005). It is believed that tannin extraction is limited by solubility. For instance, it is known that alcohol produced during fermentation improves the release of tannins from the skin into the juice. Consequently, increasing the fermentation time improves tannin extraction (Sacchi, Bisson and Adams, 2005). In contrast, anthocyanins require physical processes to rupture the vacuoles and membranes of grape cells and release the compounds.

In traditional red wine fermentation, the grape skin and juice (i.e. must) are stored in stainless steel tanks, allowing yeast to convert sugars into ethanol and carbon dioxide. Increasing the fermentation temperature by about 10°C is known to increase the solubility and cell permeability of grape skins, thus increasing tannin and anthocyanin extraction (Girard et al., 2001). The compounds combine to form more polymeric pigments, resulting in a deeper wine colour.

An alternative process involves briefly heating the must to 60-70°C, extracting the juice, and allowing it to cool prior to fermentation. This is known as thermovinification. It allows vintners to avoid including grape skins and seeds in fermentation tanks, resulting in improved flexibility on fermentation parameters such as temperature. The heating damages cell membranes, releasing anthocyanins while also denaturing polyphenol oxidase, an enzyme associated with browning. However, tannin extraction is decreased, as the grape skin is not in contact with alcohol. This results in a decrease in overall phenolic content (Auw, Blanco, O'Keefe and Sims, 1996).

FIGURE 2: MACERATION PROCESS. The skin, seed, and stem of grapes are crushed and the phenols are leached into the juice for some period of time (Eleassar, 2007).

Another popular technique is known as 'cold soak'. In this method, the must is held at cool temperatures (10-15°C) prior to fermentation in order to improve wine colour. However, many studies show no significant effects of 'cold soak' on phenolic content (Marais, 2003). On the other hand, freezing the must causes tearing of cells in the skin and seeds, resulting in an increase in both tannin and anthocyanin content (Parenti et al., 2004). Vintners have also experimented with the addition of pectolytic enzymes during maceration, which break down skin cell walls and increase juice yield (Figure 2). Many studies show that this results in an increased total phenol content (Sacchi, Bisson and Adams, 2005).

THE EFFECTS OF THE BOTTLE ON AGING

Many factors that affect wine quality are overlooked in the bottle aging process, and this can have detrimental effects on taste. The physical parameters of a wine bottle can play a significant role in the maturation process of both red and white wines. Recent research has studied the effects of bottle storage, packaging, bottle colour, and exposure to ultraviolet (UV) radiation on wine composition and evolution.

The permeability of gas through different packaging types is associated with compositional changes during the maturation of wines (Blake et al., 2009). The combination of light exclusion and cooler storage conditions tends to result in an increased retention of compounds that affect aroma. For instance, methoxypyrazines (MPs) are a potent class of grape derived, odour-active compounds which have an intricate relationship with wine quality. A study conducted with Riesling and Cabernet Franc wines found that temperature and packaging type have a prominent effect on MP concentration (Blake et al., 2009).

UV radiation is another factor that has a predominantly negative effect on the quality of wine. Light exposure results in what is known as 'light-struck' flavours which include unpleasant aromas. The key reaction involving UV light is between sulphur-containing amino acids, such as methionine and cysteine, and photochemical activators, such as riboflavin or pantothenic acid, all of which are natural constituents of wine (Maury, Clark and Scollary, 2010). In particular, riboflavin is excited energetically by UV and visible light. When an excited riboflavin molecule reverts back to its normal state, it transfers its excess energy to other molecules of the wine which produce volatile sulphide compounds. These reactions are spontaneous and occur quite rapidly. Within minutes of exposure to light, in the presence of only a small amount of sulphurous compounds, wine can develop an unfavorable taste and aroma. That being said, there are some constituents of wine that act to prevent the odours and flavours associated with light degradation. Since red wines naturally have higher phenolic content, they are less susceptible to 'light-struck' flavours than white wines, despite having higher riboflavin and pantothenic acid content (Mattivi et al., 2000).

FIGURE 3: AN EMPTY RED WINE BOTTLE. Red wines are stored in thick, darkly coloured glass that will absorb the majority of visible light (Heusser, 2004).

The ideal wine bottle would be able to reduce the exposure of volatile compounds to light by absorbing all natural and artificial light over a wide wavelength range. In practice, this would mean absorbing light in the UV region and wavelengths of around 520 nm in the visible spectrum. Bottles with these optical properties would be thick-walled (2-3 mm) and very dark in color (Figure 3). Furthermore, although most incoming light is absorbed by the bottle, some is also reflected. If a bottle is carefully crafted with consideration for light direction and storage placements, a significant amount of light can be reflected. The relative proportions of light that are reflected and absorbed depend on the direction of the incoming light and the shape of the bottle (Dias, Smith, Ghiggino and Scollary, 2012).

THE EFFECTS OF THE CORK ON AGING

Bottle closure is yet another important factor to consider during bottle aging. It can improve or hinder the quality depending on the closure type: natural cork, synthetic cork, or screw cap (Figure 4). Oxygen entry and cork taint are factors in the bottle aging process that affect closure choice (Ugliano, 2013; Álvarez-Rodríguez et al., 2002). Differences in these features are observed when examining each individual closure type.

Oxygen plays a crucial role in the development of wine, as it can change the quality and lifespan of a wine via oxidation. Examples of such changes include: the development of a vinegar-like aroma, which occurs when oxygen interacts with the alcohol in wine to form acetaldehyde; the development of a sulfurous flavour, which results when the wine is exposed to very little oxygen; and finally, a loss of varietal character in the wine that results from high oxygen levels (Ugliano, 2013; Ugliano et al., 2012). Nevertheless, a certain level of oxygen in the bottle can benefit the quality of the wine during bottle maturation (Ugliano, 2013). Thus, careful management of oxygen exposure is required, and vintners must be cognisant of effects of different closure types to produce the best-quality wine possible.

Natural corks are derived from cork oak (*Quercus suber*) trees, which produce a dense material that is very malleable. It can expand and contract according to the shape of the bottle's neck and will thus form an approximately airtight seal. However, the extent to which the cork changes shape is strongly dependent on storage temperature (Godden et al., 2001). Higher temperatures result in greater expansion, while cooler temperatures result in a loss of volume. In addition, natural corks contain microscopic gaps within their structure which transfer an intermediate level of oxygen into the wine (Lopes, Saucier, Teissedre and Glories, 2007). The issue with this closure type is cork taint, an undesirable smell and taste that occurs when the cork is degraded by naturally-occurring fungi (Álvarez-Rodríguez et al., 2002).

FIGURE 4: DIFFERENT WINE BOTTLE CLOSURES. From left to right: An image of natural cork, synthetic cork, and screw cap closures (Delgaudio, 2005; Ceragioli, 2014; Symposiarch, 2006).

Synthetic corks are largely composed of plastic material that can not be broken down by fungi; consequently, cork taint is not possible. Since the cork is made of an inert material, it can not adapt to environmental fluctuations (Godden et al., 2001). As a result, synthetic cork is less flexible than its natural equivalent, and may prompt excessive oxygenation if the stopper is an imperfect fit for the bottle (Lopes, Saucier, Teissedre and Glories, 2006). If bottled for an extensive period of time, this could damage the wine. For this reason, synthetic corks are used only for short-term bottle aging.

Screw caps are a recent innovation in bottle closures that have gained popularity in the wine industry. Unlike their cork counterparts, screw caps are mainly composed of metals and some plastic. Once again, there is no possibility of cork taint. Although this type of closure is composed of inert material, some oxygen ingress will still occur (Godden et al., 2001). In fact, screw caps provide a more consistent rate of oxygen passage throughout bottle aging. However, it is significantly lower than the oxygen entry rate in corks (Lopes, Saucier, Teissedre and Glories, 2007). As a result, many wine producers are beginning to use screw caps as their preferred closure type. It eliminates cork taint and provides a relatively stable barrier between the environment and the bottle.

ATTEMPTS TO ARTIFICIALLY AFFECT POST-BOTTLING MATURATION

As scientific understanding of bottle maturation develops, oenologists have begun to search for techniques to artificially alter the aging process of various wines. Their research includes attempts to imbue young wines with the desired traits of mature vintage and efforts to modify the final phenolic composition of an aged wine.

Much of the early research on modified bottle aging was focused on physical methods of altering a wine's chemical properties after fermentation had been completed. These techniques frequently took the form of using ultrasound or gamma irradiation to accelerate bottle maturation (Singleton, 1962; Singleton and Draper, 1963). Both of these options are still being explored, but while early experiments focused on the impact an aging treatment had on taste, recent studies are often more concerned with a treatment's effect on chemical composition (Masuzawa et al., 2000; Wilson, Moran and Boreham, 2003).

Experimentation with ultrasonic aging began in the mid-twentieth century, when experiments with high-intensity ultrasonic treatments of young wine were conducted. It was reported that ultrasound accelerated oxidation in red and white wines, but the effect was accompanied by an easily detected 'scorched' flavour (Singleton and Draper, 1963). The researchers hypothesized that this new flavour resulted from acoustic cavitation, the process by which sound pulses produce bubble-like cavities within a liquid. The subsequent collapse of these cavities produces a moment of extremely intense temperature and pressure that 'scorches' the wine (Singleton, 1962).

