Terroir

An Integrated Wine Science Publication

WHAT WOMEN WANT

an emerging consumer niche

GRAPE EXPECTATIONS

warm sunny days ahead

THE THIRSTY VINE

effective water management

NOBLE INTENTIONS

running hot or cold

ICE ICE BABY

projecting change to a delicacy

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Terroir

An Integrated Wine Science Publication

Established 2013

Terroir is published by Integrated Science at McMaster University as part of the ISCI 3A12 Wine Science Project, with management by: Dr. Carolyn Eyles and Russ Ellis

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

WINE SCIENCE

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

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

This Publication is written by members of the ISCI 3A12 class of 2015

Cover Image: Bar Wines–from red wines to white wines. Alex Brown. Uploaded to Commons on 17 June 2010. Table of Contents Image: Wine barrels in Napa Valley, California. Aaron Logan. Uploaded to Commons on 13 November 2004.

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EDITOR: Russ Ellis

BOTTLE OF THE SEXES

Girls Just Wanna Have Wine

Meena Al-Saigh, Evangeline Clark-Lepard, Dakota Binkey, Miriam Krzyzewska, & Angelico Obille, a leading group specializing in integrated wine sciences (iWine), have disclosed their findings from a meta-analytical study of womens' perceptions and purchasing behaviours towards wine in westernized regions.

As a cultural marker for privilege and power, wine has retained a symbolic role in society since early civilization (Charters 2006). Historical evidence suggests that traces of wine have been discovered in clay vessels dating back to 6000 BC in what is now known as Iran. Iran is believed to have been the original home of wine before spreading to the rest of the ancient world. As wine became more prevalent in different regions, the possession of wine held less of a symbolic meaning; instead, wine quality became the new marker of status. During this period, it was important to distinguish between "better" and "worse" wine in order to signify the position of leadership. However, wine culture has evolved drastically since then; there has been a significant shift in the social roles played by men and women. Although wine continues to act as a status symbol in the modern world, an individual's access to the highest quality wine is no longer accorded by birth or land ownership. Instead, an individual's achievement is perceived as the chief criterion for status.

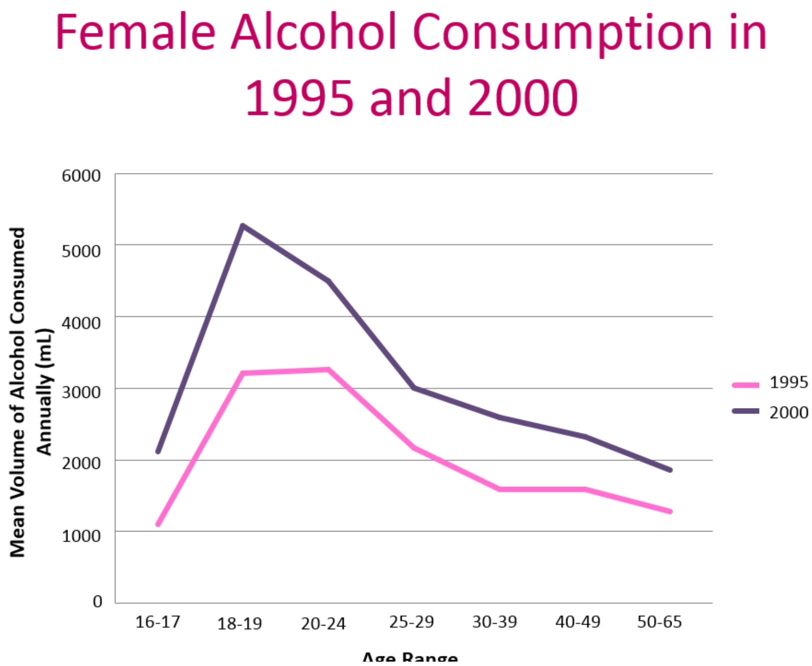

FIGURE 1: A depiction of the increase in alcohol consumption by females in Australia. Note the large peak observed in 'transitioning aged' females (McPherson et al., 2003).

During the late twentieth century, there had been remarkable advancement in the social, economic, and educational standing of women in Western culture (Inglehart and Norris 2003). Extensive amounts of research in social psychology have documented the transition of women's role in society from domestic caregivers to paid employees in the workforce (Inglehart and Norris 2003; Kohen 1981). The increasing convergence of gender roles left a powerful impact on women's lives, initiating progress and presenting them with new opportunities. As women began to embrace these opportunities to attain education and employment, they started to redefine their personal goals and domestic relationships. In the process, many aspects of a women's lifestyle have changed, such as delayed age of marriage, decreased fertility, and independent financial support (Kohen 1981).

In addition to these lifestyle changes, there has been a clear modification in women's drinking behaviors as well. Extensive research has supported the notion that more women are indulging in alcoholic beverages, specifically in the case of wine (McPherson, Casswell and Pledger 2004; Atkin, Nowak and Garcia 2007). As a result, wine consumption widened in Western culture, specifically within Australia, New Zealand, the United Kingdom, and North America. This created a greater need to establish new distinguishable factors that can display one's knowledge and ability to purchase good quality wine. Among these factors are the visual advertisements on wine bottles that convey the wine's sensory qualities (Atkin, Nowak and Garcia 2007). Studying these factors are particularly important to understanding how wine can facilitate social differentiation in modern society (Charters 2006). By noticing women's change in drinking behaviors and the importance of extrinsic cues on wine bottles, wine producers and marketers have recognized the significant contribution of female consumers on wine sales. Therefore, in the current consumer-driven economy, wine marketers are constantly on the hunt for new effective ways to market their products, increase their sales, and enhance customer loyalty (Barber 2009).

WOMENS' WINE CONSUMPTION

As wine gradually transitions into being a beverage frequently consumed by those in Westernized nations, the following prominent trend has been noticed among Westernized nations: women are buying more wine now than ever before (Atkin, Nowak and Garcia 2007; McPherson, Casswell and Pledger 2004). This trend can be attributed to the "gender convergence theory", which has gained widespread support in the past few decades. The gender convergence theory suggests that women's alcohol consumption is converging to mirror those of men's, as the line between the ascribed roles of men and women in society become increasingly blurred. A study conducted by McPherson, Casswell, and Pledger published in 2004 confirms that between 1995 and 2000, women have converged to consume almost equal amounts of alcohol at similar frequencies to that of men. This trend has been consistent across Westernized nations for many consecutive years (Atkin, Nowak and Garcia 2007; McPherson, Casswell and Pledger 2004). For instance, in the United States of America,

women are responsible for 80% of wine purchases and represent 60% of the individuals who consume wine more than once a week (Atkin, Nowak and Garcia 2007). Thus, women are prevalent consumers of wine in the modern market, and this leaves marketers with the question "What do women want?"(Forbes et al. 2010).

In addition, it has been argued that the difference between male and female alcohol consumption could be related to biological differences that pertain only to women, such as motherhood and lower alcohol metabolism or due to a shift in societal pressures (Wilsnack et al. 2000; McPherson, Casswell and Pledger 2004). If the convergence patterns outlined in the above studies are due to societal changes and not biological differences, convergence should first be observed in younger age groups since these populations are the most immersed in modern culture. McPherson, Casswell, and Pledger demonstrated that convergence was mostly present in those aged 20 - 30 (McPherson, Casswell and Pledger 2004). In addition to many other studies, these results suggested that convergence was due to societal changes and not biological differences between men and women (Wilsnack et al. 2000; McPherson, Casswell and Pledger 2004).

TARGETING WOMEN

The Canadian wine market remains an enigma among the complex global wine market. It consists of 13 autonomous provincial monopolies, each with its own principles formulated by an independent Liquor Control Board (LCB). Each provincial LCB regulates the import and distribution of wine within its jurisdiction, with exception to Alberta (Bruwer et al. 2012). This fact alone demonstrates the complexity of the Canadian wine market, and it is evident that essential local market knowledge is vital for success within the wine market in Canada. The wine industry is at a stage where simply producing a good product is insufficient to stimulate growth and produce long term success (Atkin et al. 2007). Opportunities exist for niche marketed wine brands targeted at specific demographics. Segmentation is a vital marketing tool consisting of categorizing consumers, ultimately enabling marketing managers to target the future consumers of their products more precisely and effectively (Charters 2006). Segmentation primarily integrates demographics, psychographics (the emotional attachment and attitudinal characteristics of the consumer) and purchase behaviour (such as price) in order to fragment potential markets on the basis of generic differences between consumers. One such segmentation that is prevalent in the Canadian wine market targets a strictly female audience. Marketing wine to women is not as simple as incorporating "frilly" labels, sweet aromas or pleasant label colour schemes, but requires the integration of wine into particular lifestyles (Bruwer et al. 2012).

When choosing a wine to purchase it only takes 5 minutes and 40 seconds for a consumer of either gender to decide (Webb 2015). This is relatively quick as it typically takes consumers an average of 10 minutes and 8 seconds to decide on a new article of clothing or outfit. Wine consumers with limited knowledge of terroir and subtle wine flavours are often unable to conceptualize common flavour descriptions such as "flowery" or "leathery", let alone taste them. As such, it is not surprising that when individuals state the most important factors that influence their purchase, flavours or flavour descriptions are not among the few. What remains are the "heritage and pedigree, stylistic consistency, quality and commitments, relationship to place, method of production, [and] downplaying of commercial motives" (Thomas 2008). Women place a higher value on wine packaging and label design, while men value information about grape type and terroir (Barber, Almanza and Donovan 2006; Ramsak 2015).

Characteristics that inform the consumer on their purchasing decision without containing any details on the chemical and flavour contents of the wine are called extrinsic cues, while those that do are named intrinsic cues. The function of extrinsic cues can be explained by the attribution theory. The attribution theory states that the consumer evaluates a product based on visible information so they can infer further about the product (Heslop, Cray and Armenakyan 2010). The function of extrinsic cues can be explained by the attribution theory. The attribution theory states that the consumer evaluates a product based on visible information so they can infer further information about the product (Heslop, Cray and Armenakyan 2010). When purchasing a bottle of wine, a multitude of extrinsic cues are taken into consideration due to the absence of the opportunity for consumers to engage in the sensory experience aspect of the product (Bruwer et al. 2012). Extrinsic cues may be used as a proxy for quality. Considering female information search behaviours and their preferences for extrinsic cues will assist to understand the complex underlying tactics in the seemingly oversimplified wine market targeting women.

Such extrinsic clues include gendered marketing and design, closure, the presence of a signature or photo, and the information on the back label. Despite the common appeal of alcohol to both genders, alcoholic beverages, including wine, are often associated with gender, especially in Canada (Bruwer, Lesschaeve and Campbell 2012; Barber, Almanza and Donovan 2006). Wine is associated with femininity, and as such can be marketed to play up this societal concept. When this gendered marketing is employed, individuals with stronger feminine identities gravitate to those beverages (Barber, Almanza and Donovan 2006). In terms of the physical aspects of the bottle, women perceive closure as an indicator of quality (Barber, Almanza and Donovan 2006). Screw-top closures are valued as lower quality, while a wax seal is associated with freshness and foil is associated with quality (Barber, Almanza and Donovan 2006).

Similarly to how an artist signs a work of art with their signature, the presence of a winemaker's signature on a label is perceived as a cue of authenticity and high quality (Mantonakis et al. 2013). Furthermore, a signature formulates a sense of identity, and the presence allows the consumer to feel emotionally connected to the winemaker, and consequently the wine. Other subtle influences have an impact on consumers, such as a picture on a label. Women rely on the presence of a photograph more so than their male counterparts for information processing and in decisions regarding wine purchases (Barber, Almanza and Donovan 2006). Photos increase a consumer's conceptual fluency; the relative ease or difficulty of bringing to mind associations (Mantonakis et al. 2013). Accordingly, photo presence provides the consumer with familiarity, and a false sense of confidence in knowledge of the product. The lack of a photograph creates disfluency and does not promote familiarity when processing ideas and judgements about the wine.

More women than men, read and rely on the back labels of wine to choose a product (Barber, Almanza and Donovan 2006; Barber and Almanza 2006). They also desire more data on wine and food pairings (Ramsak, 2015; (Barber, Almanza and Donovan 2006). Specifically, women under 30 or women earning over $50,000 annually are more likely to choose a wine based on pairing information. However, women are also more likely to be confused by the back labels of wine and as such value clarity and readability. Very few common products are described with a unique vocabulary specific to the industry. Winemakers, enologists (scientists who study wine and wine making processes), and even amateurs have designed a wine vocabulary used to describe its sensory properties. However, this method of classification is subjective. Many efforts have been made to incorporate scientific characterization by means of gas chromatography and other various chemical techniques (Brochet and Dubourdieu 2001, Muñoz-González et al. 2011). However, these methods remain inadequate. The taste of a molecule, or a blend of molecules is constructed within the brain of an individual. Taste is a complex experience composed of recognition of diverse properties integrated by multiple aspects of the sensory faculties of a taster. As such, the language used on the back of wine labels often does not reflect the consumers' tasting experiences and is unrelatable to the average consumer who is unable to decode the wine jargon. To minimize confusion, women prefer simple information about how dry or sweet the wine is, information about the grape varietal and food pairing options (Barber, Almanza and Donovan 2006).

Consuming wine is an intricate experience that is associated with pleasure (Fountain & Fish 2010). Pleasure encoding in the brain is an evolutionarily beneficial mechanism. Pleasure assists in determining to repeat or avoid future activities. However, the brain is a noisy environment, and struggles to decipher between the various stimuli affecting an experience. To improve its ability to perceive pleasure, the brain pieces together cues from different areas to create one coherent sense of pleasure (Veale 2008). Such factors when consuming wine include, but are not limited to, the aforementioned extrinsic cues such as signature, picture, cost, etc. For example, in many studies, people believe that the price and quality of a wine are correlated. As such, it is only natural for the brain to factor price into the evaluation of a wine's taste. Similarly, the presence of a signature, a photograph or varying closures affect the perception of the pleasure experienced while consuming a wine. Due to the fact that women value these extrinsic cues more so than males, we speculate that females are more susceptible to subconsciously factoring these attributes into their experiences.

