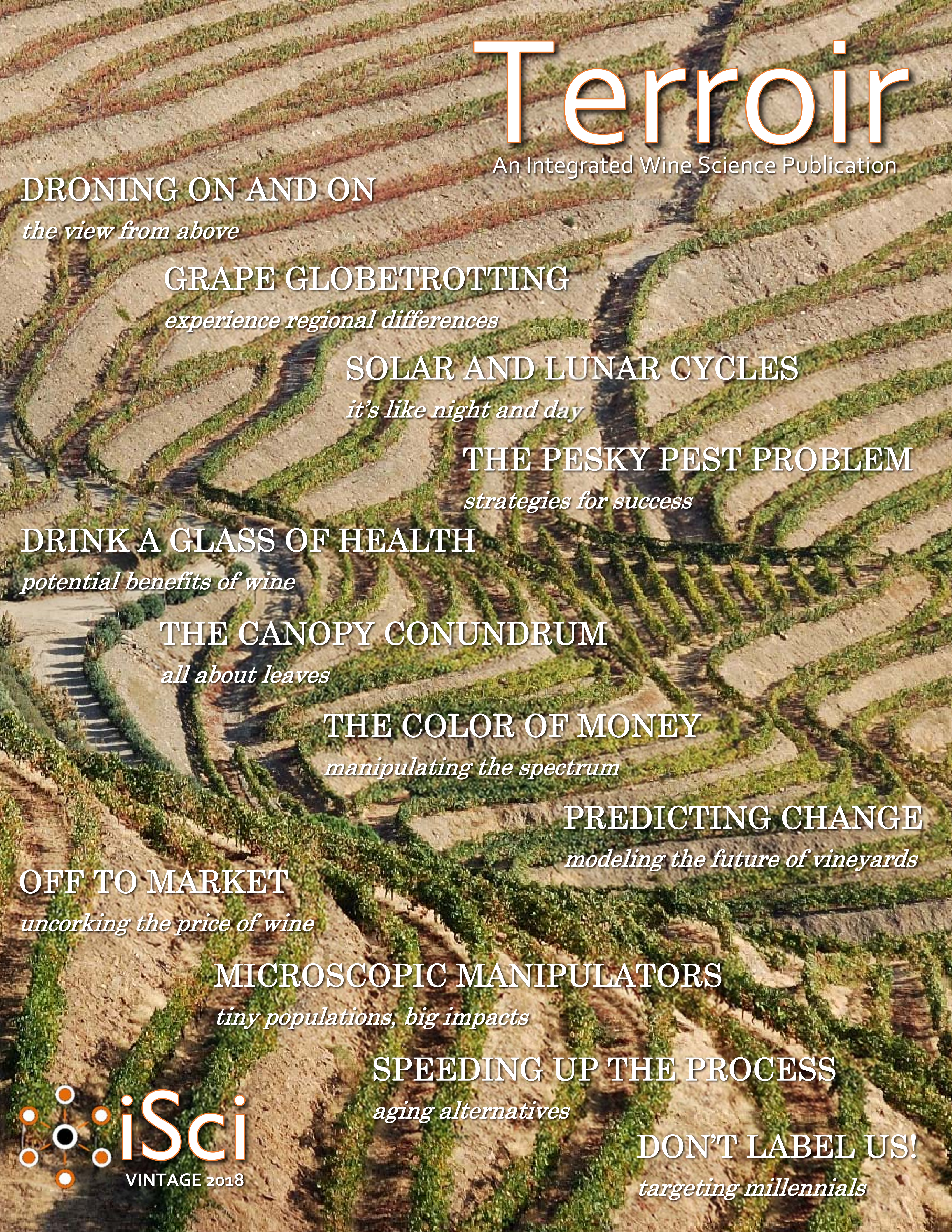

Terroir

An Integrated Wine Science Publication

DRONING ON AND ON
the view from above

GRAPE GLOBETROTTING
experience regional differences

SOLAR AND LUNAR CYCLES
it's like night and day

THE PESKY PEST PROBLEM
strategies for success

DRINK A GLASS OF HEALTH
potential benefits of wine

THE CANOPY CONUNDRUM
all about leaves

THE COLOR OF MONEY
manipulating the spectrum

PREDICTING CHANGE
modeling the future of vineyards

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uncorking the price of wine

MICROSCOPIC MANIPULATORS
tiny populations, big impacts

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

WINE SCIENCE

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

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

This Publication is written by members of the ISCI 3A12 class of 2018

Cover Image: View of the terraced vineyards in the Portuguese wine producing region of the Douro. Rosino. Uploaded to Commons on 24 December 2010. Table of Contents Image: Learning about wine from Will Roman of Rosewood Estates. Russ Ellis. 2018

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EDITOR: Russ Ellis

Precision Viticulture in Drones:

The Applicability of Unmanned Aerial Vehicles (UAV) in Monitoring Vineyards

Chen Chen, Sarah Eshafi, Megh Rathod, Chris Simon

Winemaking is a delicate process that has taken centuries to master. From cultivating vines to constant maintenance, a lot of expertise and precision (and even luck!) go into growing the best quality grapes at the highest possible yields. Greater demands for wine have led to the integration of new technologies within viticulture. One exciting new technology that has been picking up momentum is unmanned aerial vehicles (UAVs), also known as drones. UAVs gather aerial images and overcome some of the limitations of conventional aircrafts and satellites. They are equipped with imaging sensors in both near and far infrared spectral bands to provide detailed information, allowing the vintner (winemaker) to go beyond manual inspection. Vintners can gather useful characteristics about vines, such as vine vigour, water stress, and disease prevalence, to then variably apply fertilizer, water, and pesticides according to the needs of specific areas. This process is known as precision viticulture. The use of drones equipped with multispectral imaging is a powerful new technique with great potential to improve viticulture.

INTRODUCTION

Agriculture is arguably the reason humans have developed such sophisticated societies. The demand for food continues to expand due to a rapid increase in human population. Over the years, the primitive practice of farming has seen new challenges and new innovations to match. Specifically in viticulture, vintners have constantly been seeking ways to increase the quality of their grapes and maximize their yields. Agrarian science, regarding viticulture in particular, is an expanding field which incorporates new techniques in science and engineering to grow healthy grapes while also practicing sustainable farming. In order to obtain the high-quality fruit that vintners require, they need to look beyond the plant.

Monitoring a multi-hectare vineyard for specific measurements is a daunting task for vintners. Traditionally, all grape vines in a vineyard were treated and harvested as if they were homogenous in quality and yield. However, this is inaccurate, since there can be significant differences in vine and soil characteristics within a small area (Monjino and Gajetti, 2017). How can one tell if a cluster of Cabernet Sauvignon three rows away from another cluster has the same water demand? Insufficient water can lead to low levels of photosynthetic activity, resulting in low sugar levels, which then leads to low alcohol levels. This can result in grave consequences for a vintner as a wasteful yield would put the winery out of commission for a year, or make a compromised low quality product. This necessitates precision viticulture, recently made more feasible by technology such as unmanned aerial vehicles (UAVs).

The margin of error of winemaking is extremely slim: grape farmers only have a narrow window in time to acquire high quality crops (Bohle, Maturana, and Vera, 2010). Grapes ripen once annually, and roots are established many years in advance. In such a high stakes business with large investment costs, vintners benefit from as much oversight as possible, especially when many variables such as rainfall are out of their control. One way of obtaining valuable information is through the use of multispectral imaging mounted onto UAVs.

FIGURE 1: A UAV in a vineyard Example of a UAV in action in a vineyard (Matese et al 2018).