As oenologists become more familiar with the complex chemical composition of wine, some experiments with ultrasonic maturation have shifted focus, moving away from the general effect of ultrasonic irradiation on flavour perception and toward its specific impact on phenolic compounds. As discussed earlier, phenolic compounds are a known component of red wine, which as a wine matures polymerize to form beneficial antioxidant polyphenols. In 2000, researchers at the Musashi Institute of Technology applied continuous, weak ultrasonic irradiation to bottled red wine for ten days. They found that the treatment promoted polymerization of phenolic compounds, accelerating the maturation process in that respect. However, it must be noted that the researchers did not taste the treated wine, and the effects of the ultrasonic treatment on the quality and character of the product remain unclear (Masuzawa, et al., 2000).

Similar studies have looked at the impact of gamma radiation on bottled wine. This avenue was also explored by researchers in the early 1960s, with some success. Their experiments involved exposing bottles of red and white wine to cobalt-60 gamma radiation, and then offering them to a panel of courageous tasters for evaluation. The study found no change in the total polyphenolic content of the irradiated wine, but did report quantitative and qualitative changes in the polyphenols that were present (Singleton, 1963). The wine's altered phenolic profile may be a result of radiolysis and repolymerization, wherein polyphenols are destabilized by radiation and recombine to form different compounds (Velasco et al., 2014). It was observed that the radiation imbued all of the wines with a similar, difficult to describe flavour, which 5 of the 14 panelists found favourable (Singleton, 1963).

Gamma irradiation of white wine was investigated again twelve years later, when researchers observed an increase in total polyphenolic content, in addition to increased amounts of aldehydes (Yokutsuka, 1975). Unfortunately, the authors were only interested in quantifiable chemical changes, and the samples in their experiment went untasted. In contrast, a 1989 study focused entirely on sensory perception of gamma irradiated wines. In this case, Cabernet Sauvignon received doses of radiation before undergoing 18 months of storage. The treatment produced no noticeable benefits in terms of taste at low dose levels, and caused unpleasant flavours at higher doses (Caldwell and Spayed, 1989).

Evidently, attempts to alter fermented wines by physical means have produced a complicated assortment of results. At present, neither irradiation nor ultrasound treatment seems positioned to become an industry standard for advancing bottle maturation. For the time being, vintners and consumers alike will have to rely on the time-honoured tradition of cellaring to age their vintages to perfection.

CONCLUSION

Bottle aging is a complex process influenced by a myriad of variables. The various maceration and fermentation procedures that vintners employ have impacts on the extraction of phenolic compounds which dictate wine taste and colour. With recent developments in analytical techniques, an increasing number of studies attempt to delineate the significance and evolution these compounds. Also of important consideration is the bottling specifications, as ingress of UV light and oxygen can cause reactions among the phenolic compounds. Attempts have also been made to artificially alter the aging process post-bottling in order to fine-tune the wine character. It is apparent that vintners must be meticulous in controlling their manufacturing methods to ensure a consistent experience with their products. However, while many of these aging factors have been studied, there is still much uncertainty regarding their direct consequences to taste and consumer preference. All of these factors cumulate in a nonlinear way to create an incredibly complex product that cannot be predicted from its base parts. So when opening up a bottle of classic Bordeaux Cabernet Sauvignon, one can appreciate the unique character of an aged bouquet that is a result of countless experimenting, fine-tuning, and artistry from the vintner.

MORE TO EXPLORE

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Wine: The Good-For-You Drink

Matt Anderson, Oriana Koshyk, Jamie Maloney, Vivian Martin & Bridget McGlynn

Do you love indulging in wine, but also wish to maintain a healthy lifestyle? Scientific research suggests you can do both! Due to the various polyphenolic compounds comprising wine, particularly red varieties, moderate consumption of this delicacy has been correlated to a plethora of health benefits. Such benefits include a reduction in the risk of acquiring cardiovascular diseases, decreased instances of lipid oxidation and platelet aggregation, and the prevention of Type II diabetes. Furthermore, polyphenols in red wine have been attributed to the prevention of tumour proliferation, suggesting that these compounds hold significant potential for use in therapeutic protocols and treatments for cancer. Nevertheless, consuming wine alone will not present you with all of these exciting benefits. Therefore, it is recommended that regular wine consumption of 1-2 glasses per day should be coupled with a lifestyle that includes physical exercise and healthy eating.

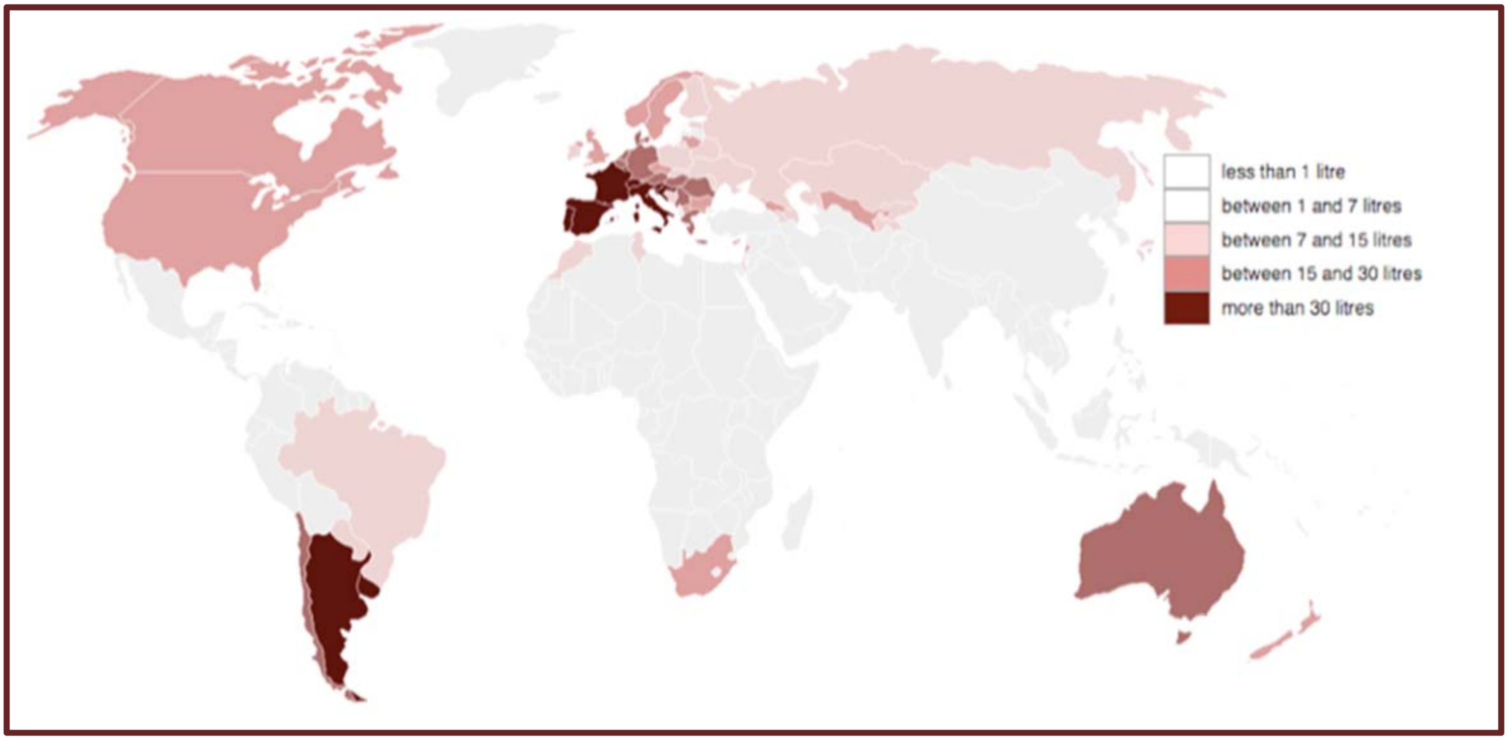

FIGURE 1: World Map showing per capita wine consumption by country over a one-year period in 2012. A darker the red colour depicts a higher percentage of wine drinkers (Pixeltoo, 2012).

As first noticed by Samuel Black in 1819, the French display lower rates of coronary heart disease than other European and North American regions. The French mortality rate for coronary heart disease is twofold lower than that of the United States, despite consuming 31 g/capita/day of animal fats more than the average American (Lippi *et al.*, 2010). This difference has led to in-depth research into the "French paradox." Presented in 1992, the proposition for the cause of this discrepancy was the difference in red wine consumption among nations (Figure 1). Whereas wine represents approximately 7% of alcohol consumed in the United States, it represents over 50% of that consumed in France. While the original hypothesis for the biochemical mechanism of action for the impact of red wine on the body was incorrect, this research spurred interest in the subject. This has led to the discovery of numerous benefits of regular, moderate wine consumption (Lippi *et al.,* 2010).

These health benefits of wine are primarily tied to its concentration of volatile compounds, despite representing only 0.5% of total wine volume (Markoski *et al.*, 2016). As it is primarily these volatiles, which are responsible for the health benefits of wine consumption, the potential health benefits of wine are primarily correlated to the concentrations of the volatile compounds within the wine. Phenolic compounds are primarily found in the skins and seeds of the grapes, and not in the flesh; consequently, as will later be discussed, red wines have nearly tenfold the concentration of phenols than white wines. This dramatic difference in phenol concentration makes red wine nutritionally superior to white. There are numerous categories of phenolic compounds within red wine, such as flavanoids, catechins, and anthocyanins. These compounds help to prevent and decrease the effects of chronic illnesses such as coronary heart disease, diabetes, and cancers. (Markoski *et al.*, 2016). Consequently, numerous molecules should be considered when investigating and describing the ability of red wine to improve the consumer's health in order to better understand its entire effect.