Females tend to purchase a higher priced wine per bottle, which is often interpreted as a risk-reduction strategy (RRS) (Bruwer et al. 2012). It is evident that certain wine consumption situations require an element in the decision process that involves risk-aversion strategies (Atkin et al. 2007). Studies propose that purchasing wine primarily involves functional risks. Such risks include social risks (may involve trying to avoid being embarrassed in front of business associates and friends), financial risks (involve the cost of wine), and physical risks (the actual effects of alcohol consumption) (Atkin et al. 2007). Furthermore, females report purchasing more award winning wines than their male counterparts (Forbes 2012), which may also be interpreted as an RSS.

When engaging with wine, females bring significant sensory preferences and behavioural differences as opposed to males. The sensory aspects, particularly the olfactory component of wine is an integral part of total product experience when consuming wine (Bruwer et al. 2011). Females have stronger taste and olfactory senses than males, and are capable of distinguishing 20% more scents than males (Bruwer et al. 2012). As such, females have a greater capacity to sense subtleties in wine that their male counterparts neglect to observe. Naturally then, women prefer wines with more subtle acidity and lower tannin content, as tannin astringency and associated mouthfeel are generally considered off-putting. This provides females with more characteristics to consider when deciding on their loyalty to a wine. This is a strong factor which dictates their subsequent behaviour, in other words, whether or not they will make a repeated purchase of a particular wine. As such, wines marketed towards females are subconsciously scrutinized more so than varieties of wines targeted to other consumers. However, these preferences appear to diminish with time (Bruwer et al. 2012). Young females report a preference for sweeter wine styles, although the preference declines as age increases (Bruwer et al. 2011). To be precise, females report a preference for white wine between the ages of 18 – 34, gradually changing as they reach the ages 34 – 54 when they tend to prefer red wines.

Furthermore, it is evident that the same amount of alcohol is metabolized differently among male and female subjects. Females claim experiencing hangovers more quickly and severely than their male counterparts after identical alcohol intakes. Biologically, females have a higher amount of body fat and lower water activity in comparison to men (Diaz-Insa et al. 2013). When metabolized, alcohol is distributed through body water, and women are left with more alcohol in their bloodstream. Therefore wine that is strategically marketed towards women will often times have a lower alcohol content so that they may enjoy sipping at their drink throughout the night without having to worry about a hang over the next morning.

IN YOUR BACKYARD: GIRLS' NIGHT OUT

Girls' Night Out is a series of wines released in 2008 by Colio Estate Wineries which is located at the southernmost point of Ontario. In addition to this series of wines, Colio Estate produces other company brands including their name brand red and whites, St. Tropez, Lake and River, and Bricklayer. They also produce a couple of single brand names, namely their Hat Trick Red and Lily Sparkling. Although each wine is produced from the same location by the same winemaker, each of the series from this estate have their own targeted customers and specialized marketing strategies. Girls' Night Out in particular explicitly uses the marketing research discussed earlier in their marketing strategies to lure their targeted consumers: women living in 21st century North America.

Furthermore, Colio Estate uses the concept of Girls' Night Out by extensively publicizing their wines in pop culture magazines such as Flare and Elle. In these pages, the wine is displayed as an essential component to a woman's social lifestyle. Girls' Night Out wines can be considered transitional wines, as they contain higher amounts of sugar, similar to sweeter beverages younger women tend to consume (A Jackson 2015, pers. comm., October 3, 2015). This wine can hook young female customers into wine drinking as they mature they are likely to purchase more traditional wines produced and consumed in the wine industry (for example, the other wine series produced by Colio Estate). This marketing technique can ensure female consumers will continue to drink wine as they grow older, which in the long term increase the amount of wine consumers in the region. This technique is exemplified in three of the Girls' Night Out wines: Sangria, Sparkling, and Chardonnay.

Sangria is the first transitional beverage branded by Girls' Night Out. This can be considered an entry wine to introduce young women to the wine-drinking industry. With a relatively low alcohol content of 6.5%, light carbonation and a relatively high sugar code, reminiscent of pop drinks, this beverage appeals to a more youthful group of people (Ogden et al., 2011). The sugar code is a numeric code that liquor vendors use to describe the sweetness of the beverage, with 0 being the least sweet (dry) and 5+ being very sweet (LCBO 2015). These intrinsic factors target a younger audience who still have sensitive palates unaccustomed to the bitterness of the traditional wines on the market.

"If only a man could be as captivating as this Spanish-inspired Sangria."

With the transparent glass showcasing the bright red colour of the drink and an image of an extravagantly coloured dress, the flamboyant presentation of the Sangria quickly catches the attention of women who are looking for a drink to accompany their party-life attitudes (Garcia et al., 2013). There is an increase in hook-up culture in 21st century Westernized societies, Girls' Night Out's description of the Sangria captivates this exact demographic by saying,

"If only a man could be as dependable as this shimming sensation. A crisp VQA sparkling wine that's elegant and bubbly – just like you!"

Sparkling wine is a transitional wine between the entry Sangria brand and more traditional wines such as Chardonnay and Pinot Grigio-Riesling. While still retaining the slight carbonation, this wine appeals to a more mature audience, transitioning away from the party attitude of the women to a classier "night out". The extrinsic factors such as the image of an elegant dress subtly tinted with sparkling colours, the tin foil covering the screw top, and the use of jewels to decorate the bottle, all demonstrate the shift in strategic marketing to appeal to a targeted group of people who would enjoy the Sparkling wine. Although the wine is more of a traditional alcoholic beverage, with a shift in intrinsic factors (such as an increased alcohol content of 11.5% and a lower sugar code value of 2) the careful presentation of the bottle keeps the youthful, yet mature, persona that is an excellent strategy to transition younger women to the general wine industry.

Lastly, Chardonnay can be considered the end of this transition. This wine appeals to middle-aged women who have established their womanhood in society. Girls' Night Out uses various marketing strategies to sell to this target audience such as the image of the little black dress. This image increases the conceptual fluency of the consumer by increasing their familiarity and a false sense of confidence in knowledge of the product.

It also appeals to the consumers' feminine identity, thus women with stronger feminine identities gravitate to the product. The back label also refer to the consumer's identity by mentioning the consumers' role as a sister, daughter and friend. This emphasizes her womanhood instead of her role as a party girl, as in other Girls' Night Out wines. In addition, Girls' Night Out Chardonnay has a screw top closure, which is more popular among women. Furthermore, it is a white wine that has the standard alcohol content for wine (12.7%), which is more than that of the transition wines and thus is a wine that is tailored to those with an acquired taste to the bitterness of stronger alcoholic beverages, which is indicative of an older target audience. Lastly, the description of their Chardonnay refers to "unleash[ing] your inner Jackie O.", the first lady of the United States in the early 1960's, who is iconic for her classy image. This older reference also indicates that the wine is targeted at an older audience. Finally, the Chardonnay is featured on the Girls' Night Out website with six awards as well as various mentions in local papers. As previously mentioned, women use awards as a risk-reduction strategy.

"This dress pairs well with everything! Wear this classy number with strappy stilettos or unleash your inner Jackie O. by donning a simple strand of pearls and oversized sunglasses."

In conclusion, as women's roles in Westernized societies have shifted to allow them to become valuable consumers in the wine industry, so have the research conducted by marketing psychologists and sociologists. Using this research, companies such as Girls' Night Out from Southern Ontario have employed many effective marketing strategies to fill this niche of female consumers of alcohol.

MORE TO EXPLORE

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Picture Credits

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Effects of Sunlight and Temperature on Grape Berries at Various Growth Stages

Alex Dhaliwal, Biran Falk-Dotan, Lucia Krivankova-Smal, James Lai, Supriya Singh

INTRODUCTION

The history of wine is as long and varied as the history of science itself. Although its roots lie in cultural and familial practices, modern viticulture and oenology are deeply scientific practices. The interplay between environment, agriculture, and wine quality has been explored with scientific rigour over the past century, refining the tactics that have been used to produce some of the highest quality yields in history.

Wine is made by fermenting grapes, most often the fruit of *Vitis vinifera* (Teixeira, et al., 2013). The final chemical composition of the wine is influenced by a variety of factors, but of prime importance is the chemical content of the harvested grapes (Kontoudakis, et al., 2011).

The chemical composition of grapes is affected by the soil and climate in which the grapes are grown (cumulatively known as *terroir*), as well as agricultural practices, such as irrigation and leaf removal. The influences of these factors also differ according to the growth phase of the grapevine (Jones and Davis, 2000). Of the chemical components in grapes, sugars and acids are two of the most common indicators of quality (Jones and Davis, 2000). Due to their importance to grape quality, it is important for viticulturists to understand the effects of factors like sunlight and temperature on the grapes' sugar and acid content,

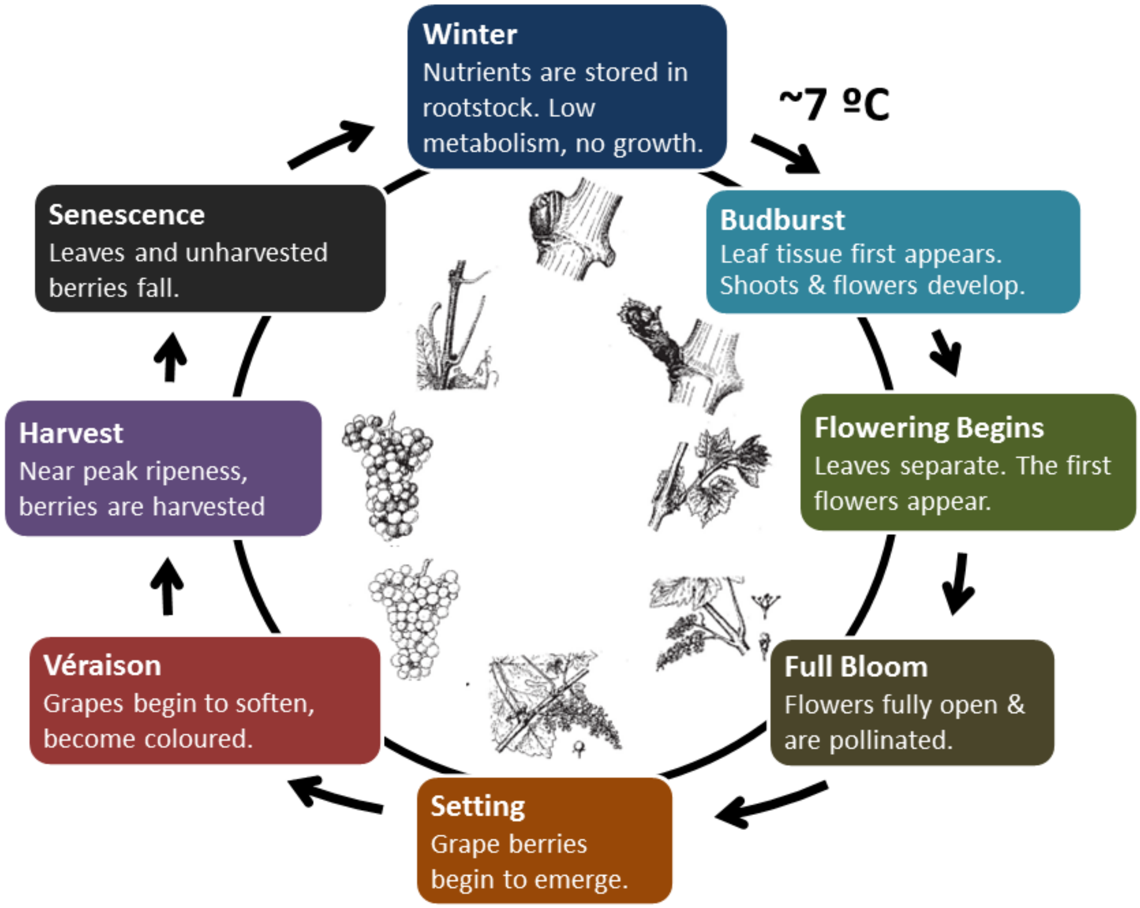

FIGURE 1: STAGES OF GRAPEVINE DEVELOPMENT. The typical annual growth cycle of a grapevine (adapted from Coombe, 1995). Each stage is accompanied by an illustration from Baillod and Baggiolini (1993).

including how these effects differ with growth stage. The growth cycle of the grapevine is summarized in Figure 1.

STAGES OF GROWTH & DEVELOPMENT

In winter, the buds are dormant. The grapevine protects itself from damage and conserves resources by shedding its leaves and slowing its metabolism. **Budburst**, the period in which buds begin to grow, is marked by the appearance of leaf tissue, facilitated by carbohydrates from the rootstock. Budburst occurs when the temperature exceeds approximately 7°C and is shorter in regions with harsher winters (Dokoozlian, 1999).

Between 40 and 80 days after budburst, the first flowers appear. By this time, leaves have already begun to separate and are photosynthesizing to accelerate plant growth. Flowers reach full bloom within a week or two of appearing (Coombe, 1995), at which time they are pollinated by insects.

When pollination ends (May in the Northern Hemisphere), **fruit set** begins, and fertilized berries start to grow. After completing most of their growth, berries enter **véraison**, the time at which they begin to soften and produce colour compounds. In red grapes, this includes the production of anthocyanins, which are responsible for the dark red colour (Coombe, 1995).

Grapes are normally harvested near peak ripeness (typically September or October in the Northern Hemisphere). As temperatures decrease and daylight hours shorten, berries begin to **senesce** (age and deteriorate). Valuable resources such as sugar are withdrawn from the berries to be stored in the rootstock, after which the berries fall and the grapevine returns to its winter state.