In recent years, the use of UAVs for crop management have improved significantly due to technological advances, cost reductions, lighter imaging equipment, and pre-programmed flights (Gago et al., 2015). Thus, UAVs present an exciting opportunity to monitor crop fields with high spatial resolution. Optimal UAVs for agricultural imaging are similar to the one pictured above in Figure 1, as these are able to carry the required payload and are cost-effective. Top UAVs for this type of work need to have Global Positioning Satellite (GPS), First Person View (FPV), stabilization technology, excellent cameras, and pre-programmed flight navigation (Corrigan, 2018). However, the specific capabilities and features of the UAV should be catered to the individual needs of the vintner. UAVs capture images of the entire vineyard that can be rapidly analysed for a wealth of accurate information. This information can be used to tailor crop management to a vineyard's specific needs.

MULTISPECTRAL IMAGE TECHNOLOGIES

Multispectral and hyperspectral sensor technologies allow the farmer to see more detail than the naked eye or a single wavelength can provide. A multispectral image sensor captures image data at specific wavelengths across the electromagnetic spectrum (Ferrato, 2012). Wavelength-sensitive filters may be used to separate light from wavelengths both within and beyond our visible spectrum, such as infrared (Ferrato, 2012). This imaging technique works based on the principle that every surface reflects back some of the light that it receives. Objects having different surface features reflect or absorb the sun's radiation in different ways. The ratio of reflected light to incident light is known as reflectance and is expressed as a percentage (Ferrato, 2012).

The images recorded using the UAV are dependent on the specific cameras used and the wavelengths of light they capture. This is an important consideration because the wavelength used determines what can be observed.

NIR (Near-Infrared) corresponds to the wavelengths in the 700 to 1300 nm range, and there is a very strong correlation between reflectance in this band and the level of chlorophyll in the plant (Corrigan, 2018). Highly significant variations of the reflectances in this range are produced when a plant is under stress. Along with the red spectral band, infrared is extensively used for compiling most of the vegetation indices in agriculture (Corrigan, 2018). NIR is sensitive to the leaf cellular structure and provides critical data to monitor changes in crop health (Corrigan, 2018). Thus, analyzing a plants spectrum of both absorption and reflection in visible and in infrared wavelengths can provide information about the plants' health and productivity.

TARGET CROP ROW IDENTIFICATION

An important part of a UAV operation in viticulture is distinguishing the pixels in the image which represent the target grapevines from the rest of the land, including soil, pebbles, and weeds (Peña-Barragan et al., 2013). This allows further analyses to only be applied to the grapevines, leading to higher accuracy. Solely analyzing pixels of an aerial image to make this differentiation can be difficult as spatial resolution may not allow for differences to be resolved, and weeds and crops can be spectrally similar (Christiansen et al., 2017). To mitigate these issues, an automatic definition of crop rows should be established to distinguish grapevines from other objects through their relative position to the rows (Peña-Barragan et al., 2012). Modern agricultural crops are usually grown in parallel, regularly spaced rows, making row orientation identical for the entire vineyard (Bah, Hafiane, and Canals, 2018).

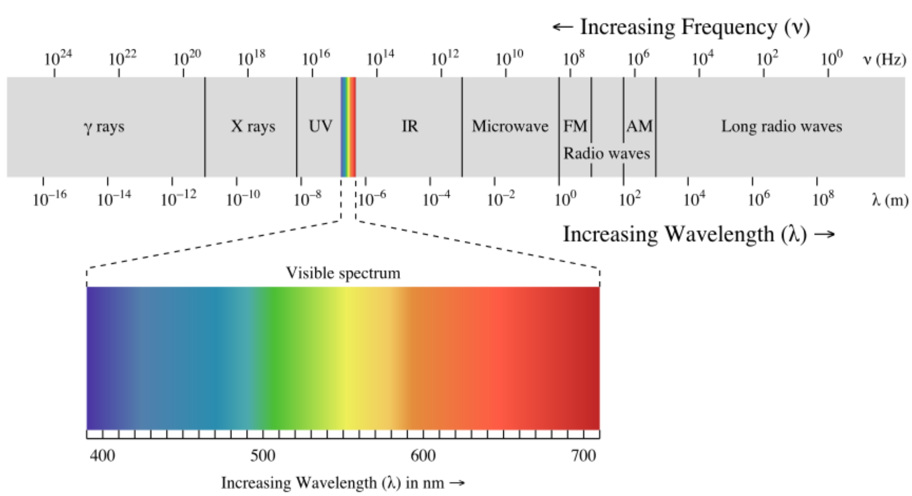

FIGURE 2: EM SPECTRUM Labelled diagram of various wavelength ranges of electromagnetic (EM) spectrum (Ronan, 2007).

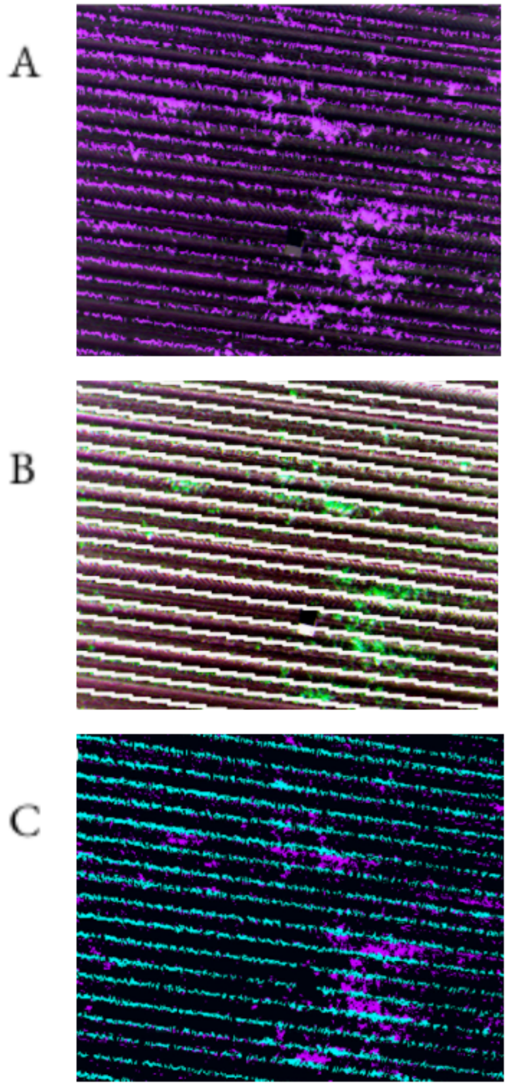

FIGURE 3: STEPS OF OBIA PROCEDURE Partial outputs from maize field in Arganda del Rey, Spain of the object-based image analysis procedure at various sequential steps generated from a UAV-produced photo. The steps shown in order from panels A to C illustrate how vegetation objects (violet) can be separated into crop objects (cyan) and weed objects (green) by identifying row objects (white) based on the known crop row angle orientation (Peña-Barragan et al., 2013).

In an object-based image analysis (OBIA) procedure, several steps are required to accurately identify crop rows. First, row orientation is calculated from analyzing images from several altitudes (Peña-Barragan et al., 2012). Next, from one image, the vegetation objects (pixels representing plants), shown in purple in Figure 3A are distinguished from non-vegetative objects (black, Figure 3A) since they reflect different wavelengths on the EM spectrum. Then, only vegetation objects which follow the established row orientation angle and merged to adjacent objects to form the crop row structure (white, Figure 3B). The other vegetation objects likely represent weeds and other plants (green, Figure 3B). Last, the set gap between rows and borders of the vineyard induce a termination in the aforementioned merging process (Peña-Barragan et al., 2013). The resultant output (Figure 3C) successfully differentiates crops (cyan) from other plants (purple) and soil (black) almost 100% of the time (Peña-Barragan et al., 2013). Automatically identifying the target crops to analyze in UAV images is the first step to access a plethora of metrics that can assist the vintner in precision viticulture.