Compounds in Wine

Resveratrol

Resveratrol is a compound produced by seed plants, including grapevines, as a defence mechanism against injury or infection. It is a type of flavonoid, which is a family of plant pigment compounds. Resveratrol is located within the skins of grapes, but not the flesh (Delaunois *et al.,* 2008). Red wines contain far more significant quantities of resveratrol as they are fermented in the presence of the grape skins. This facilitates the extraction of resveratrol molecules from the fruit. On the other hand, white wines undergo fermentation in the absence of grape skins (Frémont, 2000). Furthermore, resveratrol molecules exist in two isomeric forms: cis- and trans-resveratrol (see Figure 2). Isomers of a particular compound share the same molecular formula, but differ in the atomic arrangement of their molecules. In the case of resveratrol, the trans isomer is more dominant in wines, as this atomic arrangement is far more chemically stable than that of cis-resveratrol (Frémont, 2000).

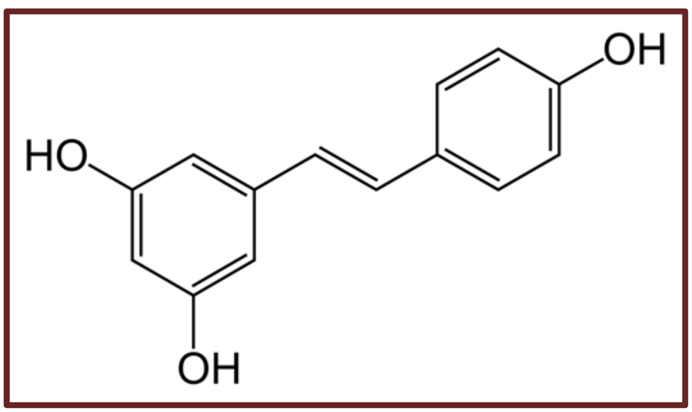

FIGURE 2: The chemical structure of trans-resveratrol (Advanced Life Research, 2007).

Studies suggest resveratrol contains several antioxidant properties that aid in the prevention of cardiovascular diseases in humans (Frémont, 2000). In addition, resveratrol has proven to reduce instances of low-density lipoprotein (LDL) oxidation and to inhibit platelet aggregation (Frankel *et al.,* 1993). LDL oxidation, characterized by the removal of electrons from lipid molecules, results in the accumulation of unwanted cholesterol within the arteries, contributing to the onset of cardiovascular diseases. Moreover, in both animal models and clinical trials, resveratrol has shown to be a key regulator of homeostasis within the body via its activities associated with protein synthesis, enzymatic function, programmed cell death, and signal transduction pathways (Frémont, 2000). However, in order to establish the correlation between resveratrol on human health, the bioavailability and metabolic pathways associated with this compound must also be acknowledged (Frankel *et al.,* 1993).

In grapevines, resveratrol is produced in response to abiotic or biotic stressors (Delaunois *et al.,* 2008). This compound is also found in other fruits and vegetables, including cranberries, blueberries, and peanuts, where it serves similar defensive purposes. The primary goal of resveratrol synthesis is to increase the tolerance and resistance of grapevines to pathogenic invaders. Thus, due to the effectiveness of this compound, the gene encoding resveratrol has been sequenced and inserted into transgenic organisms to confer a defensive advantage to them (Delaunois *et al.,* 2008).

Catechins

Catechins are a family of flavonoids found in plants in various concentrations. Dietary sources and their associated concentrations can be seen in Table 1.

In grapes they are found primarily in the skins and seeds, explaining why catechin concentrations are much higher in red than in white wines. Red and white wines vary primarily in fermentation protocols, where red wines are fermented in the presence of grape skins and seeds while whites are not. This difference in catechin concentration can be noted in the flavour components of the wine. Most catechins have a bitter and astringent taste, with some even producing a sweet after-taste. When catechins join together, they form compounds known as procyanidins (Gadkari and Balaraman, 2015).

TABLE 1: Sources of catechins widely distributed in foods (Gadkari and Balaraman, 2015).

Food Sample	Catechins[a]	Catechins[b]
Apple	20-86	10-43
Apricot	20-50	10-25
Beans	70-110	35-55
Black tea	12-100	6-50
Blackberry	9-11	9-11
Cherry	10-44	5-22
Chocolate	23-30	46-61
Cider	8	4
Grape	6-35	3-17.5
Green tea	20-160	10-80
Peach	10-28	5-14
Red raspberry	2-48	2-48
Red wine	8-30	8-30
Strawberry	2-50	2-50

[a] Values are expressed in mg per servings
[b] Values are expressed in mg per 100 g sample

Young red wines have been found to contain higher levels of procyanidins, giving wine a purple hue early in the process of wine synthesis. As the wine matures, procyanidin concentrations decrease and more stable compounds with red-orange pigments begin to form. This chemical change can be tasted in the decreased astringency of aged wines (Dreosti, 2000). Catechins are responsible for more than just short term differences already noted such as wine colour and taste. Studies show catechins may have potential benefits to humans, particularly in the prevention of degenerative diseases such as congenital heart disease, and as such are of particular interest to study (Gadkari and Balaraman, 2015).

Anthocyanins

Anthocyanins are a major subgroup of flavonoids that are responsible for the red, purple, and blue hues seen in many fruits, vegetables, and plants (Konczak and Zhang, 2004). It is the anthocyanins, along with other polyphenols, that are responsible for the red colour of red wines, and their absence for white wines. More interestingly, it has been shown that anthocyanins provide a number of health benefits when regularly consumed as part of the diet. They have been associated with reduced risks of chronic diseases, such as cancer, cardiovascular disease, virus inhibition, and Alzheimer's disease (Andersen and Markham, 2006). However, the exact mechanisms through which specific anthocyanins cause these effects remain unclear.

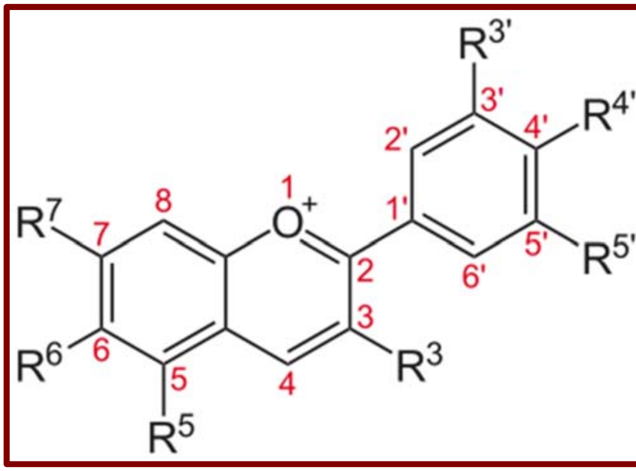

FIGURE 3: General structure of an anthocyanidin, an anthocyanin without a sugar molecule attached. The presence of many possible R chains is what gives rise to the diversity of molecular structures. (NEUROtiker, 2008).

There are over 600 different anthocyanins (see figure 3 above), which frequently interact with other phytochemicals to potentiate biological effects (Konczak and Zhang, 2004; Lila, 2004). Because of this synergistic nature, it is difficult to decipher the contributions of an individual component, and little is known about how structural diversity relates to their bioavailability and biological function (Garcia-Alonso *et al.*, 2009). Furthermore, the extensive metabolic breakdown upon ingestion makes tracking anthocyanins difficult. Thus, assessing the absorption, bioavailability, and accumulation in various organs is challenging (Lila, 2004). Despite this, evidence suggests there are multiple mechanisms by which the anthocyanins work in vivo to improve health. Anthocyanins modulate the activity of a wide range of enzymes and cell receptors (Andersen and Markham, 2006), such as blocking activation of the MAPK pathway involved in tumorigenesis (Lila, 2004). Furthermore, they act as free-radical scavengers. This reduces the amount of lipid oxidation in the bloodstream, providing protection against cellular oxidative stress; which is the harmful effects associated with unbalanced lipid oxidation (Konczak and Zhang, 2004).

While it has been indicated that anthocyanins provide health benefits in regards to various chronic diseases, they, along with other flavonoids, have not yet been adopted in Western medicine for therapeutic uses (Andersen and Markham, 2006).

Ethanol

Ethyl alcohol, more commonly referred to as ethanol, is the fundamental volatile component of all alcoholic beverages, not only wine (Figure 4) (Higgs *et al.*, 2008).

A standard glass of wine is classified as one five-ounce glass of twelve percent alcohol. This percent value refers to the percentage of ethanol found throughout the wine, or the amount of alcohol by volume (ABV). This percentage can vary depending on the type of wine. For example, an Italian Pinot Grigio typically has an alcohol content of 10 to 11%, while a California Pinot Noir typically has an alcohol content of 13.5 to 15% (Higgs *et al.*, 2008). During the winemaking process, the sugars present in the grape juice are converted into ethanol and carbon dioxide; therefore, the accumulation of sugar in different varieties of grapes plays a vital role in determining the alcohol content of specific wines (Orts *et al.*, 2005). It is important to note that the sugar composition and concentration of wines are highly variable due to several factors, such as the environment, climate, viticulture techniques, or simply due to differences in grape ripening processes (Orts *et al.*, 2005).