SUGAR & ACID IN GRAPES

The sugars in grapes are the substrate required by yeast for alcoholic fermentation during winemaking (Jackson, 2014). While most of the sugar is converted to alcohol, some residual sugar remains, and it may affect the wine's taste (Berthels, et al., 2014). The monomers glucose and fructose can be readily metabolized by cells to release energy, but they can also be polymerized into the heterodimer sucrose, used by the plant for sugar transport (Keller, 2015). Grape berries accumulate sugar as they ripen to make the fruit attractive to animals, which can help disperse seeds (Downey, Dokoozlian and Krstic, 2006).

Grape berries also contain acid, primarily malic and tartaric acid (Conde, et al., 2007). Malic acid increases resistance to heavy metal toxicity and can also be involved in metabolic processes, among other functions (Sweetman, et al., 2009). Tartaric acid is associated with the processes of cell division and elongation (Winkler, et al., 1974).

In making wine, winemakers aim not to eliminate one of either acid or sugar, but to balance them (Vine, et al., 1997). Ideal ratios vary between wines: for example, a sugar:acid ratio of 20:1 has been suggested as ideal for icewines (Nurgel, Pickering and Inglis, 2004). Thus, grape growers must consider factors that can influence the sugar-acid balance in their grapes. Among these factors are temperature and insolation (the amount of sunlight received), which can be affected by climate, planting location and orientation, and agricultural practices such as trimming (Jackson and Lombard, 1993). Therefore, it is important to understand what effects these factors have in order to inform how best to grow the grapes to achieve an optimal sugar-acid balance.

STAGE BY STAGE

Sugar production and transport in *Vitis vinifera* are a carefully regulated balancing act between photosynthetic (source) tissues that can produce energy in the form of carbohydrates and heterotrophic (sink) tissues that require energy but do not produce it themselves. Grape berries are a prime example of sink organs. Sucrose, the carbohydrate most often used for transportation throughout the plant, is moved to grape berries in a process known as allocation, and it is converted to a usable form of energy in a process known as partitioning. These processes are highly liable to change with environmental factors such as temperature and sunlight, and their balance is a major determinant of the quality of the berries.

INFLORESCENCE

Biologically, grape berries are a sex organ used to disseminate the seeds of the plant. This process begins with inflorescence, during which flower clusters appear. After the flowers open their buds (anthesis), pollination may begin, wherein pollen is transferred from the anther (male sex organ) of the flower bud to the stigma (female sex organ). Traveling down the pollen tube of the stigma, fertilization occurs and the ova begin to develop into berries.

Although inflorescence and pollination occur before significant berry growth, environmental conditions during this time can have long-term consequences on berries. High temperatures, especially in excess of 32.5ºC, have a detrimental effect on berry growth. When such temperatures are experienced before inflorescence, the number of flowers per cluster is reduced (Petrie and Clingeleffer, 2005). After budburst, but before fruit set, the effect of high temperatures on flower number is less pronounced, but heat stress nonetheless decreases ovule fertility, final berry weight, and final berry size compared to samples grown at 25ºC. This may be due to reallocation of resources from grape berries to other areas of the plant, reducing the number of cells present within the fleshy tissues of the grape (Kliewer, 1977).

The effect of solar radiation during the inflorescence stage has a minor effect on overall grape development, with no significant effect on flower number. When examined alongside the effects of temperature using multiple linear regression, there is still no clear correlation between inflorescence radiation and grape growth (Petrie and Clingeleffer, 2005). However, significantly decreased irradiance (approximately 1/4 of typical values) between senescence and inflorescence can inhibit budburst and reduce overall grape yield (Hopping, 1977). Shading by excess foliage can easily cause these decreased levels of irradiance, so it is clear that environmental factors in the latter half of the growing season can have a great effect on overall yield.

Sugar and organic acid accumulation in grape berries is almost negligible during inflorescence. Instead, this period is an essential time for the grapevine to gather and store the nutrients that will be used in later stages of fruit development. Although viticulturists may focus on stages of berry development closer to harvest, it is important to remember that grape quality is dependent upon plant health, and this is greatly affected throughout all seasons.

"Although viticulturists may focus on stages of berry development closer to harvest, it is important to remember that grape quality is dependent upon plant health, and this is greatly affected throughout all seasons."

FRUIT SET & ENLARGEMENT

Grape berries are said to have entered fruit set once their diameter surpasses 1.6mm (Dokoozlian, 2000). As previously mentioned, this is characterized by a short period of cell division, followed by a longer period of cell enlargement. Cell division ends three weeks after anthesis; from this point on, the number of cells in the grape berry is constant (Conde et al., 2007). The grapes remain firm and photosynthetically active, using chlorophyll within their skin to produce small amounts of sugar to supplement the growing process. While sugar concentration does not increase appreciably during this stage of development, the concentration of organic acids increases to its maximum level towards the end of berry enlargement. These acids consist mainly of malic and tartaric acid, comprising 62-92% of all titratable acids within grape berries (Conde, et al., 2007).

Sunlight is very important during fruit set and berry enlargement. In fact, light is thought to be an activator of cell division and an inducer of cell expansion, likely through increased photosynthetic activity and energy partitioning (Raven, 2000). Dokoozlian and Kliewer (1996) showed that, compared to control berries, berries grown in the absence of sunlight during fruit set and enlargement had lower weights and diameters; higher concentrations of malic acid; and lower concentrations of glucose and fructose when measured eight weeks after fruit set. Sunlight exposure later during development did not reverse these effects. For this reason, practices such as early summer leaf removal that increase sunlight exposure of shaded berries are immensely popular in vineyards, as they have a significant impact on overall grape quality.

The effect of temperature during this stage of growth primarily concerns hydration. Berry enlargement requires water accumulation in the pericarp (flesh surrounding the seed) of the fruit. At high temperatures, grape leaves can experience significant water loss, and this can stunt berry growth and lead to cell dehydration and death (Hardie and Considine, 1976). However, a majority of modern vineyards have irrigation techniques that can be implemented in the event of an exceptionally hot growing season. Because this factor can be artificially monitored, most viticulturists that can afford irrigation prefer hotter and drier seasons of berry enlargement, as it allows their berries to reap the benefits of high solar radiation without the detriments of water deficits.

VERAISON & RIPENING

When grapes begin to soften and lose their green colour, they are said to have begun véraison, the first stage of berry ripening. As berries lose their photosynthetic capacity, they come to rely more upon energy stores within the plant to promote chemical change and growth within the berry. The loss of chlorophyll from the berries is accompanied by an increase in anthocyanins in red grapes or carotenoids in white grapes. These, alongside other polyphenolic compounds within the skin of the grape, contribute to the different flavour, colour, and odour characteristics of specific varietals (Teixiera, et al., 2013).

Transport of sucrose to grape berries is at a maximum during ripening. During this stage, berry sugar content can be as high as 1 M, with equal levels of fructose and glucose (Conde, et al., 2007). The main mechanism for achieving such high concentrations involves the action of invertases, enzymes that catalyze the hydrolysis of sucrose within the grape berry into simple sugars. This maintains the sucrose concentration gradient and prevents reuptake by the phloem, the structural network within the plant through which nutrients are transported.

In contrast, the concentration of organic acids declines during ripening. This is primarily due to dilution, as the berry continues to grow during ripening, but synthesis and intake of organic acids is stagnant. Additionally, berries contain enzymes that catabolize malic acid, such as malate dehydrogenase, into carbon dioxide and water,

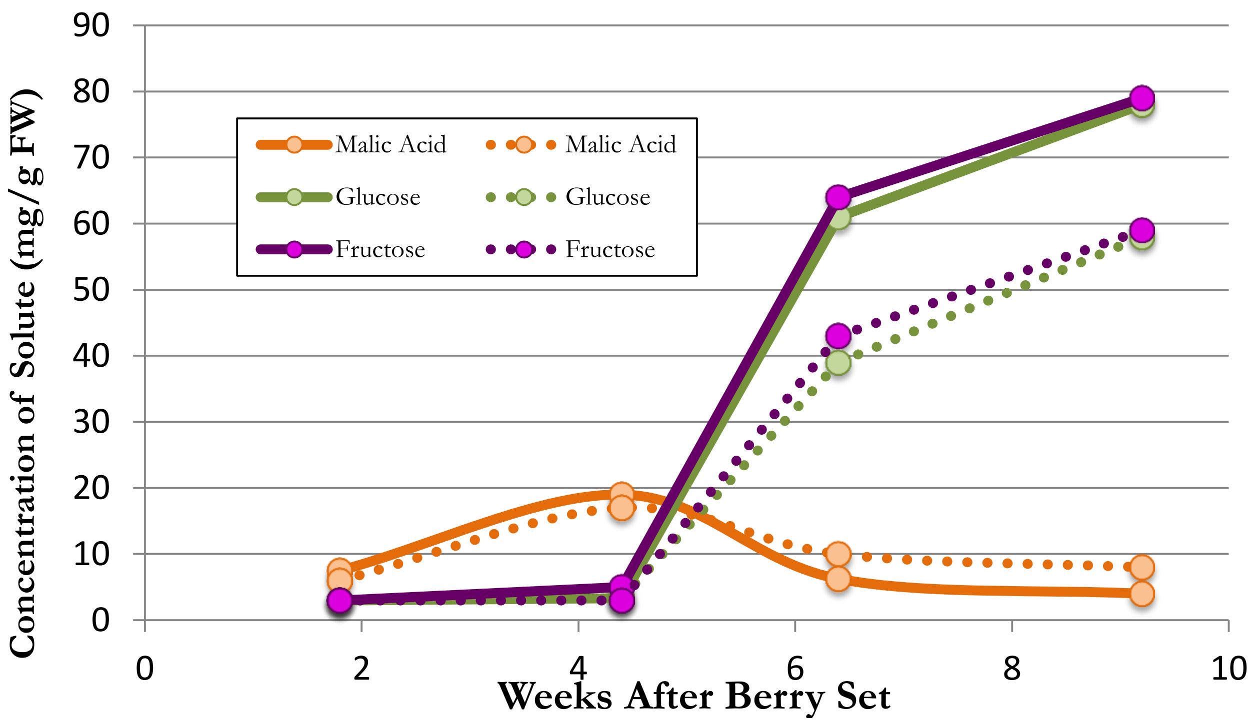

FIGURE 2: CONCENTRATIONS OF GLUCOSE, FRUCTOSE, AND MALIC ACID IN LIGHT-STARVED CONDITIONS THROUGHOUT GRAPE BERRY GROWTH. Dotted lines indicate solute concentration in plants that were grown in the absence of light, while solid lines represent the control group. Overall sugar accumulation in the grape berry significantly decreases when the berry clusters are deprived of sunlight. In constant, acid accumulation increases in these light-deprived conditions. As a result, berries with insufficient solar exposure have a reduced sugar:acid ratio. Adapted from Dokoozlian and Kliewer, 1996.

further decreasing titratable acidity as the ripening season progresses (Dokoozlian, 2000).

Solar radiation during véraison has a large impact on the sugar:acid ratio within ripening berries. Grape berries that are deprived of sunlight during ripening accumulate significantly less sugars than non-deprived berries. Interestingly, grape berries that are deprived of sunlight throughout flowering, fruit set, and berry enlargement but are illuminated from véraison onwards have initially lower concentrations of sugars, but increase to normal levels by harvest. Several mechanisms for the decreased concentration of sugars have been proposed, including an irreparable delay in véraison and decreased activity of invertases, which have been observed to display some photoregulatability (Dokoozlian and Kliewer, 1996; Kliewer and Smart, 1989).

Fruit exposed to light throughout the ripening phase have lower concentrations of malic acid than samples that have been deprived of light. Although control grapes have higher concentrations prior to véraison, malate levels decrease significantly during ripening. Because no photoregulated enzymes have been found that may increase malate metabolism during ripening, this change has been attributed to an altered fruit maturation rate (Dokoozlian and Kliewer, 1996). Tartaric acid concentrations and overall pH of juices obtained directly from harvested grapes seem to be insensitive to solar irradiation following the on set of ripening (Conde, et al., 2007).

Although solar irradiance can be beneficial, the negative effects of high temperatures can devastate grape and therefore wine quality. Temperatures beyond 40ºC during véraison can halt berry growth and sugar accumulation. This can be largely attributed to decreased photosynthetic activity in the plant at high temperatures, producing less sugar that can be allocated to berries, with the sugar being partitioned to the trunk, roots, and other central portions of the grapevine for storage (Greer and Weston, 2010).

Malic acid concentrations have been found to be negatively correlated with temperature. The catabolic rate of mitochondrial malate dehydrogenase increases up to 46ºC; as temperatures in wine growing regions rarely surpass this, the general trend of decreasing malate concentration with increasing temperature is consistent (Conde, et al., 2007). This means that moderately high temperatures in conjunction with high solar irradiance can significantly boost the sugar:acid ratio in berries by the time of harvest (Dokoozlian and Kliewer, 1996).

Harvest marks the end of the ripening period, and the decision to extend or stop berry ripening can affect the sugar:acid ratio. Sugar accumulation and malic acid metabolism continue throughout the

SPOTLIGHT: ICEWINE

The Niagara region is well-known for its icewines. Icewine is produced from grapes which are harvested after at least three consecutive days at ≤ -8ºC (Nurgel, Pickering and Inglis, 2004). The grape skins are frozen during pressing, and thus they retain much of the water with little of the sugar (since ice does not dissolve sugar well). Consequently, the grape juice is highly concentrated in sugar (up to 50% w/v), which applies additional strain on the yeast during fermentation. This causes the up-regulation of enzymes that convert acetaldehyde to acetic acid (Erasmus, van der Merwe and van Vuuren, 2003). Thus, icewines are both more sugary and more acidic than table wines.

Grapevines grown for icewine must be able to withstand temperatures below 0ºC for long periods of time, since they must be grown in cold regions. This niche is typically best-filled by white grapes, with Riesling and Vidal varietals being most common in icewines (Nurgel, Pickering and Inglis, 2004).