After identifying which pixels represent grape vines, these pixels can be analyzed for certain metrics. Precision viticulture allows for vintners to identify specific zones which need more treatment compared to others, with the resolution of a few centimetres (Bah, Haffiane, and Canals, 2018). In order to achieve this feat, vintners utilize specific metrics to evaluate the health and/or quality of a plant. This information would signify how much water, fertilizer, pesticide, or herbicide to apply in each zone of the vineyard.

VINE VIGOUR ANALYSIS

One useful metric UAVs can survey is vine vigour variability. The leaves of vines that receive enough water, fertilizer, and perhaps pesticides would display higher vigour than those with insufficient levels. The normalized difference vegetation index (NDVI) is a common index used to estimate vine vigour and is derived from remotely sensed images, meaning it requires an aerial vehicle or satellite. It is calculated using measurements of canopy reflection and absorption obtained by a multispectral camera measuring in the red-green-NIR spectral bands (Matese and Di Gennaro, 2018). The measurement has a strong correlation with chlorophyll content (Caturegli et al., 2016) and thus with biomass and photosynthetic activity (Hall et al., 2003). A higher NDVI value on a scale from zero to one indicates a healthier plant. However, it is important to note that obtaining the highest possible NDVI is not always the goal. In fact, grapes in low vigour zones tend to have higher concentrations of flavour compounds and higher sugar content, leading to greater alcohol content. On the other hand, vines in high vigour zones tend to have greater yields (Filippetti et al., 2013). There is a delicate balance desired in vineyard management and it is up to the discretion of each vintner to make decisions based on NDVI.

The vineyard can be virtually partitioned in order to visualize spatial vigour variability, providing useful information for vintners. For example, Caturegli et al. (2016) variably fertilized and subsequently measured NDVI across a plot. Their results, shown in Figure 4, indicate that the regions fertilized to the greatest extent have the largest NDVI values (i.e. the dark green blocks), while the areas with little fertilization have mid-range NDVI values (i.e. the light-green to yellow blocks). Outside of the six gradient test zones in Figure 4, Caturegli et al. did not fertilize the plot. Their results imply that viticulturists can correct for vigour variability in their vineyards by analyzing an NDVI image and selectively fertilizing specific regions. This would reduce the need for fertilizers and its associated costs and environmental impacts (Caturegli et al., 2016).

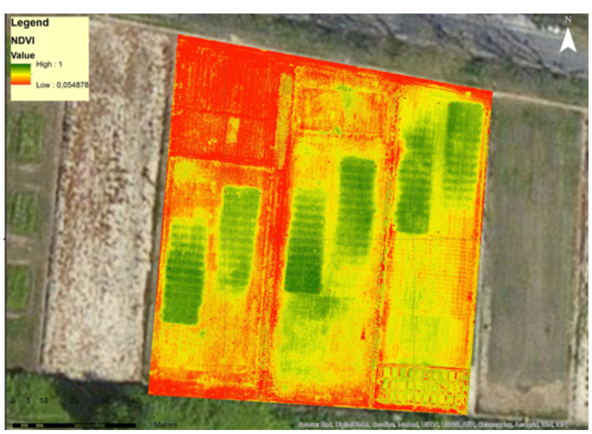

FIGURE 4: VARYING NDVI IN A FERTLIZED FIELD
Rate of fertilization using ammonium sulfate strongly correlates to NDVI level (Caturegli et al. 2016)

WATER STRESS: SEEING BEYOND THE PLANT

Water is quintessential for life, and managing the amount of water given to each zone of the vineyard is important for ensuring grape quality and also sustainability. Imaging techniques which utilize infrared waves allow features containing water to be easily detected, located, and delineated.

The utilization of infrared and thermal imagery requires an understanding of key plant photosynthetic processes. Plants gain their energy through photosynthesis, to which water is a vital reactant. The pigment molecule that allows for photosynthesis is chlorophyll. Chlorophyll fluorescence is an indicator of plant photosynthesis and thus water use efficiency under water stress (Gago et al., 2015). This is an ideal opportunity for multi-spectral and thermal images from UAVs to be utilized. UAVs are of great interest to vintners because they can provide valuable information about plant biophysical parameters (e.g. stomatal conductance and leaf water potential) (Gago et al., 2015). Tracking water availability can be done by understanding the evapotranspiration process. Evapotranspiration is the process in which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants (Jensen and Allan, 2016). Under water stress, evapotranspiration is weak and the canopy temperature increases (Zhang and Zhou, 2016), which causes the dehydration of the plant. For a specific atmospheric condition, the ratio of actual and potential evapotranspiration, which compares healthy to unhealthy grapes, can be used as a proxy for crop water stress index (Zhang and Zhou, 2016).

Thermal imaging allows for a quick determination of canopy surface temperature that, when linked to transpiration, can give an idea of a vine's water status. While NDVI is an indirect measure for water stress, soil estimation models take a direct approach since they consider moisture content, soil texture, surface roughness, presence of ions, and organic matter (Corrigan, 2018; Gago et al., 2015). Therefore, soil estimation models are an excellent indication of water stress, and can visually demonstrate to a vintner the exact locations that can receive more efficient irrigation.

DISEASE DETECTION

A major cost of grape farming is the defense of crops against pests and disease (Molenhuis, 2015). When ailments occur, quickly reducing the local spread of disease damage prevents further crop loss. As a preventative measure, some vintners choose to spray their entire fields with pesticides and/or herbicides. This type of treatment has environmental implications, as the unintentional drift of sprayed pesticides negatively affects terrestrial and aquatic ecosystems (Fornasiero et al., 2017). Selective spraying is a preferred treatment pattern but it can be difficult and time-consuming to identify individual areas for treatment with manual sampling. UAVs can aid vintners by providing detailed aerial images that can be processed to reveal specific locations needing attention.

Plants infected with a disease can often undergo a change to their leaf morphology, colour, vigour, and abundance (Jermini et al., 2010). A notable example is leafroll disease caused by the grapevine leafroll-associated virus 3, which causes leaves of infected vines to develop a dark reddish colour. Aerial imaging with multispectral sensors can differentiate between green and red/NIR. As a second example, downy mildew is a disease which impairs leaf physiology by reducing photosynthetic capacity (Jermini et al., 2010). The relative photosynthetic activity of a plant can be determined using aerial images by detecting differences in light absorption in the 650-820 nm range (Atherton et al., 2016).

However, aerial imaging has limitations, as a visually discernible change is needed for accurate detection. Underground pests, such as phylloxera , infest primarily the roots of grape vines (Gale, 2003). Such pests are not detectable by aerial imaging until they have caused enough harm to induce significant leaf damage. Furthermore, some variants of wine grapes can appear visually asymptomatic while infected and still have the potential to transmit the disease. This is the case with Sauvignon Blanc vines when infected with a specific strain of leafroll disease (MacDonald et al., 2016). However, many diseases can still be detected early and substantial crop loss can be prevented.

APPLICATION OF GIS MAPPING

Geographic information system (GIS) is a powerful computational tool used to correlate data to a map. As a final step in data interpretation, GIS is applied to link GPS coordinates logged by the UAV during flight to overlay aerial images onto a map. These images are synchronized to the known row structure of the vineyard. This visual enhancement is an essential step in creating the output that vintners can use to interpret data from their vineyards (Matese and Di Gennaro, 2018).