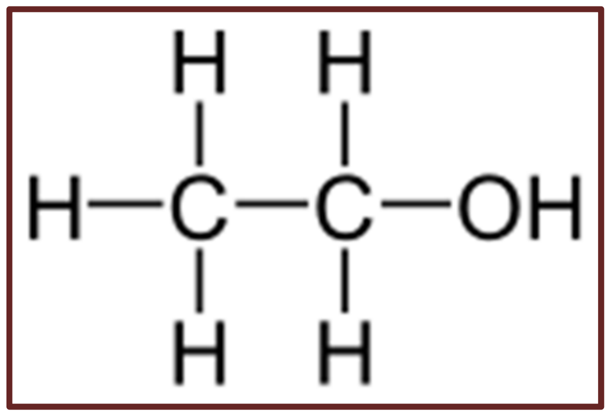

FIGURE 4: The chemical structure of ethanol (NEUROtiker, 2009)

Once in the body, ethanol is broken down into acetaldehyde, its primary metabolite, and acetic acid, its secondary metabolite (Shiraishi *et al*, 2010). Primary metabolites are directly involved in normal growth, development and reproduction, whereas secondary metabolites are not. Acetaldehyde and acetic acid are chemicals that can be very toxic at high concentrations; thus, it is important to consume wine in moderation. Acetaldehyde has the ability to diffuse across the blood brain barrier, resulting in terrible headaches or a typical hangover (Walsh *et al.*, 2002). The liver plays a major role in combating this with the responsibility of breaking down both acetaldehyde and acetic acid, as well as the removal of these toxins from the circulatory system (Walsh *et al.*, 2002).

There is often a debate on whether ethanol has beneficial or harmful effects on the human body (Figure 5). Multiple clinical studies have been completed, yet no absolute conclusions have been drawn (Higgs *et al.*, 2008). Some studies discovered that moderate alcohol consumption might be beneficial in preventing certain types of heart disease, especially atherosclerosis. Atherosclerosis is a type of cardiovascular condition characterized by the accumulation of fatty deposits within the walls of arteries, resulting in severely elevated blood pressure. (Higgs *et al.*, 2008). In a related study, participants consumed dealcoholized wine, grape seed extract, and grape juice to see if ethanol was a vital component in preventing platelet aggregation or blood clot. The conclusions from this experiment implied that alcohol is not critical, however, substantially decreases the chance of a formation of a clot (Imhof *et al.*, 2009).

Society is aware of the detrimental effects of reckless and extreme alcohol consumption. When people are intoxicated, they have a higher incident rate of accidents not only involving themselves, but others. People who binge drink or drink often are at an increased risk of cirrhosis, the most advanced stage of liver disease, and multiple upper-digestive cancers in addition to liver cancer (Higgs *et al.*, 2008).

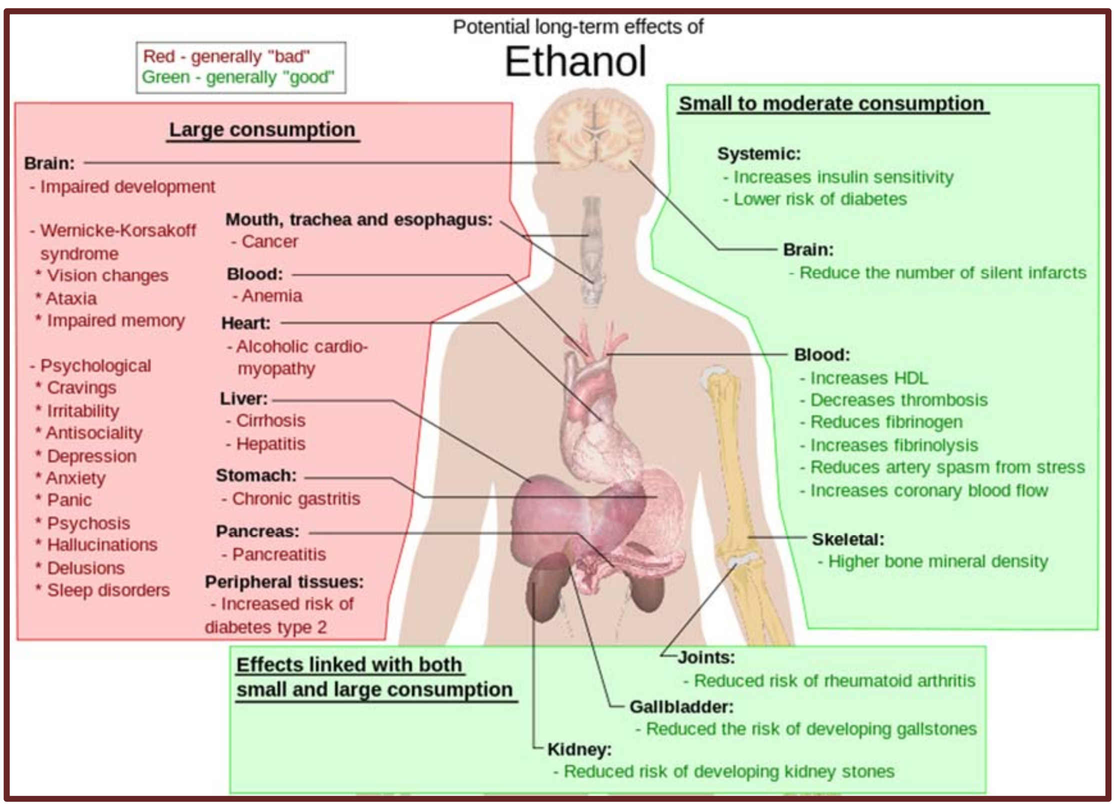

FIGURE 5: A collaboration of the potential long-term effect of ethanol on the human body. The generally 'bad' effects are shown in red and the generally 'good' effects are shown in green (Häggström, 2009).)

Effects of Wine on Human Health

Cardiovascular Health

Numerous phenolic compounds present in red wine have been correlated to an array of health benefits within the body, with one of the most prominent effects being on cardiovascular health. The theory of the "French Paradox" has often been a controversial dilemma in the world of wine science (Markoski *et al.,* 2016). Scientists believe the moderate consumption of red wine in France is one of the major factors contributing to the reduced instances of cardiovascular diseases (CVD) (Markoski *et al.,* 2016). In fact, phenolic compounds within red wine, primarily resveratrol, have been associated with the reduction of platelet aggregation and the inhibition of copper-catalyzed LDL oxidation, which is directly correlated to the onset of CVD (Frankel *et al.,* 1993).

Studies indicate flavonoids present in red wine, mainly trans-resveratrol and quercetin; reduce platelet aggregation (see Figure 6), thus decreasing one's risk of acquiring CVD (Pace-Asciak *et al.,* 1995). This is primarily due to the fact that resveratrol deactivates the synthesis of thromboxane, a lipid that plays a significant role in the onset of thrombosis (Pace-Asciak *et al.,* 1995). In an experiment conducted by Wollny et al. in 2000, rats that consumed red wine, both with and without alcohol, experienced reduced instances of platelet aggregation and, by extension, thrombosis (blood clotting) (Wollin and Jones, 2001). However, white wine, which lacks significant flavonoid levels, had no effect on the rats. This suggests that the phenols present in red wine, rather than ethanol, contribute to the reduction of thrombosis (Wollin and Jones, 2001).

In another study conducted by Frankel et al. in 1993, it was discovered that flavonoids present within red wine, primarily resveratrol, catechins, and anthocyanins, contribute to the prevention of LDL oxidation through their reactions with free radicals within the blood (Frankel *et al.,* 1993). Lipid oxidation often results in the onset of CVD due to the associated stress imparted on the body.

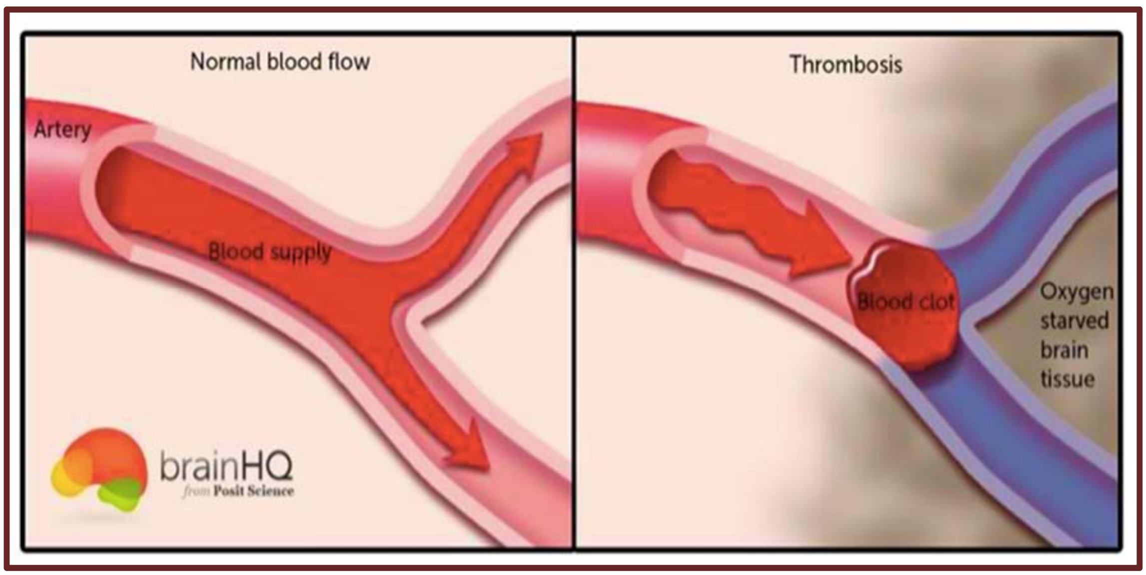

FIGURE 6: An illustration of the effects of platelet aggregation on the body (Thrombocyte, 2016).