Because they require consistently cold weather while the grapes are still ripe, icewines can be produced in only a small number of regions in the world. Canada is the leading producer of icewine in the world, with Ontario icewine comprising 75% of Canadian icewine production (Cliff et al., 2002). Regions like Niagara can be ideal for icewine, as they receive plenty of heat and sunlight during the summer before cooling quickly to -8 ºC in the fall and winter. The heat and sunlight in summer help to concentrate sugar in the grapes, an effect that is magnified as the berries freeze in winter (Nurgel, Pickering and Inglis, 2004).

entirety of berry growth in the ripening stage. After this, irradiance and temperature will only affect berry quality if they strain the grapevine in such a way that nutrients are sourced from the berries to supplement essential areas within the plant. For this reason, vintners cannot wait too long to harvest, and must be very particular if they wish to achieve a specific sugar:acid ratio that will yield wine of their desired quality. The sunlight dependence of glucose, fructose, and malic acid concentrations on sunlight can be seen in Figure 2.

GEOGRAPHICAL IMPLICATIONS

The most natural application of terroir research is to predict ideal growing locations for grapes of a desired quality. Geospatial technology can use insolation data to predict ideal growing areas for high sugar:acid ratio wines within the Niagara region.

To identify regions with optimal irradiance during relevant growth stages, ArcGIS was used to analyse a digital elevation model (DEM) of the Niagara region. This model was used to construct four maps corresponding to budburst, inflorescence, véraison, and harvest. The mean day of each growth stage was chosen to represent the entire stage. Start and end dates of the various growth stages were based upon work by Jones (2000) in Burgundy, France, since the growing conditions of Niagara are comparable to French regions such as Bordeaux and Burgundy (Ripmeester, Mackintosh, and Fullerton, 2013). The Area Total Radiation tool was used to calculate the total incident solar radiation upon each pixel of the DEM on the specified days from sunrise to sunset, using the relative position of the sun to the land across the period of a day, taking into account the angle of incidence, relative optical path length, and atmosphere transmissivity. The consequent data were then classified into intervals that would appropriately showcase relative insolation within each map.

The areas on top of the Niagara Escarpment consistently receive more solar radiation over the course of the day in all four stages of grape growth, and areas on the escarpment slope receive dramatically less radiation (Figure 3). As noted previously, sunlight is important in all stages in grape growth for the production of sugars. Therefore, the solar radiation maps suggest that the grapes with the largest sugar content would be found in vineyards which are on top of the escarpment as opposed to closer to the lake, and not on the escarpment slope.

Based on the provided data, it may seem that, because increased solar radiation is correlated with higher sugar:acid ratios, areas above the Niagara Escarpment would be ideal grape growing regions. However, a quick survey of the region appears to suggest otherwise, as all but one of the major wineries within the Niagara region are below the Escarpment. Rather than completely discrediting the importance of sunlight, this actually illustrates the importance of winter temperature.

The cold temperatures of Canadian winters can cause irreparable damage to vines during the overwintering season, including cessation of growth, wilting of shoot tips, and cessation of future fruit development (Fraser, et al., 2009). In fact, it was not expected that European grape varietals could survive these harsh conditions when they were first grafted to the native Niagara, Concord, and Catawba rootstocks. The secret to the success of wineries in the Niagara region lies in lake winds (Vintners Quality Alliance, 2015).

The high heat capacity of water means that water both heats and cools very slowly. In the spring, winds from the lake are cooler than the surrounding air, as the waters made cold during the winter require a great deal of solar radiation before they begin to heat to the temperature of the air. In the fall and early winter, the opposite is true – the heat absorbed by the lake during the summer months is slowly released, resulting in warm lake winds well into the winter months. Vineyards in the Niagara region take advantage of this effect using wind machines. These engine-driven fans work by pulling down warm air above the crop into the airspace surrounding the vines, resulting in temperature increases around the grapevines that can prevent severe injury (Fraser, et al., 2009). Thus, vineyards near Lake Ontario have an advantage over those on the escarpment, which is not obvious from solar data.

Although insolation affects the sugar:acid balance within grape berries, it is not the only factor in the choice of site. The grape-grower must also consider the effects of environmental stressors such as cold damage, as overall grape quality is highly dependent on grapevine health.

Over the past seven years, geospatial technologies have been used to study the Niagara region and to create a grape-growing database (Vitis Management System) that is maintained by the Grape-Growers of Ontario (Ripmeester, Mackintosh, and Fullerton, 2013). This data is to be used in studies performed by Brock University, Niagara College, and the University of Guelph to investigate Niagara wine quality. As we continue to learn more about the science underlying viticulture, we will improve both the consistency and quality of our grape-growing techniques.

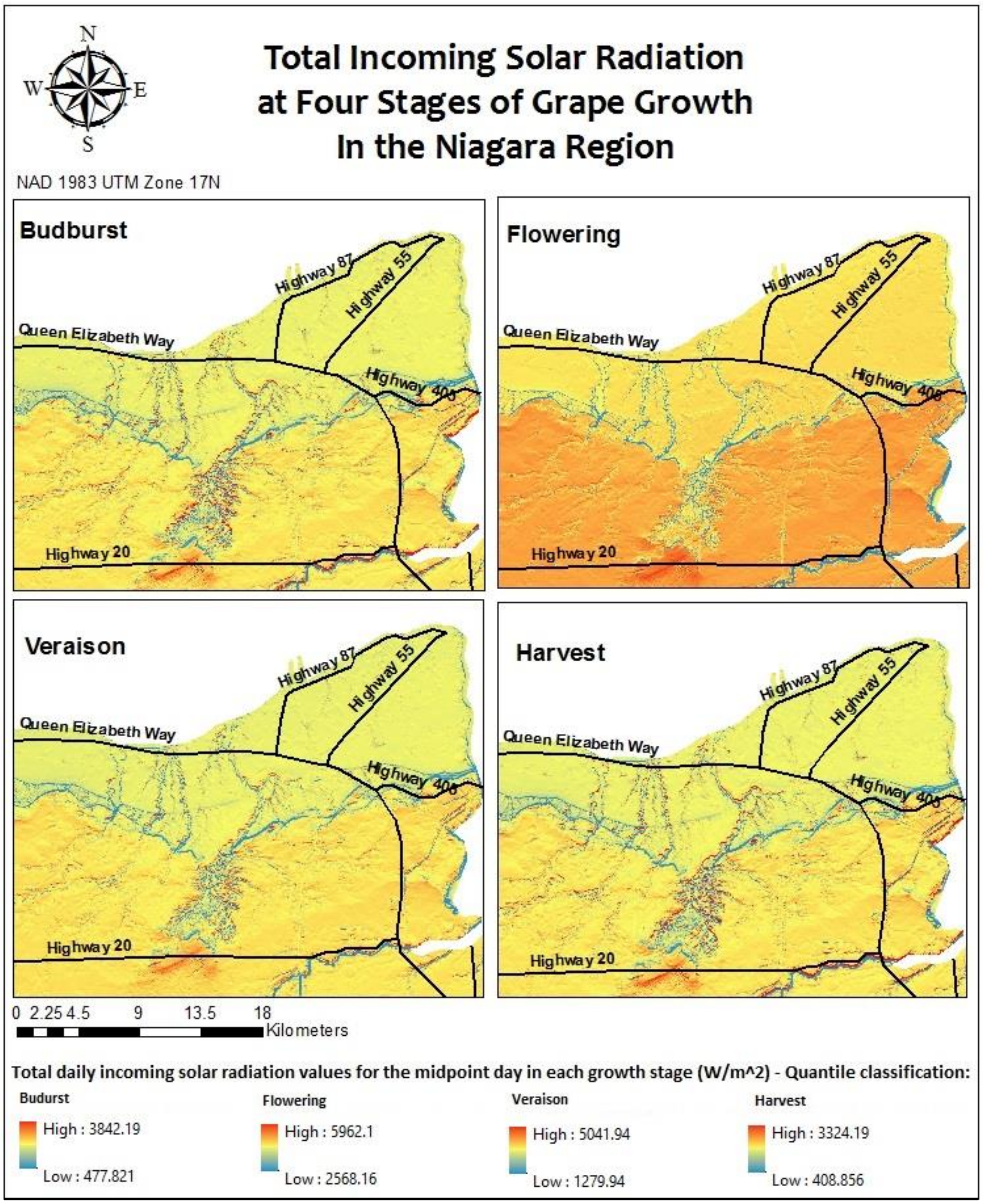

FIGURE 3: TOTAL INCOMING SOLAR RADIATION AT FOUR STAGES OF GRAPE GROWTH IN THE NIAGARA REGION. The total incoming solar radiation as calculated using ArcGIS during four stages of grape development. It can be seen that areas on top of the Niagara Escarpment receive more sunlight than other areas. The maps correspond to the dates: 23 March (Budburst), 12 June (Flowering), 17 August (Véraison), and 2 October (Harvest).

THE BIG PICTURE

Each stage in the growth and development of grapevines contributes to the ultimate composition of the harvested grape. Among the most important components are sugar concentration and titratable acidity. Manipulations during grape growth and harvest, such as leaf trimming and harvest at low temperatures, can substantially influence the sugar:acid ratio of the resulting juice and wine. Wineries can also manipulate grape berry quality through location, by being situated in moderately warm and sunlit areas. The quality of wines is thus highly dependent on environmental influences during each of the plant's growth stages. A winery that does not care sweetly for its grapes may see its business go sour.

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Water Doesn't Always Turn Into Wine

The Consequences of Niagara Water Levels

Mindy Chapman, Tim Fernandes, Jesse Provost, Martyn Siek, Heather Summers, and Michael Wang

ABSTRACT

Water availability is a topic of great viticultural relevance, as it directly affects many levels of society. For the consumer it can dictate wine quality, for wine growers it is directly linked to operational costs, and on a global scale it is tied to water conservation efforts. This paper presents a review of the present literature on viticultural water management. Described are the fundamental ways in which water interacts with both soil and vine to influence the final wine quality. To demonstrate effective water management, a model is presented in which suitable practices are applied to the Niagara wine-growing region.

INTRODUCTION

How much water should vineyards use? This is the perennial question in modern viticulture. Too much water and the vintner risks pathogenic attack and berry burst, to say nothing of the more horrific shortcomings of ignoring a global water shortage and creating bland wine (Zabihi, 2003). Too little water and the vine will be damaged, which impacts both short- and long-term wine production (Junquera et al., 2012). It is the position of the authors that improved water management strategies in viticulture can optimize wine production in terms of both quantity and quality. This issue is of interest to environmentally conscious wine growers and consumers around the world.

The interaction between plant and soil is mediated by water, and so the effects of irrigation must be considered as part of both biological and geological systems. Thus, irrigation involves three questions: when, where, and how much? Selecting optimal water timing, location, and volume requires knowledge not only of the vine water requirements, but also terroir, or the local land and climate. Successful viticulture then modifies terroir to change the incoming water quantity to whatever humans deem to be optimal. Many wine-growing regions do not receive much rainfall, and irrigation must make up the deficit. On the other hand, in locations where the terroir provides an excess of water, strategies are also needed to reduce the water input to more appropriate levels. Herein is detailed how water influences wine grape development from soil and vine perspectives, and how to best optimize the water availability for vine growth with the specific example of the Niagara region.

VINE PHYSIOLOGY

Xylem and Phloem

Prior to exploring the physiological and metabolic consequences of excess water conditions amongst grape vines, one must understand the complexities of vine nutrient and water transport. The "blood" of the vine is transported through sieve elements, which are vertically elongated vascular cells with various intercellular junctions for the diffusion or intercellular movement of variably nutrient rich water. Within *Vitis vinifera* vines, Sousa et al. (2005) found that sieve elements of the phloem, considered the lifeblood of the vine, were predominantly larger in diameter than xylem. The steep gradient of solute concentrations between the phloem and xylem is a homeostatic feedback system, as well as an explanatory characteristic for the diameter variation between vascular tissues. Due to the large concentration of solute particles in the phloem, the regulation of osmotic pressure dictates that a larger diameter sieve tube would be more efficient and less stress-inducing (Keller, 2015). Vine phloem is responsible for the transportation of cellular "fuel" and the components required for new and mature root, shoot, leaf, flower, and fruit growth (Keller, 2015). Over evolutionary time, phloem has differentiated into two subcategories identified by their anatomical location and unique solute concentrations (Sousa et al., 2005). Sink phloem transports a lower concentration of solutes than source phloem, which promotes solute movement down the concentration gradient for homeostatic nutrient regulation in times of stress (Keller, 2015). The composition of sap is predominated by sucrose, displayed by the breadth of solutes pulled along by its steep concentration gradient, including potassium ions, amino acids, glucose, fructose, and malate (Keller, 2015). The sap itself represents the collectable phloem of the vine. Across phloem subtypes, sucrose has been found to compose 50-70% of the sap osmotic pressure (Keller, 2015). This nutrient and sugar rich medium also transports microRNA (miRNA), sugar metabolism proteins, sugar transport membrane and carrier proteins, nutrient transport membrane and carrier proteins, aquaporins, plant hormones (gibberellins, cytokinins, abscisic acid), and injury response proteins including callose, which provides the long-term sieve plate pore sealant in response to damage (Keller, 2015). Although sieve elements lack protein-manufacturing machinery, the miRNA may be used as long-distance signaling units (Keller, 2015). The available genetic information has been shown to both promote and inhibit protein production in target cells; however, inhibition is its predominant function (Keller, 2015; Reynolds & Naylor, 1994; Cramer et al., 2007). The principal inhibitory pathway, miRNA gene silencing, decreases protein synthesis metabolism (Keller, 2015).