The evaluation of the data interpretation is the next step in precision viticulture. Being aware of the variability within a vineyard is important, but the key step is addressing it. Using GIS, vintners can evaluate the data on NDVI, water stress, and disease detection to create treatment zones. As a result, vintners can variably apply fertilizer, water, and pesticides to optimize the treatment of their plots and limit adverse environmental impacts (Mathews, 2013).

ADVANTAGES AND LIMITATIONS

While other remote sensing tools, such as satellites and aircrafts have been used in viticulture, UAVs overcome some of their limitations. Specifically, UAVs are more affordable and allow for more flexibility in flight planning, scheduling, and data acquisition (Caturegli et al., 2016). Since UAVs are able to fly closer to the ground than satellites and aircrafts, they can have a much higher spatial resolution. Moreover, a series of images captured by a UAV can be digitally stitched together to cover the same field of view as a single satellite image, and various algorithms can remove random noise and optical artifacts. Also, they are relatively easily accessed by vineyard owners and UAV operators, who could interchange multiple camera attachments on a single drone between uses. Additionally, UAVs can be used on overcast days with better results than satellites and aircrafts since they fly below cloud coverage (Caturegli et al., 2016). Alternatively, compared to traditional manual measurements, UAVs are more time efficient and provide quantitative data (Caturegli et al. 2016). Furthermore, vintners can learn how to fly drones relatively easily reducing the need for external operators.

Two major limitations to the use of UAVs in agriculture are flight times and payload capacities (the maximum weight a UAV can carry). They are closely related, as more power is needed for both longer flight times and an increased payload capacity. Most drones applicable to agricultural imaging only have flight times under sixty minutes (Valencia, Hidalgo, and Calle, 2017). Increasing flight times requires more power and thus larger batteries. However, batteries, the only power source, contribute a significant portion of a UAV's weight alone (Valencia, Hidalgo, and Calle, 2017). There is a diminishing power-weight ratio (the motor's work rate compared to the weight of the vehicle)

as the battery capacity increases, since an increase in capacity leads to significant increase in weight.

Having multiple batteries replaced between flights is the most practical solution for limited flight times and the pilot needs to be aware of the remaining charge throughout flight. However, the advantages of the use of UAVs outweighs the associated limitations, and there continue to be efforts by both researchers and commercial companies to improve flight times and motor efficiency.

COST ANALYSIS

When considering whether or not to implement new technology in any industry, one of the essential questions is always, is it financially beneficial? To answer this question, the cost of utilizing UAV remote sensing must first be determined. This is a complicated task as market values in different regions vary, as do labour costs. Total costs greatly depend on the additional expertise vintners require with regard to flying UAVs and data interpretation. Moreover, each nation has different regulations. For example, Canada necessitates an extra certificate if a UAV used in agriculture weighs over 25 kg with its payload, adding training fees into consideration (Transport Canada, 2018).

TABLE 1: UAV OPERATION COSTS Costs predicted for each component of a UAV precision viticulture operation in Italian viticulture context. These were obtained from computer modelling in a study completed in collaboration with Deloitte Consulting S.r.l. Aviation & Transportations (Mondino and Gajetti, 2017).

Fee	Price (CDN converted from Euros)
UAV	1,510.00 - 22,650.00
Insurance (annual)	755.00
Rotor replacement (each) - average 1 annually	176.50
Battery pack (each) - average 3 annually	36.24
UAV pilot* - average 200 hours annually	30.11/hour
Data processing staff* - average 8 hours annually	30.11/hour
Tetracam ADC Snap[1] (Matese and Di Gennaro 2018)	4,543.50 (Tetracam Inc. 2018)
Tetracam uMCA 6 Rolling Shutter[1] (Pena et al 2013)	16,893.50 (Tetracam Inc. 2018)
Total in first year of UAV application	**13,356.60 - 46,846.60**

*optional depending on vintner expertise

[1]possible multispectral cameras, specifically used in studies cited in this review article

The characteristics of each vineyard also change the costs of a UAV operation. A larger vineyard requires more flying hours since the UAV must take more images to maintain the same field of view as other aerial vehicles while keeping high spatial resolution. This increases the number of battery packs purchased annually, rotor replacements, and labour costs for a UAV pilot and data processing staff, as necessary. Moreover, the climatic conditions at each vineyard dictate the type of UAV a vintner must purchase, and also affect maintenance and safety fees. However, regardless of these variances, some item and service costs remain consistent (Table 1).

TABLE 2: TRADITIONAL VITICULTURE COSTS

Manual Viticulture Costs: Average annual costs calculated from four years presented for an average 50 acre field in Ontario vineyards, according to Ministry of Agriculture Food, and Rural Affairs (Molenhuis, 2015)

Operation/Product	**Average cost per year (Canadian $)**
Labour (hand)	32,050.00
Labour (machine)	26,150.00
Insecticide	5,433.33
Fungicide	25,066.67
Herbicide	2,466.67
Machine maintenance	8,050.00
Fuel	16,050.00
Irrigation	8,300.00
Consulting	2,500.00
Weed control	11,500.00
Pesticide	12,183.33
Fertilizer	2,916.67
Total	**152,667.00**

For comparison, costs of operating a vineyard in Ontario which are relevant to the UAV applications presented in this article are displayed in Table 2. Unfortunately, there were no cost analysis data for UAV application and traditional vineyard operations published in the same geographical region.

Each of the costs in Table 2 can be reduced based on data obtained through UAV remote sensing. For example, should the NDVI be too low only in certain areas of the crop, fertilizers need only be applied to those areas, reducing fertilizer and labour costs. It may be possible to reduce enough costs from the $152,667 in operation costs (Table 2), which can then be spent to cover the extra costs of a UAV (Table 1). However, even if initial UAV costs are high compared to potential savings, UAV remote sensing may still reap a profit by improving efficiency, while surpassing current yields and improving quality. Ultimately, since the requirements for each vineyard varies considerably in size, environmental conditions, and existing expertise of its staff, the decision about using a UAV is vineyard-specific. However, the list of applications presented in this article is by no means exhaustive, and other benefits have yet to be realized.

SUMMARY

Drones have a wide variety of useful applications in viticulture and can capture vital crop information to be processed for optimal vineyard management (Figure 5). A multispectral camera, which can produce images in wavelengths outside of the visible spectrum, enables vintners to notice features of their vineyard that are undetectable to the naked eye. The camera is able to distinguish rows of vines relative to its surroundings in order to provide a more accurate analysis. It can also provide information on vine vigour, water stress, and disease stress, as well as the spatial variability of these factors. UAVs are arguably the best tool to implement the use of multispectral cameras, since traditional aircrafts and satellites are more expensive and must travel at a higher elevation. This UAV-based imaging technique enables the vintner to gain more precise and quantitative information about their vineyard while wasting less time surveying their plots. Using this information, farmers can variably treat their vines with water, fertilizers, and pesticides, leading to more cost-effective and environmentally-friendly farming practices. This is necessary with the ever-growing demand for grapes and wine, and will likely become even more apparent in the future. In fact, the most exciting aspect about the future for UAVs in viticulture is that it is a relatively new technology and its numerous promising applications have yet to be fully explored.