Based on *in vivo* experimentation, the authors of this study concluded that the flavonoids complex with free copper radicals reduced the net charge on these ions, rendering them incapable of catalyzing the reactions associated with LDL oxidation. The results were only distinct when red wine, rather than white wine, was used in the study, suggesting that white wine lacks the flavonoid concentrations necessary to contribute to the reduction of copper cations (Frankel *et al.,* 1993). Furthermore, catechins activate the synthesis of antioxidant enzymes, which subsequently protects cells from oxidative stress-induced cell death (Pace-Asciak *et al.,* 1995).

Type II Diabetes

Diabetes affects millions of Canadians. As of 2015, 22.1% of all people above the age of 20 are affected by diabetes, especially those who are part of visible minorities. Incidence rates are expected to rise by 44% by 2025 (Canadian Diabetes Association, 2015). Type 2 diabetes occurs when either the pancreas does not produce enough insulin, or when the body does not appropriately use the produced insulin, resulting in the rapid accumulation of glucose in the blood (Canadian Diabetes Association, 2016). Studies have found a positive correlation between moderate daily wine consumption and the prevention of type 2 diabetes, along with it's associated complications (Caimi, Carollo and Lo Presti, 2016). A variety of studies have been conducted on mice, rats, and humans using grapes and grape components in the absence of ethanol that demonstrated therapeutic effects in type 2 diabetes patients caused specifically by polyphenols present, although the exact mechanisms and molecules is yet to be fully understood (Zunino, 2009). For example, the oral administration of muscadine grapes (particularly high in polyphenols) in humans resulted in a decrease in fasting blood insulin and an increase in blood insulin to glucose ratios (Banini *et al.*, 2006). Studies have also found that regular alcohol consumption may result in an approximately 30% decrease in risk of developing type 2 diabetes. Nevertheless, dose-dependency must be considered as over-drinking was shown to increase the risk by 43% (Howard *et al.*, 2004; Koppes *et al.*, 2016). Summarizing the results from a multitude of studies, it can be assumed that the effects of both the alcohol and polyphenol components of red wine are additive. When these components are consumed in moderation, they may prevent the onset of type 2 diabetes while also providing therapeutic effects in already diagnosed type 2 diabetes patients (Guilford and Pezzuto, 2011).

Cancer

Cancer is the leading cause of death worldwide for both men and women, and claims over 6 million lives each year (He *et al.*, 2008). Conventional cancer treatments themselves are also a leading cause of death and if not, result in serious side effects while typically only extending a patient's life by a few years (He, Sun and Pan, 2008). Improving treatments and finding ways to prevent the formation of cancer is a major focus of contemporary research. There is now a voluminous amount of literature regarding not only the role of wine polyphenols in preventing cardiovascular disease, but also in protecting against cancer development.

The development of cancers is known as carcinogenesis. There are 3 discrete stages of carcinogenesis: initiation, promotion, and progression. It has been shown that resveratrol affects all 3 of these stages by modulating signal transduction pathways that control key processes, such as cell division and growth, programmed cell death (also known as apoptosis), inflammation, angiogenesis, and metastasis (Shukla and Singh, 2011). Of particular importance is the effect of resveratrol on apoptosis. Apoptosis is the process that many current anticancer drugs aim to induce in cancerous cells (Shukla and Singh, 2011). In one study, red wine polyphenols were associated with increased levels of the p73 protein and active caspase-3 (Sharif *et al.*, 2010). This is significant because these proteins are pro-apoptotic factors, and p73 can induce apoptosis in cancer cells that have mutated resistance to the p53 tumour suppressor gene (see figure 7) (Sharif *et al.*, 2010). In other studies, it was shown that resveratrol modulated levels of the Fas and FasL transmembrane ligand proteins, thus inducing apoptosis (Shukla and Singh, 2011). This is a similar process to contemporary cancer drugs, as the Fas receptor is known as the 'death receptor' (Shukla and Singh, 2011).

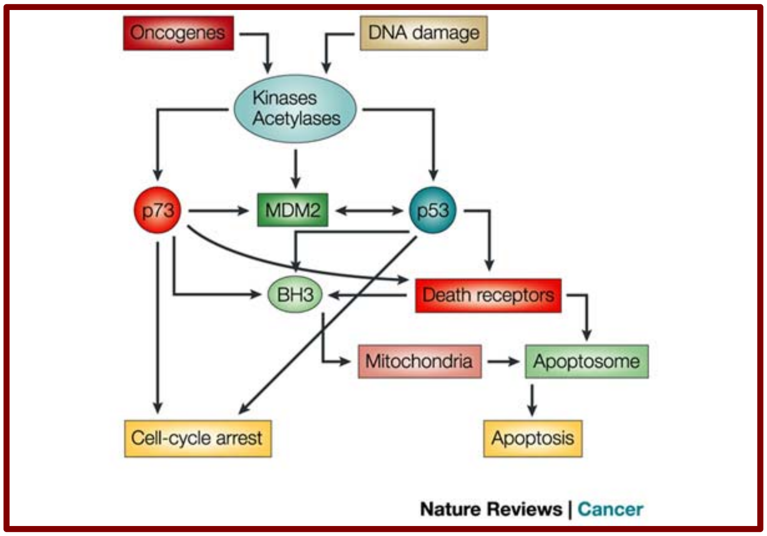

FIGURE 7: A diagram of a signalling pathway for apoptosis influenced by resveratrol. Resveratrol is associated with increased p73. The diagram shows that p73 can lead to apoptosis just as p53 can. (Melino, De Laurenzi and Vousden, 2002)

Another way in which wine polyphenols provide protection against cancer is through the inhibition of angiogenesis. Angiogenesis, the development of new capillaries from pre-existing micro-vessels, is a key pathogenic process in cancer (Scoditti *et al.*, 2012). Tumour growth is angiogenesis-dependent, as this process facilitates the growth of blood vessels into the tumour, thus supplying the oxygen necessary for its continued propagation (Brkenhielm, 2001). Resveratrol has been shown to suppress angiogenesis via the inhibition of fgf-2- and VEGF-receptor mediated endothelial cell responses (Brkenhielm, 2001). Moreover, the cocktail of polyphenols in red wine has been revealed to reduce inflammatory angiogenesis via MMP-9 and COX-2 inhibition (Scoditti *et al.*, 2012). This is significant because MMP-9 promotes metastasis, as it degrades the extracellular matrix holding cells together, a process normally intended for the penetration and reshaping of endothelial cell connective tissue (Scoditti *et al.*, 2012).

Conclusion

Regular, moderate consumption of red wine influences the body through multiple pathways, creating a plethora of health benefits in the prevention and treatment of chronic illnesses. Regular red wine consumption has the ability to aid in the prevention of type 2 diabetes onset. Resveratrol has the ability to modulate cancer growth pathways by inducing apoptosis in cancerous cells. Flavonoids, the category of molecules that includes resveratrol, decreases the rate of coronary heart disease development. Through a combination of antioxidant and antiquaggulation effects, red wine reduces platelet aggregation and, ultimately, arteriosclerosis. These biological effects can be viewed, in part, as a biochemical explanation of the French paradox. Ethanol magnifies these effects, which suggests wines lower in alcohol content are not as effective in preventing coronary heart disease. However, due to the harmful effects of ethanol, wine must be consumed in moderate quantities in order for overall health benefits to be experienced. For most populations, one to two drinks per day, which is approximately 10–30 g of alcohol, can be tied to overall cardiovascular benefits (Lippi *et al.*, 2010). The beneficial effects of red wine are best seen in conjunction with a healthy lifestyle that promotes overall wellbeing.

Acknowledgements

Our group would like to thank Dr. Carolyn Eyles, Russ Ellis, Sarah Robinson and the multitude of guest speakers who spoke to our class throughout the project (Figure 8).

FIGURE 8: Wine Research Team

MORE TO EXPLORE

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To Irrigate or not to Irrigate:
That is the Question

Ian Fare

Varsha Jayasankar

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Jason Schneider

Sunny Tian

The Niagara Peninsula is home to the largest region for the production of quality wines in Canada. Currently, wineries in the area do not practice widespread irrigation due to a perceived lack of need. However, the last few growing seasons have been characterized by prolonged periods of drought. This can have detrimental effects on both the quality and yield of the grapes, which in turn can affect the final wine product. The key to mitigating this issue and ensuring the survival of the industry is through the implementation of irrigation systems. Determining an irrigation system requires analysis of soil texture, drainage and local precipitation– the perfect balance creates the ideal system.

Everyone knows that water is the most important factor of a healthy life. The delicate balance to ensuring the optimal amount of water is received is like a harmonious song that every living substance dances to. The song is quickly coming to an end in the Niagara Peninsula for wine grapes, as periods of drought are becoming far more frequent and are posing a large problem for growers whose only source of water is mother nature. Options must be further explored in order to restore this balance of getting the right amount of water to the grapevines. Niagara, however, is divided into 10 sub-appellations, each of which have various heterogeneous soil types, drainage qualities, and precipitation levels. Thus, each appellation must be considered separately when adjusting this dance and choosing whether or not to irrigate, and if to irrigate, what method to choose.