In contrast, xylem sieve elements transport only water and dissolved nutrients in the form of ions (Keller, 2015). As a result, the xylem is able to transport electrical signals stimulated by injury or hydraulic pressure waves (Keller, 2015). The evident osmotic pressure gradient created between the phloem and xylem is imperative to maintaining solute homeostasis (Keller, 2015). Transfer of dissolved nutrients from phloem to xylem tissues dictates phloem flow direction in shoots and roots, and buffers ephemeral xylem concentration fluxes (Keller, 2015). The bidirectional nature of phloem sieve tubes is necessary for sufficient leaf growth and energy transport.

DEVELOPMENT OF THE VINE

Following the winter season, the vine buds that have survived will go through a renewed growth period known as budbreak. This period occurs when sufficient glucose and other essential nutrients have been mobilized and transported towards the existing bud, promoting the growth of flowers and eventually fruits. During this time, remobilization of the starch stored in the woody organs of the vine will be stimulated by the gibberellin plant hormone, and transported as soluble sugar in the phloem (Keller, 2015). The phloem carries the metabolites required for budbreak and new growth to meristems in vine branches and roots (Keller, 2015). As leaves begin to form and mature, they will initiate the production of assimilates (Keller, 2015). Leaf maturity occurs in leaves between two to three weeks of age (Keller, 2015). Here, glucose will be transported from mature leaves to woody organs, as well as from woody organs to nearby leaf and shoot meristems through bidirectional phloem flow (Keller, 2015). As a result of this continuous fuel flow and relatively consistent leaf senescence period, the later leaf formation and maturity occurs during the growing period, the progressively smaller the payback period becomes (Keller, 2015). The payback period can be defined as the amount of time available for a leaf to offset its construction cost with produced assimilates (Keller, 2015). Additionally, in periods of leaf stress, decreased sun exposure, or decreased photosynthetic efficiency, such as overcast weather or mineral deficiencies, the woody organs provide necessary carbon energy units (Keller, 2015). As leaves approach the period of senescence, they begin to slow their assimilate exportation until an eventual end point, wherein energy production evolves into mineral nutrient release (Keller, 2015). This release is triggered by the resorption of proteins and their constituents (Keller, 2015). The metabolic and structural regulation of vascular and mesophyll tissue are all reliant on proper protein and organelle function.

LEAVES: STRUCTURE AND FUNCTION

In order to maintain proper function within leaves, structural integrity is essential. The leaf matrix is composed mainly of polysaccharides including hydrophilic pectin and hemicellulose, which is a cellulose binding glycan composed of xyloglucan (Keller, 2015). During rapid periods of leaf growth, there is increased cellulose production due to the high cell wall construction requirement (Keller, 2015). Through increased photosynthesis, cellulose production stress can be proportionally decreased (Keller, 2015). In young leaves, biosynthetic organelle manufacturing compounds are drawn inwards, and very little to no energy is produced. In mature leaves, photosynthesis increases with age, with maximum energy production rate attained approximately five weeks after leaf unfolding (Keller, 2015). Due to the higher proportion of atmospheric oxygen to carbon dioxide, the ratio of oxygen in mature chloroplast fluid will reach 24:1, favouring photorespiration (Keller, 2015). Though it is a very inefficient and counterproductive process by which energy is consumed and nitrogen toxicity occurs, photorespiration is presumed to protect against electron overload during very bright conditions (Keller, 2015). If vines are exposed to excess water, photosynthesis will be favoured.

IMPACT OF PRECIPITATION ON VINES

Increased precipitation stimulates lateral shoot growth, which is attributed to the presence of excess nutrient and water availability in the phloem (Keller, 2015). Gibberellin aids in shoot growth by mobilizing the stored starch in the woody regions of the vine, and the resultant sugars are transported via phloem sieve elements to the new shoots (Keller, 2015). The dense canopy resulting from this stimulation provides a moist environment, ideal for fungal and bacterial growth on the grapes. This is a function of decreased airflow and sunlight exposure. Furthermore, the decreased osmotic pressure within the sieve elements decreases the turgor pressure, and can cause wilting of the plant, as well as longer response time to external stimuli (Keller, 2015; Reynolds & Naylor, 1994). Reaction time is dictated by the relative concentration and availability of plant hormones and miRNA fragments; in waterlogged sieve elements, these concentrations are greatly decreased (Keller, 2015). Furthermore, if roots become waterlogged, they lose the ability to exclude [KI2] sodium and chloride ion uptake (Keller, 2015). Increased salt content within the phloem and xylem can cause irreversible tissue damage, as a result of osmotic water movement and cell rupturing (Keller, 2015).

PRECIPITATION AND BERRY QUALITY

Different developmental stages for berries during the growing season require varying levels of water (Heinen, 2013). For example, optimal grape quality during the early stage of budbreak to bloom is contingent upon adequate water. At this stage, water is required to achieve even budbreak on vines, to allow for continuous nutrient uptake by vines, to increase berry size, and to promote the production of chemicals that enhance the fruitfulness or flavour compounds including phenolics of berries (Heinen, 2013). Berry development from the early post-bloom stage to veraison (onset of ripening) also requires adequate water in order to increase berry size and to enable the flower buds for the following season to form. Although water is a critical resource for vines, paradoxically, too much water can lead to problems. Excess water can increase the susceptibility of the newly formed flower buds to deleterious effects of winter injury. Later in the season, during veraison until harvest, excess precipitation can be particularly damaging due to fewer hot sunny days to dry up the berries and the likelihood that increased moisture promotes decay of the berries (Heinen, 2013).

According to the Grape Growers of Ontario, on average every second year receives insufficient rainfall during critical water-requiring stages of berry development (Heinen, 2013). Fortunately, irrigation can mitigate the problems that would otherwise reduce the quality and size of the berries. However, excessive precipitation is much harder to manage, particularly late in the season. Typically, the maximum rainfall in the Niagara region is during September, a period coinciding with the maturation of the grapes and start of harvest (Ripmeester, Mackintosh and Fullerton, 2013). Moreover, at any time during the season the presence of high water content in the soil inevitably poses problems for viticulturists as grape vines grow optimally in regions that experience moderate water deficits. Excessive soil water can adversely affect the growth, production, and quality of the berries (Heinen, 2013). Not unexpectedly, periods of heavy rainfall are typically associated with lower temperatures and lower light intensity due to cloud cover (Keller, 2015). These adverse conditions are exacerbated by the reduced flow of air through canopy leaves that raises humidity around berries leading to their increased susceptibility to diseases (Heinen, 2013). In addition to the normal uptake of water into berries via xylem connections to the vine, exposure of berries to water on their surface can lead to an increased uptake of water across the berry exocarp (skin), leading to larger berry size and eventual cracking (Keller, 2015).

The need for water by precipitation or irrigation in vineyards is unquestionable. Adequate water is critical for vine canopy development for photosynthesis. However, heavy precipitation at inappropriate times of vine development can have serious deleterious effects. Excess water can delay the onset of veraison and slow berry ripening altering the desired sugar-acid balance of the fruit (Keller, 2015). Earlier in the season, abundant precipitation can lead to a dense vine canopy that reduces light penetration to the berries, producing low sugar concentration in the fruit (lower Brix value), higher berry acidity, and reduced pigmentation, all of which inevitably compromise wine quality (Heinen, 2013; Keller, 2015).

EXCESS WATER: BELOW GROUND IMPACTS

Vigorous vines are dependent upon healthy roots and favourable soil properties. For example, the rootstock can be chosen to be resistant to phylloxera, or it can be chosen to mitigate the effects of saline soils (Fisher, 2015). However, rootstocks vary only slightly when it comes to their ability to withstand wet soil conditions. Depending on the soil type, climate, and many other factors, it may be necessary to remove excess water.

Grapevines are able to grow in large volumes of soil given the correct soil moisture, pH, and soil texture conditions, soil moisture being the factor that most directly affects the health and function of the grapevine (Fisher, 2015). Fine-grained soils, such as silt and clay, are most likely to cause damage to the grape vine due to excess water. The fine-grained soils have high water-holding capacities, which results in a high water table in regions with medium to heavy rainfall.

TILE DRAINAGE

To eliminate the negative effects of excess water, a tile drainage system can be used. A tile drainage system is a network of perforated plastic pipes, called the drainage tiles, which are installed underneath the soil of the vineyard. The tile drainage system transfers the excess water to a drainage ditch or out of the vineyard (Fisher, 2015). The drainage tiles are laid at a depth that is dependent upon many factors, such as the depth of the high water-holding capacity soil or the amount of rainfall in the region. The drainage tiles have to be installed such that the slope of the land can be used to transfer the excess water away. Once the water table reaches the height of the drainage tiles, the excess water flows into the drainage tiles and is then transferred away from the roots (Fisher, 2015).

Tile drainage systems have been shown to improve vine survival, yields, and fruit quality (Merwin et al., 2009). Whether the vineyard is new or established, improving the soil drainage is an idea worth considering. Installation of such a soil drainage system is relatively inexpensive and will pay itself off in a few years from the increased yields (Merwin et al., 2009). A study done by Merwin et al. (2009) showed that the distance from the vine to the nearest drainage tile significantly influenced the vine size during a dry summer. They found that the closer the vine was to the drainage line, the greater the pruning weight. Another study done by Brown et al. showed that after an excessively wet year in 1996 in a vineyard near Lake Erie, vines that were located closer to the drainage tile grew better in comparison to the vines located farther away. These studies show that tile drainage is not only a viable option for wet areas, but is also a beneficial option for dry areas.

APPLICATION TO THE NIAGARA REGION

The Niagara on the Lake and Niagara Escarpment appellations are divided into ten sub-appellations as seen in Figure 1. These sub-appellations have varying soil characteristics that are important to consider when installing drainage tiles.

Beamsville Bench:

The Beamsville Bench has a heterogeneous mixture of boulders, gravel, sand, silt, and clay with bits of shale, limestone, and sandstone from erosion of the Niagara Escarpment. This complex mix gives the soil high a water-holding capacity.

Creek Shores:

Streams in Creek Shores created lighter soils with interspersed patches of loamy soils that are thick and porous and allow deep root penetration. The southern part of this sub-appellation contains primarily clay soils.

Four Mile Creek:

This sub-appellation developed on the bedrock of the Queenston formation, and has high clay and silt content. Four Mile Creek also contains Halton till and rich clay loam, which has high water-holding capacity.

Lincoln Lakeshore:

The Lincoln Lakeshore is also on top of Queenston shale and over half of this sub-appellation is covered by well to moderately drained light sandy soils. There are patches of clay loam that have high water-holding capacity.

Niagara Lakeshore:

This sub-appellation has glacially deposited silts and clays. There are sandy soils in the areas adjacent to the shore of Lake Ontario. Clay loam soils with high water-holding capacities are in the centre of this sub-appellation.

Figure 1: Sub-appellations in the Niagara region (VQA Ontario, 2015).

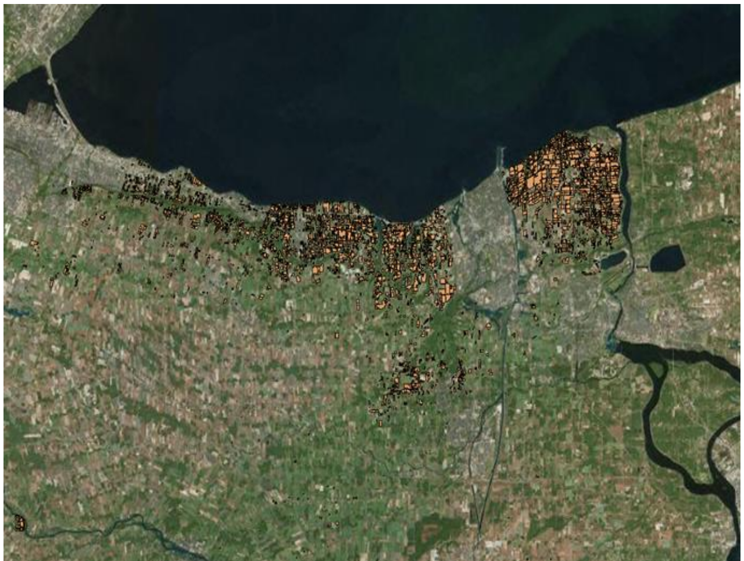

Figure 2: Niagara region base map overlaid with Agricultural Operations Index data layer. Data is shown above in orange highlights crop yield operations (ESRI, 2011).

Niagara River:

The Niagara River has significant soil variation in terms of drainage. The northern area of the sub-appellation has soils with low water-holding capacity and the southern area has soils with high water-holding capacity.

Short Hills Bench:

The soils are primarily silt and clay in this sub-appellation but have lower layers of sand and gravels, which provides good drainage for the roots of mature vines.

St. David's Bench:

The St. David's Bench has silty clay and clay loam, which absorbs the winter melt and holds the water until the start of the next growing season.

Twenty Mile Bench:

This sub-appellation is primarily clay and till with a mixture of limestone and shale from the Niagara Escarpment. This allows the Twenty Mile Bench to have a high water-holding capacity.

Vinemount Ridge:

Vinemount Ridge is made up of clay loam till that is composed of a large amount of silt and shale from the Niagara Escarpment. This gives this sub-appellation a high water-holding capacity; however, there is natural drainage due to the underlying Vinemount Moraine (VQA Ontario, 2015).

The Niagara region is considered one of the best agricultural regions in the province due to its unique microclimate resulting from its location in between Lake Ontario and the Escarpment. It is ranked 38th in total land area with 1,854 km^2 (Statistics Canada, 2015a). Despite this, it is ranked 11th in number of farms with 2,236, 25th in farmland acres with 231,728, as seen in Figure 2. Altogether it is 3rd in gross number of receipts with $671,680,773 (Statistics Canada, 2015a). When combined, Niagara farms generate $2,899 gross farm receipts per acre, the highest in the province (Statistics Canada, 2015a).