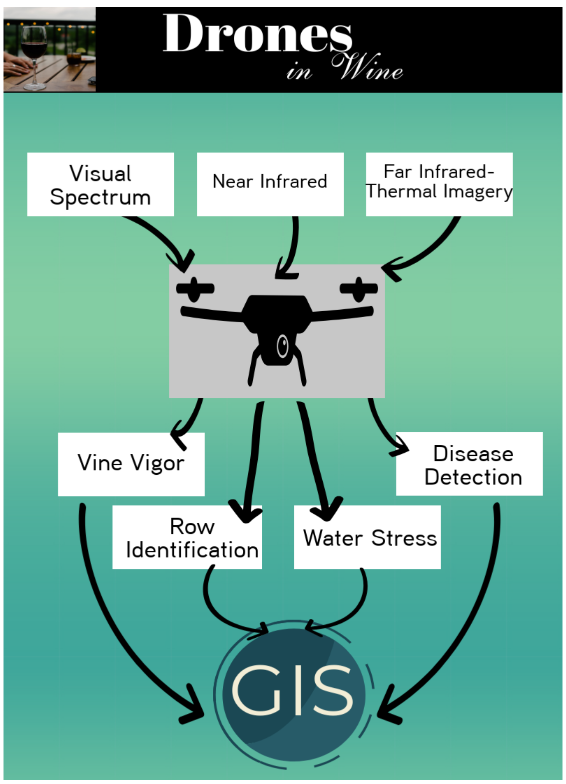

FIGURE 5: SUMMARY OF INFORMATION PROCESSING IN UAV OPERATIONS IN VITICULTURE UAVs collect data from a range of EM spectra to measure plant biometrics collected. The data generated are analyzed and evaluated using GIS for application to vineyards.

MORE TO EXPLORE

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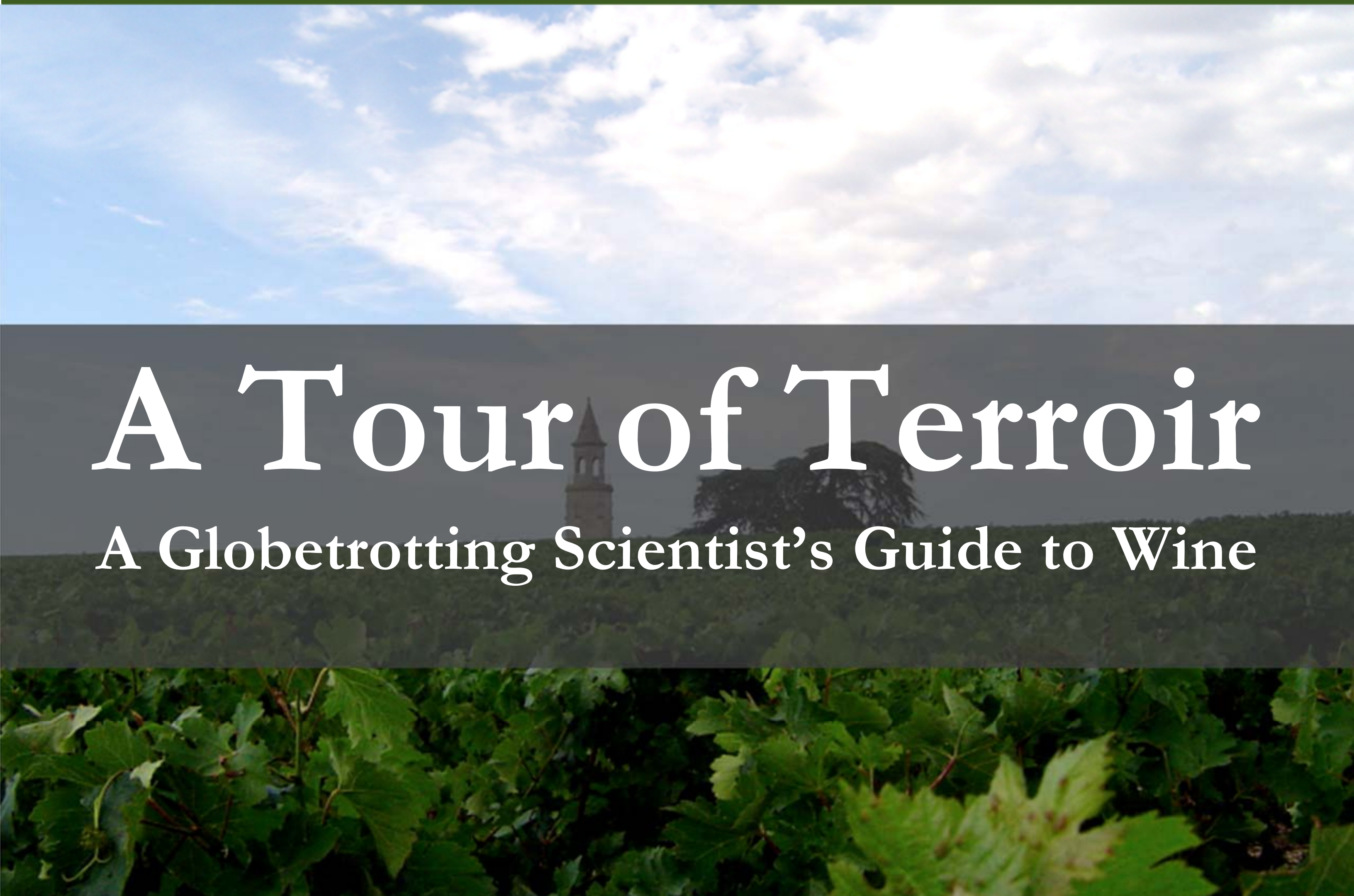

A Tour of Terroir

A Globetrotting Scientist's Guide to Wine

Kate Brooks, Emily Lalonde, Felipe Rivera-Madrinan, and Ruby Yee

Come along on a trip around the globe to four of the world's most environmentally diverse wine regions, and get a taste for the unique wines they each produce. Explore the variable temperatures, topography, soil, and precipitation which comprise the mesoclimates of La Rioja, Spain; Bordeaux, France; the Elqui Valley, Chile; and the Niagara Peninsula, Canada.

THE WORLD'S FAVOURITE FRUIT

The enjoyment and production of wine is universal to cultures all across the globe. Grapes are incredibly versatile – thriving in countless far-flung locations around the world, the wine they create is as varied as the environments in which they are grown.

While it is true that grapes are grown on nearly every continent, they require specific environmental conditions. Regions with extreme hot or cold temperatures are ill-suited to growing grapes. Temperatures below -20°C inflict permanent damage on most grape varietals; extended periods of temperatures in the 30-40°C range cause grapes to shrivel and can inactivate enzymes like Rubisco which are necessary for photosynthesis (Davenport, Keller and Mills, 2008; Artem et al., 2016). As a general rule of thumb, grapes are only grown between latitudes 51°N and 45°S, with a small band about 10° wide at the equator without grape cultivation (Tonietto and Carbonneau, 2004).

Even these temperature restrictions offer a large margin for variation. Delving a little deeper, there are plenty of other environmental factors which can vary greatly while still yielding wine-quality grapes. Take soils, for example – grapes are known to grow successfully on sandy soils, clay-based soils, and nearly everything else in between (Ubalde, Sort, Zayas and Poch, 2010).

In this way, the world of wine can be quite daunting to newcomers. Due to regional environmental variances the characteristics of wine resulting from the particular location of grape-growing seem almost impossible to understand. Stick with us as we guide you along a world-wide journey to discover the character and charm of some of the most unique wine regions in the world.

FIGURE 1: Our wine tour spans four diverse countries across three continents – a testament to the environmental versatility of grape vines (Harvey, 2008; Mono, 2013).

TERROIR… WHAT ON EARTH!

The French term "terroir" encompasses the belief that wine characteristics are derived from the unique environment in which the berries are grown (Dougherty, 2012). There are a multitude of geographic factors which are thought to influence both the olfactory and taste profile of wines, including climate, water drainage, soil, topography, and elevation (Dougherty, 2012). One of the most important parameters used to distinguish wine quality is phenolic compound content (Monagas, Bartolome and Gomez-Cordoves, 2005). These compounds possess benzene rings and are responsible for characteristics such as color, bitterness, and aroma (Monagas, Bartolome and Gomez-Cordoves, 2005).