NIAGARA'S DROUGHT

There are many definitions with regards to drought. Typically, drought can be defined in three ways–meteorological, agricultural and hydrological (Wilhite and Glantz, 1985). Meteorological drought occurs when there is less than average rainfall, progressing to agricultural and meteorological drought if sustained for 3-6 months. Over the last few years, the Niagara Peninsula has been approaching meteorological drought conditions. From the years 1998 to 2007 in the Niagara Peninsula, six growing seasons were affected by periods of prolonged drought (Reynolds, Lowrey and De Savigny, 2005; Reynolds et al., 2007). Precipitation in both the 2014 and 2015 summers fell below the historical (1981-2010) averages (Niagara Region, 2016). While the earlier droughts were bad, the summer of 2016 was especially ruthless. The precipitation dropped to less than half of the historical average (Figure 1), and the season was considered the driest summer since 1934 (Fraser, 2016). The Canadian Drought Monitor determined that the Niagara Peninsula was experiencing a severe drought with agricultural implications, the highest rating any

COMPROMISED FRUIT COMPOSITION:
lower soluble solids
high titratable acidity
lower pH

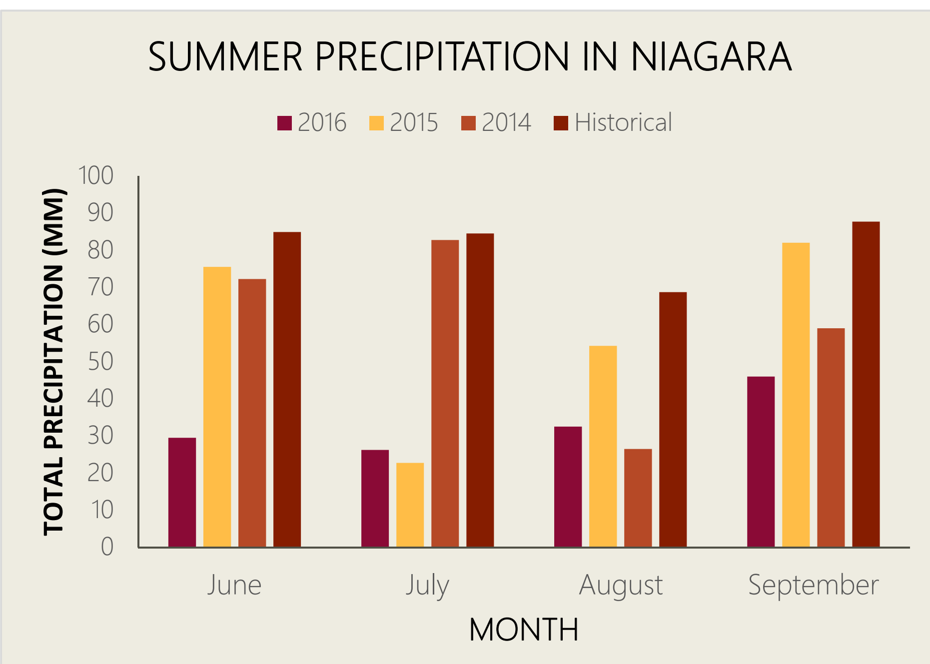

FIGURE 1: SUMMER PRECIPITATION IN NIAGARA. The data is an average of three weather stations spanning the Niagara Region–Vineland Rittenhouse, Port Dalhousie and Niagara Falls. Historical data is the average rainfall between 1981 and 2010. Precipitation dropped minimally from the historical average in 2014 and 2015. In 2016 however, precipitation was less than half of the historical average in June, July and August, and around 60% in September (Niagara Region, 2016)

region in Canada received this year. (Agriculture and Agri-Food Canada, 2016).

Only one variety of grapevine is grown in the Niagara Peninsula–*Vitis vinifera*, also known as the common grapevine. Drought often leads to poor shoot growth, lower yields, increased susceptibility to pests, compromised fruit composition, and produces an overall a lower wine quality in *Vitis vinifera* (Reynolds, Lowrey and De Savigny, 2005; Reynolds et al., 2007). Despite all the consequences, there are still some, albeit few, benefits to drought. Plants in drought conditions have longer roots with increased branching (Król, Amarowicz and Weidner, 2014). In some cases, a limited drought increased sugar content in individual berries (Reynolds et al., 2007)

Irrigation of *Vitis vinifera* is a very common practice in arid climates such as California, Australia, and South Africa (Reynolds et al., 2007). Historically, irrigation has not been widely practiced in the Niagara Peninsula due to the lack of benefit found when analyzing cost: benefit ratios (Reynolds, Lowrey and De Savigny, 2005). The increase in frequency and severity in drought however have made it imperative to seek information on the never-used irrigation methods for the Niagara Peninsula. To determine which irrigation methods are best, the soil composition and the precipitation of the Niagara Peninsula must by analyzed.

NIAGARA SOILS

The creation of the Niagara environment was a long process of weathering and organic erosion and breakdown of glacial, lacustrine, fluvial, and alluvial sediments resulting in heterogeneous soils (Willwerth, Reynolds and Lesschaeve, 2015). The heterogeneity of the soils gives the Niagara Peninsula many distinct *terroirs*. With many different terroirs creating the Niagara Peninsula, The Vintners Quality Alliance of Ontario (VQA) split the region into ten sub-appellations. Six are located in Western Niagara (Beamsville Bench, Creek Shores, Short Hills Bench, St. David's Bench, Twenty Mile Bench, and Vinemount Ridge) and four are located in Eastern Niagara (Four Mile Creek, Lincoln Lakeshore, Niagara Lakeshore, Niagara River) (Willwerth, Reynolds and Lesschaeve, 2015). Each region has a different mixture of soil textures, with the most common soil types being clay loam, sandy loam and silty clay (Figure 2; Table 1).

TERROIR: the ecosystem of a specific place, namely the soil, climate, and vine environment that influences the characteristics of the grapes

TABLE 1: SOIL TEXTURE AND DRAINAGE OF NIAGARA PENINSULA SUB-APPELLATIONS The heterogeneity of texture and drainage is depicted in Figure 2.

Sub-Appellation	Soil Texture and Drainage
Niagara River	Mostly sandy loam with some silty loam; imperfect drainage
Four Mile Creek	Mix of clay loam and silty clay with some silty loam; poor drainage
Niagara Lakeshore	Sandy loam; imperfect drainage
St. David's Bench	Silty clay; well drainage
Creek Shores	A mix of sandy loam and silty clay; imperfect drainage, well near creeks
Short Hills Bench	A mix of silty loam and silty clay; good drainage
Vinemount Ridge	Silty clay; poor drainage
Twenty Mile Bench	Mix of clay loam and silty clay; well drainage
Beamsville Bench	Mix of clay loam and silty loam; well drainage
Lincoln Lakeshore	Mix of loams, silts, and clays; poor drainage

SOIL AND WATER RETENTION

An important component of the terroir's effect on wine is the amount of water supplied to vines, and how it is applied. The climate determines how much water that vines receive from precipitation, and both the topography and the soil's properties dictate how fast it flows to or away from the roots. For that reason, it is very useful to consider how the properties of a vineyard's soil affect the water supplied to the plants, and therefore the quality and yield of wine. It is important to note that good-quality grapes can be produced in a very wide range of soils. However, it is not possible to say that certain types of soil are better than others for growing vines, or assume a specific region would be good for wine-growing based on the type of soils it contains (Van Leeuwen and Seguin, 2006). However, it is possible to look at regions that are performing particularly well or poorly, and determine why this is based on their soils. The best soils consistently provide a moderate amount of water; too much or too little decreases the quality of wine.

It is useful to consider why some soils are considered good for viticulture. In the Grand Crus Classés of the High-Medoc in France, the gravel-sand soil is very permeable, allowing for deep roots to form, which can penetrate the water table up until August, just before grape maturation. These soils makes deeply-rooted grapevines resistant to both drought and heavy rainfall. During drought, plants can easily access the water table, while excess water from heavy rainfall quickly evacuates, avoiding an excess water supply (Seguin, 1986).

At the same time, clayey soils can also provide protection against heavy rainfall, but in different ways. When young vines are planted in clayey soils, some of their growing radicles die, since the clay, being non-porous, does not have space for oxygen for them to grow. For that reason, the high water content of the soil is tolerated, since there are fewer roots to absorb the water, resulting in an acceptable water supply to vines. During heavy rain, the clay swells and becomes less permeable, limiting the water that makes it to the roots and avoiding the effects of excessive water supply; the rest runs off at the surface (Seguin, 1986).

Now, what circumstances are bad for vines? Outside of the normal detriments and benefits of water supply to vines, waterlogging, which can occur when vines grow in soil with poor drainage (Van Leeuwen and Seguin, 2006). When sandy loam, or some relatively permeable soil in the soil's top layer, where roots grow, sits on top of a layer of less permeable sandy clay, water accumulates at the interface between horizons the layers, since water from rainfall can't drain vertically through it. This leads to waterlogging (Cox and McFarlane, 1995). When roots are waterlogged, they can't absorb oxygen, and their roots decompose. These examples illustrate how specific types of soils cannot be labelled as beneficial or detrimental on their own. However, it *is* possible to study cases of good and bad soils, and use the information gained to predict how similar sets of soils might handle water elsewhere, and ultimately inform our decisions on whether, or how, to irrigate.