A notable contribution of Niagara's agricultural output comes in the form of wine. Although wine is not the most common agricultural product produced in the Niagara region, its wineries are among the most successful and expensive in Canada, averaging $40,000 per acre (Wine Country

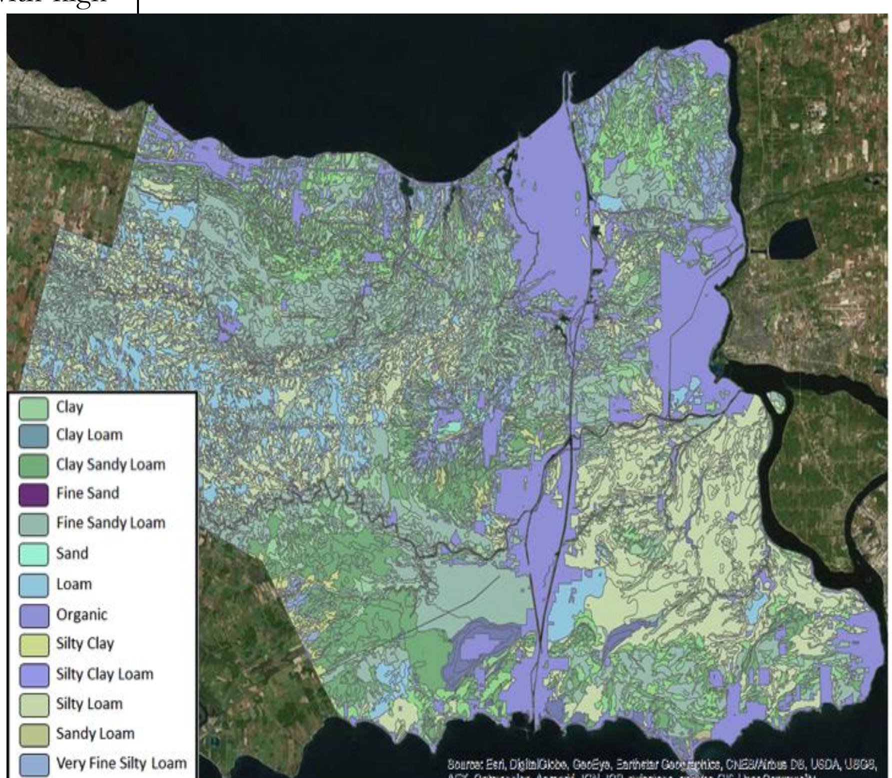

Figure 3: Soil composition of the Niagara Region. Niagara base map was overlaid with Soil Survey Complex data and characterized by ATEX1 metadata (ESRI, 2011).

Ontario, 2015). As such, the winery owners invest countless dollars trying to increase or maintain their yield. This is most often accomplished through tillage and irrigation systems.

Irrigation is a common tool used by many Niagara region winery owners and farmers to offset possible drought conditions by providing water in times of minimal rainfall, and to offset the effects of soil composition on water accumulation. The soil composition of the Niagara region can be seen in Figure 3. It is estimated that 38,409 cubic metres of water was used for irrigation purposes in 2012 (Statistics Canada, 2015b). Irrigation methods can vary and the use of irrigation often depends on weather patterns. From 2010 to 2014 the number of farms using sprinkler irrigation in Ontario fell from 670 to 260 from, micro-irrigation fell from 270 to 180, and surface irrigation from 240 to 30 (Statistics Canada, 2015c). Tile drainage systems are used frequently in infrastructure to help facilitate the drainage of water. The overall drainage efficiency of the Niagara region is seen in Figure 4.

They are also used in the agricultural sector in order to prevent crop from becoming over watered. It is estimated that there was approximately 100,000,000 feet of locally produced corrugated plastic drainage pipe and clay tile used for agricultural purposes in Ontario in 2000, as seen in Figure 5 (Land Improvement Contractors of Ontario, 2015).

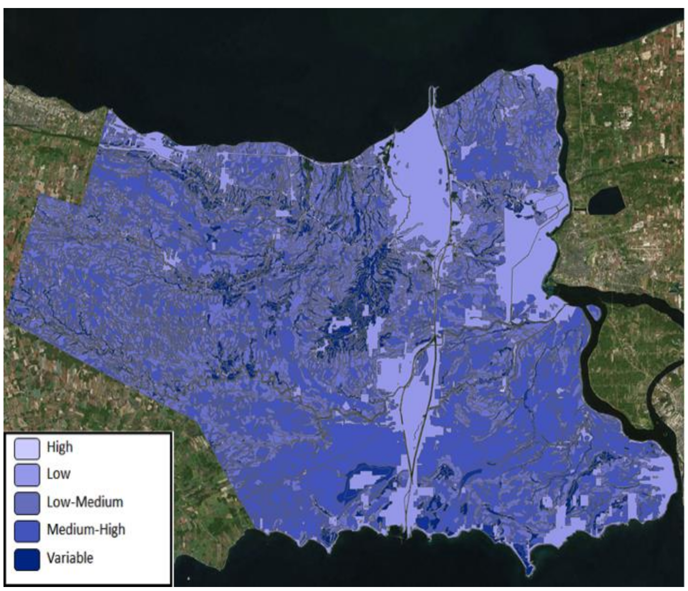

Figure 4: Drainage efficiency of soils in the Niagara Region. Niagara base map was overlaid with Soil Survey Complex data and characterized by DRAINAGE metadata (ESRI, 2011).

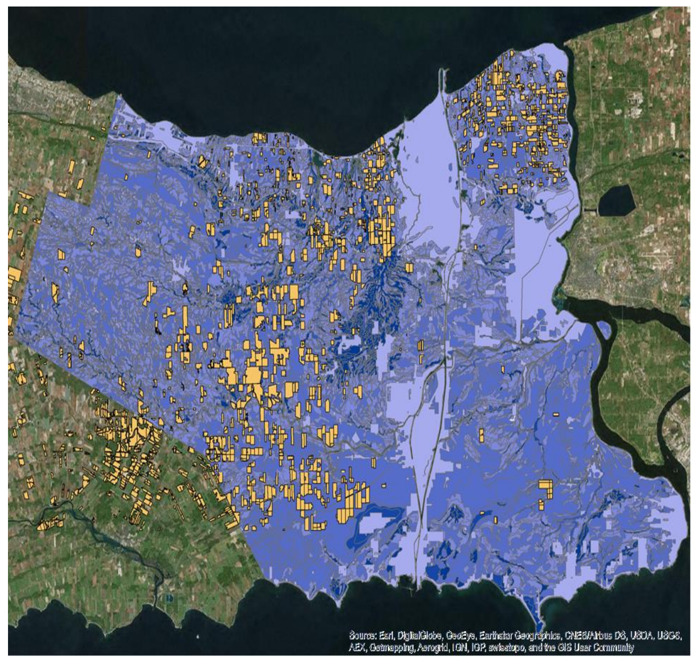

Figure 5: Drainage efficiency of soils in the Niagara region overlaid with tillage information of agricultural operations with tile. Niagara base map was overlaid with Soil Survey Complex data and characterized by DRAINAGE metadata, and layered with agricultural tile (ESRI, 2011).

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(Anon, 2011)

THE DRIER THE BERRY, THE SWEETER THE JUICE

Jaime Knoch, Stephanie Black, Max Lauch, Kylee Innes, Deep Inamdar

ABSTRACT

Though both are intended for dessert drinking, wines produced from freezing and from noble rot fungal infections differ significantly. The two opposing production processes each have similar effects on sugar concentrations but differing methods of extracting important phenolic compounds, like anthocyanins, tannins, and flavonoids. Icewine relies on creation of water crystals to dehydrate the grapes and break the cells while noble rot infections utilize pectolytic enzymes to break the cells and cause dehydration. Despite vastly different circumstances, one requiring bitter cold temperatures while the other requires a warm, dry environment; the end products are both characteristically sweet wines.

FROZEN AND ROTTED GRAPES

With the national affinity to the sweet taste of maple syrup, it comes as no surprise that Canada is paving the way for their very own international recognition of fine dessert wines. Given the freezing temperatures and harsh winters, it was a wonder that temperate European grapes could even survive, let alone produce wine. Fortunately for the maple syrup capital of the world, Canada's freezing problem became an undeniable asset in the production of their now-iconic icewines. It began with the immigration of German winemakers carrying the tradition of Eiswein (German icewine) to British Columbia and Ontario in the 1970's. The Niagara Region in particular has almost ideal climate conditions for reliable production of icewine: warm summers to ripen the grapes, and cold winters to freeze them (VQA, 2015).

Sub-zero temperatures aren't the only factor working against grapes in the Niagara Region. Due to an environment prone to rainfall and humidity, winemakers often have to battle the grey rot fungus, *Botrytis cinerea*. Winemakers in Eastern Europe have been utilizing this fungus to produce their own dessert wines, known as noble rot wines, for centuries.

Despite vastly different circumstances, one requiring bitter cold temperatures while the other requires a warm, dry environment; the end products are both characteristically sweet dessert wines. So how do these dissimilar processes result in similar outcomes? The answers, of course, lie in the chemical and biological processes that generate these unique wines.

ICEWINE PRODUCTION

Icewine is classified as a dessert wine due to its characteristic sweetness, which is a result of its unique harvesting process. Traditionally, grapes are harvested immediately after they ripen. This maintains the desired acidity and sweetness, while ensuring seeds, skin, and stems are fully developed. Icewine berries however, are harvested much later in the season.

"Temperatures below -8 degrees Celsius for three consecutive days before harvest" (Canadian Vintners Association, 2014)

The uniquely late harvest can only occur after the grapes have been properly frozen while on the vine. According to the Canadian Vintners Association, proper icewine grapes must be subjected to temperatures of below -8°C for three consecutive days before harvest (Canadian Vintners Association, 2014). On the third day, the grapes are picked after midnight to avoid an increase in ambient temperature from solar radiation (Bell, 2012).

The grapes must remain frozen during production, so they are immediately pressed that night, often outside or in unheated cellars. Normally these grapes would be around 80 percent water, but for icewines, the water is frozen while the grapes are pressed (Inniskillin, 2015). In order to force juice out of the frozen grapes, the hydraulic press employs much higher pressures than the regular presses (VQA Ontario, 2015). This effectively "dehydrates" the juice, as most of its water content is left behind. Removing this water concentrates sugars to a final level of at least 35° brix, which is approximately equivalent to the percentage of sugar in the wine (Canadian Vintners Association, 2014; VQA, 2015).

However, this high sugar concentration hinders fermentation, as it creates a hostile environment for yeast (VQA Ontario, 2015). As a result, fermentation takes much longer than for other wines, and the alcohol content tends to be much lower.

CHEMICAL COMPOSITION OF ICEWINE

Winemakers are constantly monitoring a number of factors that enable them to produce their desired refined product. Icewine makers not only have to closely monitor temperature, but also berry exposure to sunlight, soil moisture content, and total fermentation time, to name a few.

The quality of the final production is assessed through taste, colour, and aroma. Due to the qualitative nature of these assessments, there is no easy quantitative method to determine the end quality of the wine. However, all these characteristics (taste, colour, and aroma) are governed by the concentration of specific molecules within the wines. In 2004, a study by Nurgel et al. acknowledged that the key impact molecules contributing to icewine characteristics had not yet been identified.

The freezing process does not simply alter the sweetness of the wine, it also has significant effects on phenolic compounds (compounds whose presence is responsible for taste, aroma and colour) (Vidal et al, 2004). Through cryoextraction methods, which use artificially frozen grapes, it has been shown that the formation of ice crystals physically breaks the lining of grape cells and organelles, specifically the vacuoles within grape skin cells. These vacuoles contain phenolic compounds like tannins (responsible for astringency and flavour), anthocyanins (a pigment responsible for colour), and other flavonoids that give the grapes their unique characteristics (Sacchi, Bisson and Adams, 2005).

Icewines are unique because the extract from the pressed frozen berries is highly concentrated with sugar due to natural freezing. As mentioned before, during the frozen pressing, much of the original water content remains in the presses as ice, while the extract contains highly concentrated sugars, acids, and phenolic compounds. The sugar ultimately leads to the signature sweetness of icewines; however, it also leads to a complication in fermentation. The elevated sugar content in the juice creates a hostile environment for the thriving yeast by having sugar levels exceed those that allow for sustainable fermentation by the yeast. Thus, the yeast requires a longer fermentation period of 2-4 weeks, as opposed to the traditional 1-2 weeks, to successfully produce an appropriate amount of alcohol. Due to the stress placed on the yeast by the high sugar and increasing alcohol concentrations, alcoholic fermentation typically ends while there is still considerable residual sugar present. As a result, icewine maintains a high concentration of sugars, acids, and phenolic compounds with a lower alcohol content.

FIGURE 1: FROZEN GRAPES PRIOR TO HARVEST. These grapes have frozen on the vine in substantially cold temperatures for three consecutive days, and are now ready for harvest (Rivard, 2012).

NOBLE ROT WINE PRODUCTION

Even when a winemaker is cursed with a temperate climate, they can still produce sweet dessert wines; they may just have to get their hands a little dirty. *Botrytis cinerea* is a parasitic fungus that has been involved in the production of wine for centuries. *Botrytis cinerea* can give rise to two different forms of fungal development; the detrimental grey rot (or bunch rot) and the beneficial noble rot. Grey-rotted grapes produce wines that are of extremely low quality (Jackson, 2008). The same cannot be said for noble rotted wines. In fact, noble rot has been attributed to some of the world's finest sweet white wines such as the acclaimed Tokaji Aszu, Sauternes, and Trockenbeeren auslese (Fleet, 1993).

Typically, *Botrytis cinerea* infections spread through spores that originate from the mycelia of previously diseased, overwintered fungal tissue. Infections that initiated on developing grape clusters may result in latent infections that can be reactivated. The fungal resistance of any given plant declines during fruit maturity. This allows for the development of both latent and novel infections (Jackson, 2008).