Environmental factors directly impact the biosynthesis of phenolic compounds in wine grapes (Artem et al., 2016). Temperatures which exceed 35°C inhibit biosynthesis pathways, while moderate temperatures during the day and night (15-25°C) promote production and accumulation of polyphenols called anthocyanins in berry skins (Artem et al., 2016). High light intensity also increases the development of pigmentation in berries through increased rates of photosynthesis, resulting in accumulated glucides, an essential compound in the synthesis of polyphenols (Artem et al., 2016).

Hydrological conditions are also another vital aspect in the production of high-quality wine. Studies have shown that some water deficit in the soil has a positive effect on the accumulation of phenolic compounds, which determine olfactory and taste profiles of wine (Artem et al., 2016). As a result, soil characteristics including texture, structure, and thickness have an important influence on grape quality (van Leeuwen et al., 2004). Additionally, the effect of a moderate water deficit correlates with a decrease in berry size, affecting the skin-to-weight ratio and the resulting concentration of phenolic compounds (van Leeuwen et al., 2004).

Although there is evidence that the phenolic composition of wine is partially conditioned by geographic location, grape variety and wine-making techniques also play an important role in the extraction of polyphenol flavour compounds (Dougherty, 2012). Some scientists question the validity of terroir, although the existence of legally binding zoning laws which define specific locations in multiple countries is evidence of its near universal acceptance (Dougherty, 2012).

Here, we'll travel to four distinct wine-growing regions to explore how different aspects of their terroir contribute to the uniqueness of their wines (Figure 1). Our first region, beautiful La Rioja, Spain boasts a picturesque mountainous landscape from its location in the Ebro River Valley. As such, the topography is the predominant regional influence on its wine. The historically rich background of the Médoc in Bordeaux, France provides a traditional perspective on wine-making, as many of its terroir characteristics are not typically favourable for grapes. The Elqui Valley in Chile borders the Pacific Ocean and rises towards the Andes mountains, creating a region known for beautiful vineyards and scenic views. Lastly, the Niagara Peninsula in Canada provides an example of a wine-region idealized by its mild climate, moderated by nearby water bodies and geological formations. All of these regions produce viable grapes for wine-making – yet as you will witness, they are all incredibly distinct with respect to geographical characteristics.

FIRST STOP: LA RIOJA, SPAIN

La Rioja is a small and charming province in the northern Iberian Peninsula of Spain. With over 10% of the land in this province covered in vineyards, it's no wonder that La Rioja has remained one of the world's favourite sources of Spanish wines for two centuries (Lopez-Rituerto et al., 2012). The geographic location of this region is one of its most beautiful and unique characteristics. The province is sandwiched between two mountain subranges: Sierra de la Demanda in the west and Sierra de Cantabria in the east. These mountain ranges form a point in the N-W direction, protecting La Rioja from the coldest air masses moving off of the Atlantic Ocean while allowing a fair amount of climatic influence from the Mediterranean Sea (Vicente-Serrano et al., 2010). The Ebro River valley runs parallel to the Sierra de Cantabria range in the North-East of the province (Rodríguez Martín et al., 2007). The isolation of the valley from the sea air masses creates a semi-arid interior which covers most of the province, mimicking the characteristics of a continental climate, with temperate warm days and cool nights (Kottek et al., 2006). This temperature gradient is ideal for promoting the production of phenolic compounds in berries during growth, influencing the unique flavour, scent, and pigmentation of the fruit (Artem et al., 2016). A principal characteristic of the area is its aridity, a result of uncertain rainfall events and high potential evaporation in the center of the valley (Vicente-Serrano et al., 2010). The main section of the Ebro River basin contains considerable spatial variability contributing to the distinct terroir which exists between the three sub-regions: Rioja Alavesa, Rioja Alta and Rioja Baja (Vicente-Serrano et al., 2010) (Figure 2).

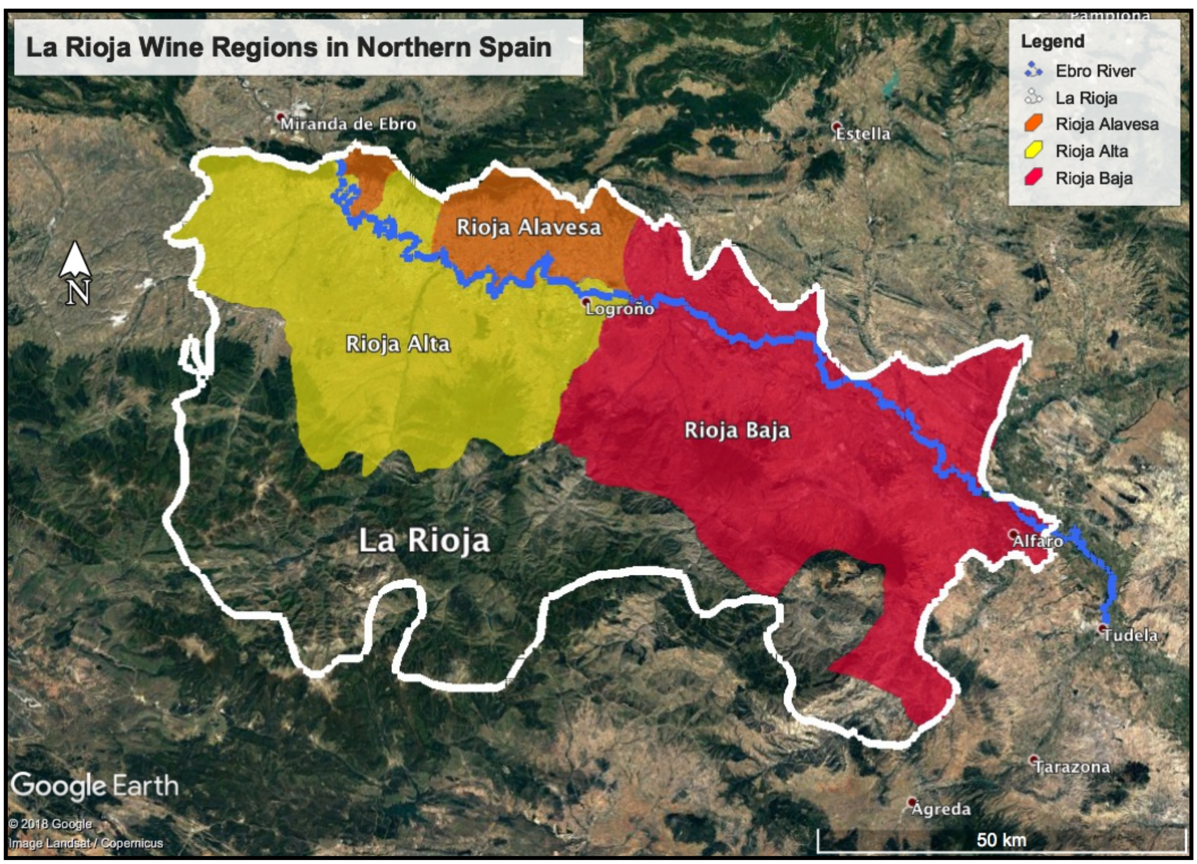

FIGURE 2: The Ebro River valley traverses La Rioja, which is split into three distinct sub-regions (Google Earth, 2018 [1]).