Waterlogging: the saturation of soil with water, which can result in consequences such as root rot

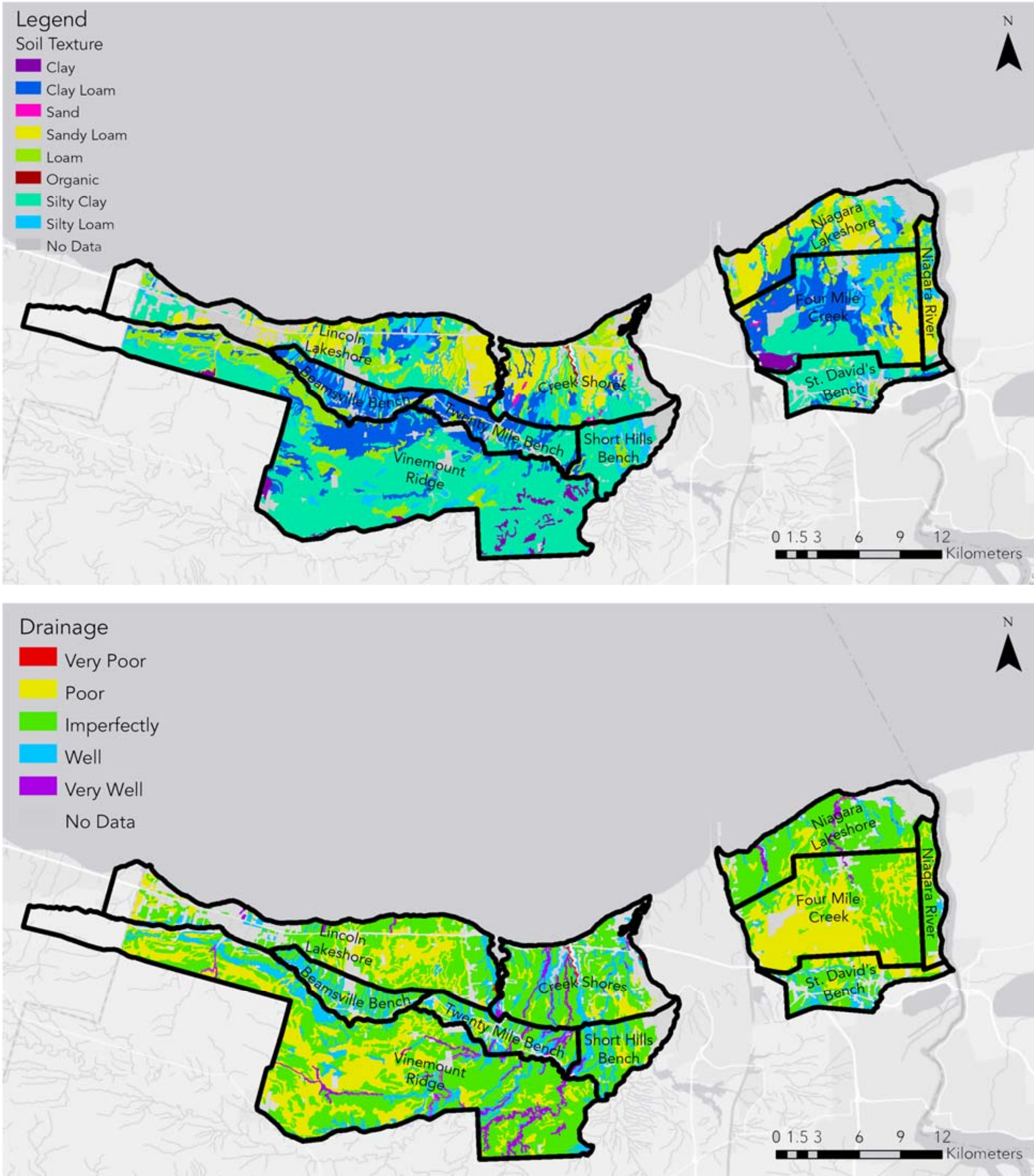

FIGURE 2: THE 10 SUB-APPELLATIONS OF THE NIAGARA PENINSULA COLOUR CODED WITH THEIR RESPECTIVE HETEROGENOUS SOIL COMPOSITIONS (TOP) AND DRAINAGE QUALITIES (BOTTOM) USING GIS. The 10 sub-appellation of the Niagara Peninsula are largely heterogenous due to its formation by glacial degradation. The various colours represent the different soil compositions and drainage qualities, which although have large variations within small regions, result in unique microclimates and mesoclimates (ArcGISPro 1.1.3; Agriculture and Agri-Food Canada, 1990; VQA Ontario, 2016a).

TYPES OF IRRIGATION

DEFICIT IRRIGATION

Deficit irrigation is the art of balancing sustained grape quality while utilizing less water than full crop water requirements. Mainly, it means keeping the water level above the permanent wilting point of vines, but still below field capacity (Reynolds et al. 2007). There are many benefits when considering deficit irrigation, such as it being a more sustainable practice, which would shine a favorable light on the vineyard in terms of consumer outlook. There is also the more practical aspect of the decreasing availability of water that can be used for irrigation in certain drought-prone locations, such as California (Keller 2005).

The biggest factor may be that deficit irrigation, or depriving the plant of the full amount of water it needs to flourish, is actually beneficial in producing high quality grapes, contrary to what some may believe. The reason is that excessive water can lead to a denser canopy, which would partially block the light that is available to the grapes, negatively affecting the sugar, anthocyanin, and phenol content (Santos et al. 2003). Moreover, a denser canopy would also negatively affect air circulation around the grapes, which may promote more disease to the crop (Santos et al. 2003).

On the other hand, when the grapevine undergoes moderated mild to moderate water stress, the berries retain better color, sugar content, and acidity balance than when watered in excess. Berries that ripen while under water deficits have relatively more skin, which is where flavonols and anthocyanins are largely synthesized. These compounds have a large effect on the color and taste of wines, especially red wine (Castellarin et al. 2007).

There are many different ways that grape vines can be irrigated. One of the most widespread methods is simply called regulated deficit irrigation, or RDI. RDI is when the water deficit is timed to occur during a part of the growing season. Grapes are categorized to have two growth phases, with a lag phase in between. The transition from the lag phase to the second growing phase is called veraison, and is considered to be when the grapes ripen and sugars accumulate (Castellarin et al. 2007). Winegrowers have a choice then when deciding when to enact the deficit. Usually, it can be done pre-veraison or post-veraison, and which one is more beneficial is often up for debate. Pre-veraison deficits were found to have a greater effect on anthocyanin biosynthesis by some researchers, who discovered that having the early deficit up-regulated the biosynthesis of desired flavonoids. However, early deficit also seemed to have no effect on the ripening post-veraison (Castellarin et al. 2007). Pre-veraison deficit also works to reduce canopy density, bringing more benefits to the grapes (Keller 2005). Post-veraison deficits, when done moderately, have also been found to reduce berry size and improve the composition, but have also been found to potentially reduce desirable qualities (Keller 2005).

PARTIAL ROOTZONE DRYING

Another technique that exists is called partial rootzone dying, or PRD for short. PRD works by supplying one side of the vine with full irrigation, while the other side dries down, and then the sides are alternated. There is no encompassing procedure for the timing each side receives irrigation, and often depends on the soil drying rate and crop water requirement (Kang and Zhang, 2004). PRD maintains berry size and yield, but reduces canopy density significantly more than RDI as found in certain varietals (Santos et al 2003). Furthermore, some have found PRD to produce comparatively better berry quality than RDI in years of low rainfall and also easier to control vine growth, which would allow for a better canopy micro-climate (Santos et al. 2003). Also, PRD possibly encourages vines to increase root growth and depth, which could be useful in the dry season to reach water stored deeper in the soil (Santos et al. 2003). However, as the technique is newer, the installation and implementation costs may offset the benefits for vignerons (Santos et al. 2003).

VIGNERON: a person who cultivates wine grapes in a vineyard for the purpose of winemaking

FULL IRRIGATION

Another option when growing grapevines is to irrigate all the time. While the grapevines themselves grow quite well with a consistent, high volume water supply (the definition of high volume changing between different grape varietals), fully irrigating the vines all the time does not generally lead to a high quality product.
Grapevines receiving ample amounts of water will tend to produce larger berries (M.A. Matthews and V. Nuzzo, 2007), which is actually a bad thing for a number of different reasons. Firstly, larger berries tend to have lower sugar concentrations (M.A. Matthews and V. Nuzzo, 2007). The more sugar is in the grapes, the more money they are worth to the winemaker. Also, in Ontario, the VQA has a minimum sugar concentration (which differs between varietals) where wines made from grapes below this standard cannot be VQA certified (VQA Ontario, 2016b). Secondly, the increase in fruit size can start causing the skins on some of the grapes to split open (Barbetti, 1980) This splitting can be an easy entry for insects to eat the fruit, in addition to providing an easy entry point for diseases like bunch rot. Once one grape is infected, the rot can easily spread to other, healthy grapes in the cluster, then from that cluster to other clusters, and then to other grapevines, so it is important to have as few grapes become infected as possible. Also, split grapes are not used in winemaking and must be discarded.
Short term flooding causes distinctly different problems from a long term, large supply of water. Flooding lasting only a few days can cause partial or complete death of leaves, as well as (somewhat paradoxically) the drying out of the vine's shoots (Striegler et al., 1993). The effects here can be mitigated by using more flood resistant rootstocks, however these rootstocks tend to be less drought resistant (with drought resistant rootstocks being less resistant to flooding).
Another somewhat tangentially related issue is still water. Still water means water that is not flowing through the soil, but rather is retained by the soil. Still water in the soil is a problem because it can lead to the roots of the grapevines to rot and die (Hallenn et al., 2006). Often this rotting is due to a fungus. Still water can be caused by wet conditions (precipitation, flooding) mixed with poorly draining soil.