Past the point of infection, the type of fungal formation developed is dependent on several factors. Grey rot development is promoted by berry splitting, which typically occurs in shallow-rooting, highly humid environments. These conditions are ideal for grey rot, as they optimize *Botrytis cinerea* parasitism (Ribereau-Gayon, 1988). Instead, the formation of Noble rot occurs later in season and requires conditions that fluctuate in humidity. These unique conditions are ideal, as they allow for *Botrytis cinerea* infection while limiting fungal growth and metabolism. *Botrytis cinerea* is highly sensitive; thus slight variations in conditions will heavily affect the yield of infected grapes (Ribereau-Gayon, 1988). This is demonstrated by the variable expression of healthy, noble-rotted, and grey-rotted berries within a single infected grape cluster. Even microclimates within infected plants can affect the formation of the fungus (Jackson, 2008).

Following the initial infection, new spores can be produced by fungal hyphae within the span of a week. These spores typically spread the fungus to unaffected portions of the plant. Upon infection, several hydrolytic enzymes are released into the host plant. Pectolytic enzymes have the most noticeable biochemical effect on plants. As suggested by the name, pectolytic enzymes break down the pectin building blocks of the plant cell walls. This degradation results in a loss of physiological control: moisture can freely escape infected grapes.

During fruit maturation, this is problematic as vascular connections with the vine become disrupted; plant cells can no longer replace lost moisture in order maintain internal water

FIGURE 2: GRAPES INFECTED WITH NOBLE ROT. Noble rot dehydrates the grapes and concentrates sugars, producing a sweeter wine (Tosi et al., 2012).

levels and are thus subjected to their environmental conditions. Under dry environmental conditions, moisture is lost form plant, effectively dehydrating the grape. Grape dehydration is ideal as it concentrates the sugar content while limiting the water dependent metabolic growth of noble rot. This ensures that noble rot does not completely parasitize its host. Wines produced from such grapes are high in quality, having a sugar content similar to icewines. (Tosi et al., 2012). If environmental conditions do not remain dry, fruit moisture will be replaced. Dehydration does not occur and thus the sugar is not concentrated. Furthermore, the hydration allows *Botrytis cinerea* to grow and further parasitize the host fruit until the cell walls collapse and cellular death occurs (Jackson, 2008). This presents an issue for wine makers. *Botrytis cinerea* requires moist environments in order to infect grapes. However, too moisture will result in grey rot. *Botrytis cinerea* is very difficult to control as there is a delicate moisture balance. That being said, wine growers can implement various strategies in order to promote the growth of the noble-rotted grapes.

When producing noble rot wine, vineyard locations should be chosen in order to maximize sun exposure and control the humidity conditions that that allow grey rot to thrive. Wine growers should grow resistant varietals that are less susceptible to grey rot (Rombough 2002). It is fundamental to utilize pruning and training systems to improve air circulation and promote rapid leaf drying. In particular, pruning around the grape cluster will increase air circulation directly around the cluster, allowing for dry microclimates. In the production of noble rot wines, it is important to strictly maintain nitrogen levels; excess nitrogen promotes tender plant growth that is more susceptible to the fungus (Rombough, 2002).

Although some cellular activities are negatively impacted, the associated grape dehydration can be beneficial to the wine industry. After all, by removing water, the concentration of the remaining juice is drastically increased, leading to a sweeter and uniquely flavourful wine.

THE CHEMISTRY OF NOBLE ROT

There are two major types of chemical changes that occur to a wine that is produced from noble-rotted grapes. The most noticeable change is the sharp increase in sugar concentration, but there are also many chemical effects that occur due to the metabolic activity of *Botrytis cinerea.*

As mentioned previously, the concentration of juice produced from noble rot wines is much higher due to the dehydrating effect of the fungus. This means that the resultant wine has significantly higher sugar content than wine made from healthy grapes. Just like the dehydration from freezing, this drastically increases the sweetness of the wine.

There are many interesting chemical changes in noble-rotted wine that come about as a result of the metabolic processes of the invading fungi. Thiamine (vitamin B1) and pyridoxine (vitamin B6) have been shown to largely decrease in noble-rotted must (Dittrich et al., 1975). *Botrytis cinerea* is also able to synthesize many chemical compounds that can influence the characteristics of the wine. For instance, it produces two different groups of polysaccharides (carbohydrate chains): pure β -D-glucan, and a second group of polysaccharides containing mannose, galactose, glucose, and rhamnose (Jackson, 2011).

The β-D-glucan group is comprised of polysaccharides containing β -1,3 linkages in the main chain. These types of polysaccharides are neutral in terms of their effect on the sensory experience of the wine; however, they tend to form strand-like colloids in the alcoholic environment. These linear strands make filtration of the wine very difficult because they plug up the filter sheets typically used by winemakers (Jackson, 2011).

The second group of polysaccharides that B. cinerea produces was described by Doubourdieu in 1978, and it consists of mainly mannose and galactose, with small amounts of glucose and rhamnose (Jackson, 2011). They are thought to bring about the acetic acid and glycerol production from the yeasts used during fermentation (Donéche, 1993).

These polysaccharides may also explain why noble rot wines are so notoriously difficult to ferment compared to wines that are derived from healthy fruit. They promote a substance once called "botryticin", which is thought to be a mannose-based, neutral heteropolysaccharide that acts as an antibiotic during fermentation (Hornsey, 2007).

Aside from polysaccharide synthesis, one of the main chemical differences between noble rot wines and wines made from healthy grapes is the higher concentration of phenylacetylaldehyde, which is thought to bring out honey and ginger notes in the wine (Jackson, 2011). Other odourous compounds are also found in higher concentration in noble rot wines such as: benzylaldehyde, vanillin, 4-terpineol, 1-octen-3-ol, and sherry lactones, which are thought to bring about the aromas of citrus and dried fruits (Jackson, 2011).

CONCLUSIONS

The international market for Canadian icewine is credited to the Inniskillin wineries. The harvest of icewine grapes at Inniskillin's Niagara location has ranged from December to February. Due to the dependence on climate for icewine production, there are few regions worldwide that are suited for its production; this includes all Canadian winemaking provinces, Northern USA wineries, and some European countries, primarily Germany.

Noble rot wines, on the other hand, are difficult to maintain in the Niagara wine region. Due to the largely humid and wet growing season, winemakers cannot maintain the dry-humid balance that is required for the fungus' benefits. On the other hand, it is much more viable for dessert wine production in California and Eastern European wine regions.

Similar to proper raisin wines, icewine and noble rot wines get their dessert wine certification from the high sugar concentration of the final product. Regardless of sweet taste, the wine's characteristics will depend largely on varietal, region, and environmental factors. Of course, after a great meal, and paired with a fine dark chocolate or cheese spread, it's up to the consumer to decide whether they want a wine made from freezing temperatures or from a fuzzy fungal infection.

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Climate Change and the Niagara Icewine

Loryn Byres, Tristan Goodwill, Kyra Simone, Julianna Stangroom, and Charlotte Tousaw

FIGURE 1: FROZEN VINES. Through the process of freezing grapes on the vine, grape growers in the Niagara Region are able to make the sweet specialty wine for which Niagara is famous (Hatfield, 2007).

INTRODUCTION

Ice wine is a sweet specialty wine made from the concentrated juice of partially frozen grapes. This process creates the sweet dessert wine enjoyed across the globe. In particular, ice wine is very important to the Niagara Region, as the rare climatic conditions allow for the region to be both warm enough in the summer to grow grapes and cold enough during winter to make ice wine. As expected, the production of this wine is highly regulated by the Vintners Quality Alliance (VQA) to ensure that Niagara only produces quality ice wines. Consumers can feel confident that they have selected a product that adheres to these standards if it is labelled "icewine" (without the space), a Canadian trademark (Soleas and Pickering, 2007). The production of icewine relies on extremely specific climatic conditions, and is therefore very susceptible to climate change. This article outlines a scenario of how climate in the Niagara Region is projected to change over the next 50 years, and how these changes may potentially affect Niagara's icewine industry.

KEY FACTS ABOUT NIAGARA ICEWINE

Icewine made up 50% of the Ontario's wine export revenue in 2014 (Pickering, et al., 2015). In the Niagara Region, icewine is predominantly made from two varietals: Vidal and Riesling (Turvey, Weersink and Chiang, 2006). To understand the vulnerabilities of the Niagara icewine industry, it is important to understand how icewine is made, and how it is different from other Niagara wines.

Grape growers are legally required to wait until there have been three consecutive days below -8℃ before they can harvest grapes for icewine (Rolle, et al., 2010). The sustained cold temperature causes some water in the grapes to freeze, which concentrates sugars in the residual juice. The requirements for icewine making are complicated by the fact that grapes completely freeze around -12℃. This prevents grapes below that temperature from being pressed. These two temperature requirements limit the range of icewine harvest to between -12℃ and -8℃ (Cyr and Kusy, 2007). Once a temperature in this interval has been sustained, grapes are harvested and pressed to extract this concentrated grape juice. The juice is then fermented into the sweet beverage that we know as icewine.

PREDICTED CLIMATE CHANGES

In the attempt to predict the impact of future events, it is first important to understand how and why the event will occur. In the case of climate change, the extent of its effects is largely unknown, and must be predicted based upon forecasted trends in other factors. The predictions of this review are based on the third version of the

Canadian Coupled Global Climate Model (CGCM3). The Canadian Centre for Climate Modelling and Analysis developed CGCM in 2005. It is based upon mathematical models of atmospheric and oceanic circulation, and thermodynamic activity of sea ice and land surface, and outlines scenarios based on two possible trends in atmospheric carbon dioxide (King, Solaiman and Simonovic, 2010). In the context of icewine production, the most extreme example will be considered: the A2 Scenario (Figure 2), which predicts climatic effects in the event that atmospheric CO_2 reaches 1320 ppm by the year 2100 (Colombo, et al., 2007).

The A2 Scenario outlined by CGCM3 assumes an exponential global population growth rate, and thus an exponential increase in energy consumption. Conversely, the proposed B2 Scenario assumes a somewhat linear increase in population and energy usage. It is important to consider the impacts of the drastic A2 temperature and precipitation changes on Niagara's icewine industry, so as to be adequately prepared for the potentially serious effects.

CGCM3 is the most commonly used model in Canadian climate change studies. One such study compared data from forest sites with model predictions, and found that the model reproduced observed trends in net radiation, air temperature, and precipitation (Chun, et al., 2014). While CGCM3 failed to fully explain data obtained for relative humidity and wind speed, this review is mainly concerned with projected differences in Southern Ontario's precipitation and temperature.

Should CO2 levels increase according to the A2 Scenario, the Niagara Region may experience increased temperatures and decreased precipitation, as shown in Table 1.

However, it must be acknowledged that CGCM3 does not entirely account for variation in precipitation frequency and intensity. As a result, the incidence of extreme storm events, which is expected to increase, cannot be fully predicted by this model (Hewitt and Jackson, 2008). Furthermore, CGCM3 does not take into account extreme temperature variations, which are predicted to occur much more frequently as climate change intensifies (Easterling, et al., 2000).

SUMMER

Icewine production does not come without risk. For every wine type, there are many sensitive times of year during which extreme weather can ruin a

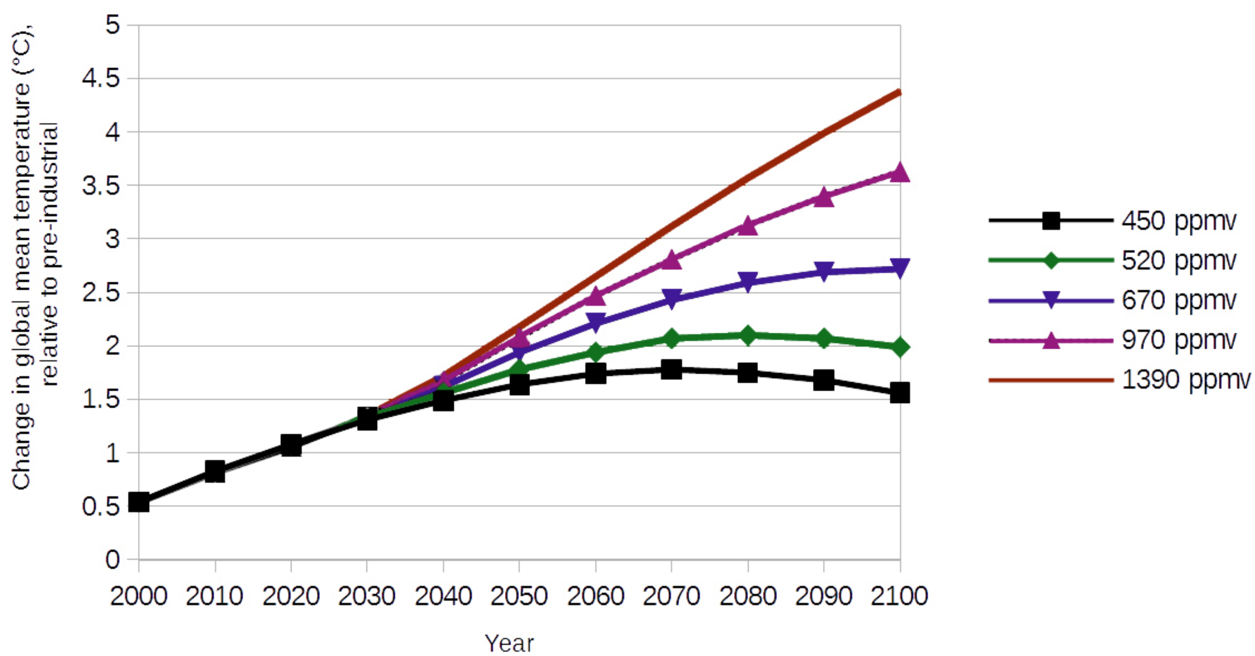

FIGURE 2: INCREASING ATMOSPHERIC CO_2. This is a graphical representation of several predictions for global atmospheric carbon dioxide levels. The A2 scenario proposed by CGCM3 most closely resembles the red trend line, while the pink line approximates the B2 scenario (970 ppmv) (Enescot, 2014).