Rioja Alavesa is thought to be the most distinct region in the La Rioja province due to its chalky soils and high elevation (Lopez-Rituerto et al., 2012). When visiting Rioja Alta and Rioja Baja, you will notice the soil is orange-red in colour. This is a characteristic of iron-rich limestone-clay soils prominent in both of these regions (Lopez-Rituerto et al., 2012). One seemingly consistent attribute of all three is the presence of fine-grained, fertile alluvial soils, due to the close proximity to the Ebro River Valley (Vicente-Serrano et al., 2010). Historically high tectonic activity in the La Rioja region and the presence of Ebro River fluvial deposits are responsible for the diversity of soils and altitudes in the La Rioja (Garcia-Castellanos et al., 2003). What truly sets Rioja Alta and Rioja Baja apart is their difference in elevation, with Alta sitting over 300m above Baja. This distinction results in significantly different **mesoclimates**, with vineyards in Baja limited by hotter temperatures and greater water deficits (Puckette, 2013). As mentioned previously, water deficits are an important factor influencing berry quality and phenolic compound content, directly influencing the unique terroir of the final bottled product (Artem et al., 2016).

Mesoclimates: The combined effect resulting from climate factors generated due to the presence or absence of elevation changes, bodies of water, slope change, urban areas and vegetation cover. These processes occur on the scale of tens to hundreds of kilometres and in viticulture are often unique to a single vineyard site.

For many years the business model adopted in La Rioja by the majority of winemakers has been to put greater emphasis on volume rather than value, resulting in the practice of blending grapes from these three distinct regions (Alonso-Gonzalez, 2017). Spain is the leading wine exporter in the world by volume and one of the only European countries without concrete zoning policies for terroir. However, as the focus of many wine consumers and producers has shifted towards the uniqueness of certain locations and vineyards, La Rioja has begun to move away from these blends. As a result, zoning policies and identification of origin certificates are being developed to protect vineyards against fraud and to accentuate their originality and value (Alonso-Gonzalez, 2017).

Tempranillo is the featured wine of La Rioja, and the main Spanish grapevine variety used for red wines. Cultivation of Tempranillo grapes accounts for 80% of the vineyard surfaces in the La Rioja province and over 20% of the wine-growing surface in Spain (Balda et al., 2013). Tempranillo is typically oak-aged for 6-18 months and carries notes of cedar, leather, cherry, and fig. It is characterized by medium-high tannin and medium-low acidity, with deviations attributable to the variable altitudes and corresponding temperatures across the three La Rioja sub-regions (Puckette, 2013). This full-bodied varietal contains delicate constituents which pair best with a view of the valley from a warm, mountainous perch in the beautiful rolling hills of La Rioja.

TABLE 1: Prominent grape varietal and environmental statistics for La Rioja region (Tonietto and Carbonneau, 2004; Intrigliolo and Castel, 2009). The Huglin Index used to quantify the sum of temperatures over 10°C in a region and adjusts values for latitude and growing season.

Prominent varietal	Tempranillo
Precipitation (over growing period)	100-200mm
Temperature (over growing period)	Avg: 21°C Min: 10°C Max: 30°C
Elevation	1000-2000m (mountain range)
Latitude	42.3°N
Huglin Index Category	Temperate warm

BIENVENUE À BORDEAUX, FRANCE

The wine regions of Bordeaux, France are internationally known for their rich history and for producing what are considered by many to be the highest quality wines (Ashenfelter, 2008). Approximately 50 different distinct zones, called appellations of origin, lie within the Bordeaux area – all of which have their own characteristic terroir (Belis-Bergouignan, 2011). However, it is important to note that the advancement of Bordeaux as a prosperous fine-wine region is due more to geography, history, and human influence than to terroir (Lawther, Johnson and Wyand 2010).

Due to the vastness of Bordeaux, let's narrow our scope towards an interesting sub-region within this locality – the Médoc and more specifically the Haut-Médoc region (Figure 3). Prior to the 17th century, the Médoc was unfavourable for development and agriculture as it was marshy and only accessible by boat via the Gironde Estuary (Lawther, Johnson and Wyand, 2010). However, during this period, the land was drained by Dutch engineers and vineyards were planted (Lawther, Johnson and Wyand, 2010). The Médoc truly flourished during the 19th century, as the "Golden Age of Bordeaux" brought affluent individuals from afar who established the great estates and Chateaux located there today (Figure 4) (Lawther, Johnson and Wyand, 2010).

Although Bordeaux developed as a wine-growing region for reasons other than its optimal terroir, located at the 45th parallel, it does possess an

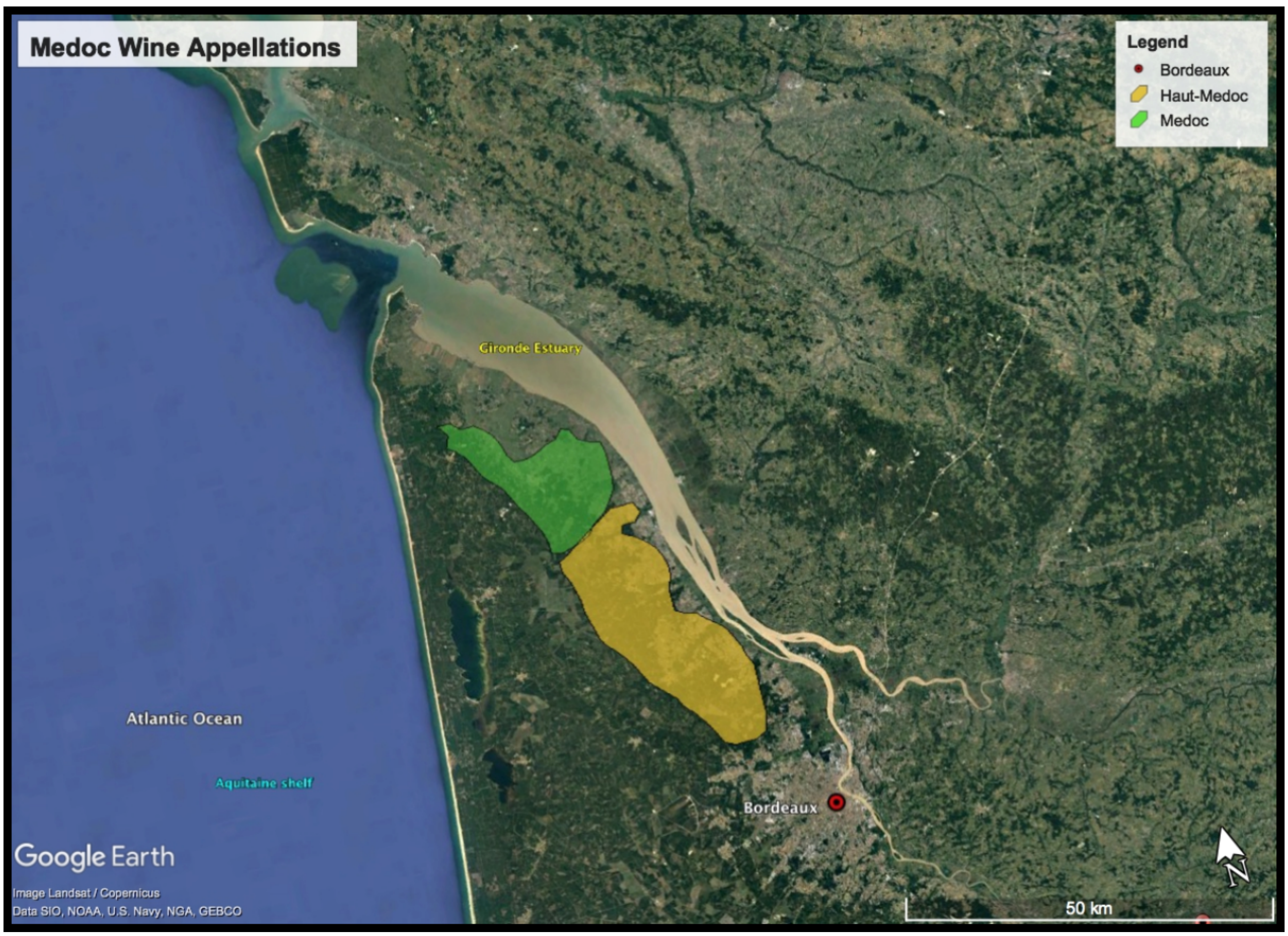

FIGURE 3: Wine-growing appellations of the Médoc. Note the Haut-Médoc and Médoc, as well as their proximity to the Gironde Estuary (Google Earth, 2018 [2]).