NO IRRIGATION

Some vineyards choose not to irrigate at all. Especially in the Niagara Peninsula where rain is not uncommon, having no irrigation system is a completely viable option. In areas like California (where there has been a drought since 2013 as of the time this was written), irrigation may be necessary in order for the vines to survive and produce fruit. In vineyards that choose not to irrigate, they are at the mercy of the weather. During years where there happens to be an insufficient amount of rain, trucks can be hired to come spray down the crops, though this is expensive to have to rely on. When there is a lot of rain, one could end up with the same effects as Full Irrigation as previously described above.

Therefore, having the equipment for irrigation already set up will allow for much better control of the amount of water the vines get. In addition, grapevines do not need a lot of water. In an experiment conducted on Cabernet Sauvignon, the best grapes were produced by grapevines that received little water, and absolutely no water after veraison (ripening) (Castellarin et al., 2007). Likewise, any vineyard, irrigated or not, could receive large amounts of rain and end up closer to one that was fully irrigated.

COST-BENEFIT ANALYSIS

One of the most important things to keep in mind for vignerons considering the different methods of irrigation is to know which methods will give them the greatest profit. Whether no irrigation, full irrigation, RDI, or PRD produces the best-quality grapes is an interesting scientific question, but grape quality for its own sake is likely not the goal of most vignerons. The cost of implementing each irrigation method must be weighed against the increased revenue resulting from higher-quality grapes. The impact of irrigation on the grape yield must be considered, too.

There has been research comparing the financial costs and benefits of different irrigation methods. However, it is important to note that the costs of irrigation will vary between terroirs with different amounts of rainfall and different degrees of soil drainage. A region with more precipitation will likely need less irrigation than one with less, reducing the cost of irrigation. However, with no research on the costs and benefits of irrigation specifically in the Niagara Peninsula, it is necessary to look at research from other regions and compare the similarities and differences.

A cost benefit analysis of vineyard irrigation was conducted in Southeastern Spain. The soil type was fine clay (a mix of 48% clay, 30% silt, and 22% sand), and the climate was semi-arid, with an average of 255mm of precipitation per year over the past nine years (García, Martínez-Cutillas and Romero, 2012). The soil is similar to a small part of the Four Mile Creek sub-appellation (Agriculture and Agro-Food Canada, 1990). If it was 12% sand, rather than 22%, it would be silty clay, which is the most common soil type in the Niagara Peninsula (Agriculture and Agro-Food Canada, 1990; Agriculture and Agro-food Canada, 2013). Their control group was constantly irrigated at 60% of the plants evapotranspiration rate. They found that decreasing water (either through further RDI or PRD) increased the grape quality, but when the lowered yield and added costs from doing RDI or PRD were factored in, all treatments made less money than the control. In any case, the precipitation in the region being examined is, on average, higher than that in the wine-growing areas in Niagara during drought (as evident in Figure 3). This would increase the need for irrigation in the Niagara Peninsula to more than that in the Southeast region of Spain examined by Garcia, Martinez-Cutillas, and Romero. Since they found that a sustained though mild deficit irrigation was the most economically viable, this should also transfer over to the Niagara Peninsula on average. As stated in the section "Niagara's Drought," many vineyards in Niagara do not irrigate at all, often citing cost as the factor. If Niagara enters a drought and that ceases to be an option, the cost of irrigation would likely not be high enough that the vineyards would cease to be profitable since. Compared to Southeast Spain, Niagara has less permeable soil and cheap water with the Great Lakes nearby, and the vineyards in Spain still turn a profit.

EVAPOTRANSPIRATION: the process by which water is transferred from the land to the atmosphere by soil evaporation and transpiration by plants

Of course, it is important to note that this is based on just one study. While there are many studies and documents analyzing up-front costs of irrigation, or the cost of just one type over time, there do not appear to be any others that compare between types in the context of grape-growing.

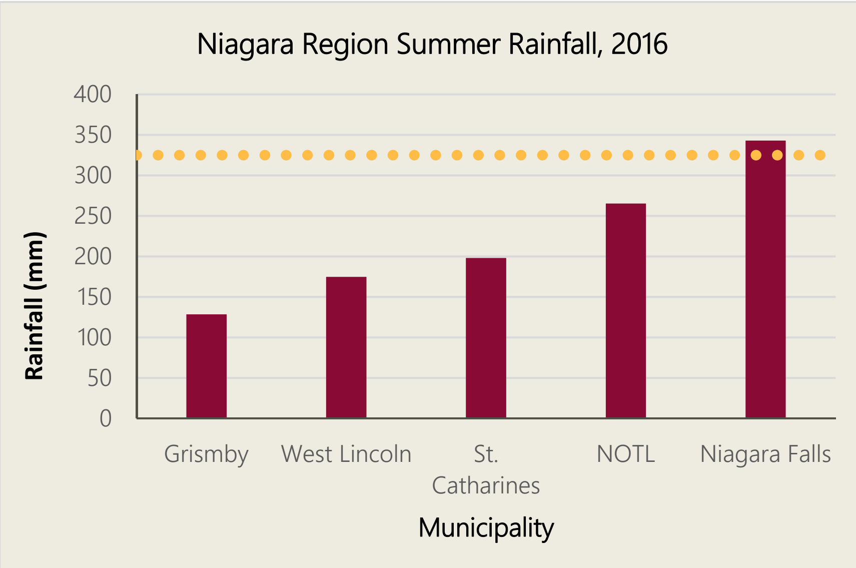

FIGURE 3: SUMMER 2016 TOTAL PRECIPITATION IN THE NIAGARA REGION, SEPARATED BY MUNICIPALITY. The historical average (mean summer rainfall between 1981-2010) of the five municipalities is indicated with a yellow dashed line. Grimsby, West Lincoln and St. Catharines had ~50% of the average rainfall, while Niagara-on-the-Lake had ~80% of the average. Niagara Falls was the only region to have above average rainfall (Niagara Region, 2016).

PAIRING IRRRIGATION WITH SUB-APPELLATION

To determine which irrigation system to use in each sub-appellation, soil texture (Figure 2A), soil drainage (Figure 2B) and local precipitation in Niagara Municipalities (Figure 3) were taken into concentrations. Table 2 summarizes the pairings devised.

TABLE 2: NIAGARA PENINSULA SUB-APPELLATION WITH CORRESPONDING IRRIGATION SYSTEM PAIRING. The pairings were determined using soil texture, soil drainage and local precipitation.

SUB-APPELLATION	IRRIGATION SYSTEM
Niagara River	No Irrigation
Four Mile Creek	No Irrigation
Niagara Lakeshore	RDI
St. David's Bench	No Irrigation
Creek Shores	RDI
Short Hills Bench	RDI
Vinemount Ridge	PRD
Twenty Mile Bench	RDI
Beamsville Bench	RDI
Lincoln Lakeshore	PRD

Overall, it is evident that a severe drought attacked the Niagara Peninsula in the summer of 2016. Since Niagara has many macro and mesoclimates, the drought affected different municipalities in different ways. Grimsby, West Lincoln and St. Catharines all had around half of the historical average in total summer rainfall. Niagara-on-the-Lake (NOTL) and Niagara Falls were not as affected by the drought as the Western Niagara municipalities. NOTL received only 20% less than the average, while Niagara Falls had above average rainfall. The distribution over the summer months is similar in all five municipalities, with most rainfall occurring in late August to September. The Eastern Niagara municipalities, especially Niagara Falls had fair amounts of rain in June and July, compared to the other area.

In general, Eastern Niagara sub-appellations were blessed with more rainfall, and therefore do not require irrigation. Additionally, the poor drainage of these area make them a poor candidate for irrigation. The only exception is Niagara Lakeshore– with sandy loam and imperfect drainage, the area could utilize RDI supplement the minimal June/July Rainfall.

With lower precipitation, Western Niagara would experience more benefit with irrigation. Economically, deficit irrigation systems are more beneficial; full irrigation is therefore not recommended for any area. The two sub-appellations within St. Catharines, Creek Shores and Short Hills Bench, have similar silty loam/clay soils. With generally well drainage, these two areas could utilize RDI to supplement the minimal rainfall. The soils of Twenty Mile Bench have slightly more clay content than the St. Catharines areas, but have similar drainage and could also benefit from RDI. The other West Lincoln region, Vinemount Ridge consists of silty clay with poor and imperfect drainage. Therefore, this sub-appellation would benefit from PRD, as it would prevent the formation of stillwater. The Grimsby municipality, consisting of the Lincoln Lakeshore and Beamsville Bench sub-appellations, experienced the lowest rainfall of the entire Niagara Peninsula. Both regions have similar silt, loam and clay mixes in the soils, but have differences in drainage. Beamsville Bench's imperfect and well drainage could handle RDI, while the poor drainage of Lincoln Lakeshore would better benefit for PRD.

CONCLUSION

To provide a single, firm answer to the question "*to irrigate or not to irrigate?"* is virtually impossible. The Niagara region is a mosaic of different climates, soil textures, and drainage; therefore, no one system will work the best. Even within sub-appellations there are differences in the soils. Individual vignerons notice different *terroirs* within a single winery, thanks to the Niagara Peninsula's microclimates (Roman, 2016). Suggestions given are based on the drought of 2016. To implement an irrigation system, one should examine more than a single season, in order to determine the best solution. As no one winery is the same, it can be said the irrigation is the choice of the grower–they must weigh the pros and cons of a system to determine if it works for their needs.

MORE TO EXPLORE

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