TABLE 1: CLIMATIC CHANGES FOR NIAGARA. This table summarizes the climatic changes to the Niagara Region according to the A2 scenario ([1]Colombo et al., 2007; [2]Environment Canada, 2013).

		Mean Current Value	Change	Predicted Value in 2050
Summer	Temperature (May-August)	19°C[2]	+ 5°C[1]	~27.3°C
	Precipitation (April-September)	496 mm[2]	- 20%[1]	~397 mm
Winter	Temperature (December-February)	-2.5°C[2]	+ 4 to 5°C[1]	1.5 to 2.5°C
	Precipitation (October-March)	451.7 mm[2]	- 10 to 20%[1]	~361.4 to 406.5 mm
	Atmospheric CO_2	~575 ppm[1]	+ 130%[1]	~1320 ppm[1]

crop. As the growing season begins, vines are subjected to conditions that threaten their survival and productivity. Summer months can bring variable temperatures and rainfall, as well as other potentially detrimental weather conditions, such as storms or high winds (VQA Ontario, 2015). While the Niagara Region will likely be affected by changing climate conditions, the predicted changes may not be as detrimental to this region as they may be to others for a variety of reasons.

With the predicted increase in CO_2 levels by 2100, grapevine health and growth will be affected. In particular, these increases may actually be of benefit to overall plant and vine health, as photosynthetic rate increases in the presence of increased CO_2 (Bindi, 2001). This higher CO_2 concentration would be most beneficial to the plant earlier in the growing season, while its nutrient uptake is maximal, to facilitate the production of new l1iving tissue and fruit. At this time, growing carbon sinks are the main regions that require increased fixation of atmospheric carbon. Upon grape maturation, increased CO_2 concentration is no longer beneficial to the plant, though its presence has not been found to have adverse effects on quality or flavour of final wine products. Thus, projected increases in atmospheric CO_2 on their own should not cause any significant negative impacts on the wine industry (Bindi, 2001).

In contrast to the predicted benefits of increased CO_2, the projected decrease in rainfall is expected to cause challenges for the icewine industry. Under drought conditions, photosynthesis is inhibited and CO_2 uptake is thus decreased (Flexas, Escalona and Medrano, 1999). Under slight water stress, this would reduce vine growth and grape production, yet produce sweeter grapes (Wang, Sun and Chang, 2015). Reduced precipitation could also introduce a need for irrigation in some wine-producing regions. However, due to the high water-retention of clay-rich soils, and the fact that Niagara currently receives significant rainfall during the growing season, this may not be of great concern to most local vintners (Hannah,w2 et al., 2013; VQA Ontario, 2015). Additionally, reduced rainfall in wine-producing regions could limit the rate and diversity of diseases that affect grapevines and berries, as much of their growth and dispersal is influenced by water availability (AAFC, 2008). Thus, a reduction in precipitation throughout the growing season in Niagara would be mostly beneficial to grape growth and wine production.

Increased summer temperatures will also certainly affect grape production from the Niagara Region. This change will lengthen the growing season and increase the number of growing degree days (the sum of temperatures on days above 10°C). This should lead to an increase in speed at which grapes ripen (VQA Ontario, 2015). However, excess heat causes further water evaporation, and will create a greater need for damage-reduction techniques, including application of water to grapes to prevent heat stress of the vines and the resulting reduced grape yield from dehydration (Hannah, et al., 2013). Thus, temperatures will affect the productivity and water usage of vineyards in the Niagara Region.

WINTER

As the growing season ends, grapes destined to become icewine face a new and greater set of challenges. The greatest threat that climate change poses to the icewine industry is likely through increased winter temperatures. During the El Niño event in the winter of 1997-1998, winter temperatures averaged 6°C above normal, which resulted in $10-$15 million in losses to the icewine industry (Cyr and Kusy, 2007). Based on observations from previous warm-weather years (1997-1998 and 2001-2002), the predicted increase in temperature by 4-5°C will be sufficient to delay harvest from the ideal time period of mid-December or mid-January to February or March (Turvey, Weersink and Chiang, 2006). Due to this delay, some growers may be forced to harvest non-frozen grapes, which would result in low-quality, late-vintage table wines, or simply grape juice (Turvey, Weersink and Chiang, 2006). Growers who wait for optimal conditions may expose their grapes to additional risks.

The longer grapes are left on the vine, the greater the risk of significant crop loss due to predation, rot, and wind or storm events (Cyr and Kusy, 2007). During harsher winters, the risk of grape loss to birds and deer is minimal, and netting can be used to further minimize risk. However, during warmer winters, some birds, such as Starlings, may not migrate south, increasing the predation risk for grapes (Cyr and Kusy, 2007). While there are strategies to limit predation, such as netting, they are only partially effective. The risk of rot also increases drastically as winter progresses, as freeze-thaw cycles can stress grapes and cause them to rupture, making them more susceptible to rot. Different varietals are affected by each potential danger differently; for example, freeze-thaw cycles are more dangerous for thinner-skinned Riesling grapes than Vidal grapes (Nurgel, Pickering and Inglis, 2004).

The delayed icewine harvest will have two other major effects. Partially frozen icewine grapes only yield 15-20% of the juice volume, in comparison to that produced by autumn-harvested grapes (Cyr and Kusy, 2007). This is a result of partial freezing and dehydration that occurs through evaporation. Such volume reduction is necessary to achieve the required sugar concentration, represented by a brix value of 35°. However, excess dehydration occurs when grapes are left longer on the vine, and it can further reduce juice yield, which greatly cuts into the profits of winemakers (Cyr and Kusy, 2007).

A second major effect concerns vine health. If grapes are harvested in the fall, there is time between harvest and winter in which vines can store nutrients and prepare for winter. However, if the vine continues to devote resources to the grapes, it cannot prepare as effectively for winter (Turvey, Weersink and Chiang, 2006). This means vines that produce icewine are inherently more susceptible to winter damage than their table wine-producing counterparts. As icewine harvest is pushed back, vines selected to produce icewine are more likely to be damaged by winter storm events.

The CGCM3 climate model also predicts a 10% decrease in winter precipitation. This would lead to a reduction of insulating snow cover, and potentially increase the risk of winter damage. However, the predicted precipitation decrease may not take into consideration the impact of reduced ice cover on Lake Erie and Lake Ontario. The lake effect is one of the factors that makes the wine industry in Niagara successful by moderating cold winter temperatures. However, from late autumn into early winter, the Great Lakes create a great deal of instability in the surrounding weather systems (Notaro, et al., 2013). This instability is a result of their role as a source of moisture, but also due to the higher temperature of the water surface compared to the surrounding air. As winter progresses, increased ice cover decreases evaporation from lakes, and partially negates differences in temperature, which reduces instability. During the unstable period, areas directly around the Great Lakes may experience greater diurnal temperature fluctuations due to turbulent fluxes (Notaro, et al., 2013).

Warmer winters may delay the formation of significant ice cover and decrease the overall ice cover, increasing the duration of the unstable period (Figure 3). This could result in an increase in extreme weather events and freeze-thaw cycles later in the winter, when temperatures would normally have stabilized, damaging both the grapes and the vines (Vihma, 2014). Decreased ice cover could also result in increased snowfall in the surrounding regions, due to increased evaporation

FIGURE 3: FREEZING GREAT LAKES REGION. This satellite image depicts typical Great Lakes ice cover in a typical a non-El Niño year (NASA, 2005).

from the lakes (Burnett, et al., 2003). This may be beneficial to the icewine industry, as increased snow cover may blanket rootstocks and protect them from further damage. Although warmer summer temperatures and increased snow cover may benefit grape health, climate change is nonetheless still likely to severely damage the icewine industry due to delayed harvest and crop loss.

PESTS

The effects of climatic warming on viticultural pests should be considered in reference to the production of wine. In particular, *Harmonia axyridis* and *Paralobesia viteana* should be examined. Pests will have some influence on icewine production in Niagara. They can damage crops before harvest, reducing the yield and quality of the wine. They may also lure predators, such as birds, into infested vineyards. Upon entry, these predators can damage the grapevines or consume the grapes (Cyr and Kusy, 2007). Additionally, MALBs secrete a chemical compound that produces an unpleasant flavour in wine. Dead MALBS may also be harvested along with icewine grapes, and can release IPMP during the crushing process, which taints the wine (Pickering et al., 2008).

Paralobesia viteana, the grape berry moth, is the most economically significant pest insect in Canadian winegrowing regions (Figure 4) (Trimble, 2015). It causes damage throughout each stage of development, and can produce 3 to 4 generations annually. The location in which moth eggs are laid is seasonally dependent. In early spring, eggs are deposited on the stems, leaves, and young fruit of the vine. After spring, eggs are laid almost exclusively on the fruit (Botero-Garcés and Isaacs, 2003). After 4 to 8 days, the eggs hatch. Spring larvae feed on the new grape shoots, flower buds, and fruit. Larvae of second the stage and onwards burrow into mature fruit: each individual larva can damage up to 7 berries. The destruction of shoots and flowers also further reduces yield. Additionally, injured berries prematurely ripen and spread rot within the cluster (Botero-Garcés and Isaacs, 2003). Following maturation, spring larvae cut flaps in leaves to serve as pupation chambers. Fall or late summer generations pupate on the ground inside fallen leaves. The moths overwinter in their pupal stage, and first generation adults emerge in late May to mid-July, followed by later generations throughout the summer (Botero-Garcés and Isaacs, 2003).

Moth development and initiation of diapause, the period in which developmental delay begins in response to adverse environmental conditions, are dependent on photoperiod and temperature. Photoperiodic cues determine whether or not larvae will develop into diapausing pupae or continue into adulthood. After the post-summer solstice, all eggs will pupate. Thus, the number of degree-days before this point determines moth voltinism – the number of generations (Tobin, et al., 2008). According to the model proposed by Tobin, et al., voltinism will be significantly affected once mean temperature increases by 2 or more degrees, which is within the predictions of the

FIGURE 4: AN ADULT GRAPE BERRY MOTH. Of the pests that affect Niagara's wine industry, this insect is likely to be most economically damaging in the future. This moth lays its eggs within plant tissue, particularly in grapes, and its larvae causes significant grape damage (Reago and McClarren, 2014).

climate model. Therefore, milder winters and warmer springs will influence voltinism. Adults will leave overwintering pupae sooner and in greater numbers, which increases the chance of oviposition before the solstice. This will result in additional generations of adults. Hotter summers will not, however, affect voltinism.

This model of grape berry moth voltinism does not consider food availability or larvae mortality beyond 34°C. However, there is no projected significant decline in grape production in the future. The climate model also does not predict extended periods of elevated temperature at or surpassing 34°C. Therefore, this model may still be considered relevant with respect to climate change.

Another viticultural pest of concern is *Harmonia axyridis*, commonly known as the multicoloured Asian lady beetle, is an invasive species that has spread throughout North America (Figure 5). MALBs are predators of common agricultural aphids and are often used as a method of biological control in croplands. Though usually considered a 'helpful' species, these lady beetles have become pests in Ontario vineyards (Pickering, et al., 2008). During the fall, MALBs have a tendency to accumulate in vineyards, where they gather on and within grape clusters. When stressed or killed, this species releases 2-isopropyl-3-methoxypyrazine (IPMP) as a defense mechanism. This chemical is the source of 'ladybug taint' in wine, and the resulting flavor is unpleasantly rancid and 'green' (Pickering, et al., 2008).

FIGURE 5: TWO MULTICOLOURED ASIAN LADY BEETLES. This invasive species was introduced to control pests in North American cropland, but has since grown in abundance. If present on grape bunches, it may be incorporated into wine, where it causes an unpleasant taste known as 'ladybug taint' (Taken July 2015).

Prediction of changes in MALB populations requires an understanding of tritrophic interactions. Aphid population density is a limiting factor of the growth of MALB populations. Aphids are dependent on mutualistic interactions with cornfield and winter ants for survival. Other predators, especially parasitoids that attack aphids, also control their numbers (Sentis, et al., 2015).

Climatic warming is predicted to reduce aphid abundance, which will likely result from a breakdown of the mutualistic interaction between common aphids and winter ants that defend them. These ants prefer low temperatures and so their aboveground numbers will dwindle as the climate warms. This will likely expose aphids to attack (Barton and Ives, 2014). High atmospheric CO_2 levels will impair aphid escape response, and increase successful attacks (Hentley, et al., 2014). Finally, reduced precipitation and hotter summers will decrease sap production of the host plants upon which phytophagous aphid populations feed (Barton and Ives, 2013).

Warmer winters and springs would reduce MALB overwintering mortality. Such weather would also increase their range (Selvaraj, et al., 2013) and attack rates (Barton and Ives, 2014). Aphid parasitoids fare poorly in hot environments (Sentis, et al., 2015). Some studies predict that these factors will cause a spike in MALB numbers. However, warming decreases prey availability, constraining predator population density. Higher temperatures have also been found to decrease the lifespan of lady beetles (Sentis, et al., 2015). Therefore, it can be concluded that MALB population fluctuations due to climate change are unpredictable without substantial further research (Trimble, 2015).

CONCLUSION

Based on the predictions of the CGCM3 A2 model, the effects of climate change on the Niagara icewine industry are uncertain. While the potential positive effects are numerous, the severity of negative winter impacts cannot be ignored. Harvest delays, destruction of crops by storms, and variable temperatures are projected to causes losses in the future. Historical evidence also supports these loss predictions. Though the effects of climate change are difficult to predict and all climate models contain inherent flaws, it is valuable to examine these predictions. Therefore, it would be most economically favourable for viticulturists to keep careful observational records of local conditions in their vineyards with this model in mind.

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VINTAGE 2015