FIGURE 4:
The Bémédan vineyards in the Haut-Médoc of Bordeaux. Notice the Chateau on the horizon, characteristic to the Médoc region (Roux, 2005).

ideal seasonal climate that contributes to the quality of the wine (Jones and Davis, 2000).

When visiting the region, one could expect a temperate oceanic climate consisting of cool, wet winter and spring seasons, followed by warm and dry summers (Baciocco, Davis and Jones, 2014; Chone, van Leeuwen, Chery and Ribereau-Gayon, 2017). This characteristic maritime climate is influenced by its proximity to the Atlantic Ocean, the effects of which are carried inland by the Gironde Estuary (Lawther, Johnson and Wyand 2010). The cool nights experienced during the ripening period in this region are ideal for the colour, aroma, and acidity retention in the grape, and thus contribute to the elegant textures and crisp quality characteristic of Bordeaux wines (Tonietto and Carbonneau, 2004).

An unfavorable aspect of Bordeaux's climate is its relatively high precipitation levels compared to other wine regions. It is considered to have a sub-humid or moderately wet climate, meaning the local vineyards undergo an "absence of dryness" (Tonietto and Carbonneau, 2004). The sub-humid climate of the Médoc creates problems for wine growers such as decreased pollination and increased disease (Lobell, Cahill and Field, 2007). These effects are amplified in the Médoc, as its proximity to the coast causes the region to experience higher annual precipitation levels than other wine growing sub-regions in Bordeaux (Tonietto and Carbonneau, 2004).

Many of these precipitation-related consequences are reduced by the nature of the soil in the region. The soil of Médoc is highly variable. On one estate in Haut-Médoc, nine different types of soil were identified over only one hectare (Chone, van Leeuwen, Chery and Ribereau-Gayon, 2017). Despite this, limestone-rich soils with gravel terraces are characteristic to the region. The gravel nature of the soil increases its drainage (Ubalde, Sort, Zayas and Poch, 2010).

Cabernet Sauvignon is the region's grape of choice. The gravelly nature of the soil allows the grapes to withstand the sub-humid climate. Additionally, Cabernet Sauvignon thrives in the cool nights and temperate climate of the Haut-Médoc (Tonietto and Carbonneau, 2004). However, the region does not have a distinct wine profile of Cabernet Sauvignon. This is due to both the variability of the soil and also the differences in winemaking practices and quality standards of each Chateaux (Lawther, Johnson, and Wyand, 2010).

TABLE 2: Prominent grape varietals and environmental statistics for the Médoc region (Tonietto and Carbonneau, 2004; Lecocq and Visser, 2006; Geny and Marchal, 2017; Leve, 2018).

Prominent varietal	Cabernet Sauvignon
Precipitation (over growing period)	~ 380 mm
Temperature (over growing period)	Avg: 17.4°C Min: 11°C Max: 26.9°C
Elevation	3-44m
Latitude	45°N
Huglin Index Category	Temperate

ON TO GREATER HEIGHTS IN THE ELQUI VALLEY, CHILE

Nestled between the Atacama Desert to the north, the Andes mountains to the east, and the Pacific Ocean to the west, the Elqui Valley boasts some of the most beautiful vineyards in all of Chile.

Because of its location, the Elqui Valley is a very arid region – a characteristic that allows for the production of popular wines. Average precipitation in the region is about 110mm per year but varies greatly from year to year and between elevations in the valley (Kalthoff et al., 2006). Rainfall is limited to a few winter months when grape development does not occur. Because of this, vineyards in the region hug the banks of the Elqui River (Figure 5) which winemakers use to irrigate their vines during the crucial bud break and grape ripening periods. This ensures that water intake is closely monitored, so as to create the mild water-stress conditions that ensure high sugar and phenolic content in grapes (van Leeuwen and Seguin, 2006). Although the river is

FIGURE 5: The Elqui Province in Chile. Outlined are the Elqui River, which flows from the Andes Mountains to the Pacific Ocean, and the agricultural area described by Young et al. (2010). This huge area hugs the banks of the river (Google Earth, 2018 [3]).

FIGURE 6: A typical view of the Elqui Valley. Skies stay clear year-round, contributing both to the temperature and the beauty of this region (Padmanaba01, 2013).

relatively reliable, its water comes from glacial snowmelt in the high Andes and is at times prone to low flow. Canals and holding tanks are used to ensure that winemakers can provide the perfect amount of water to their vines year-round (Young et al., 2010). Conveniently, the proximity all vineyards have to the river ensures that traversing this wine region is simple. Just follow the river road from La Serena on the Pacific up to the Alcohuaz Winery, one of the world's highest vineyards at 2200m above sea level.

Of course, the mountains are another big factor which make the Elqui Valley such an attractive destination. Not only do the Andes offer beautiful scenery (Figure 6), they are also central to creating the clear and warm summer days that are perfect for vines. Due to the differences in elevation along the valley, several temperature and moisture gradients exist. This creates a system of valley winds which ensure only a few days of the year are cloudy, making the Elqui Valley a perfect place to stargaze at night (Khodayar, Kalthoff, Fiebig-Wittmaack, and Kohler, 2008). Along with these clear skies and the proximity of the Elqui Valley to the equator, the hottest summer month averages 28.5 ºC, providing grapes enough light and heat to fully ripen (Sierra and Alfaro, 2007; van Leeuwen and Seguin, 2006).

The Elqui Valley experiences periodic disturbances to its normal weather due to the El Niño-Southern Oscillation phenomenon every four to seven years. During these events the high-pressure systems that normally maintain climate are thrown into disarray and parts of South America including the Elqui Valley experience high levels of precipitation (Meza, 2013). El Niño increases both rate and severity of natural disasters in the region, such as flooding and debris flow, which are some of the biggest

TABLE 3: Prominent grape varietal and environmental statistics for the Elqui Valley region (Young et al., 2010; Sierra and Alfaro, 2007; Instituto de Investigaciones Agropecuarias, 2010).

Prominent varietal	Syrah
Precipitation (over growing period)	< 100 mm
Temperature (over growing period)	Avg: 16.6°C Min: 6.3°C Max: 28.5°C
Elevation	Up to 2200 m
Latitude	30°S
Huglin Index Category	Cool to warm, depending on elevation

dangers to the Chilean wine industry (Young et al., 2010).

The Elqui Valley is one of the only regions in the world to grow Carmenere grapes. Originally from Europe where it is all but extinct, Carmenere was grown and bottled in Chile as Merlot for many years until it was identified as a separate variety in 1994 (Belancic and Agosin, 2007). The wine produced from this varietal tends to be high in the phenolic compound pyrazine and as a result possesses distinct green pepper notes (Belancic and Agosin, 2007). This sought-after taste is only possible when vines are exposed to high amounts of heat and sunlight, a true testament to the conditions of the Elqui Valley (Montes, Perez-Quezada, Peña-Neira, and Tonietto, 2012).

WELCOME HOME TO CANADA: THE NIAGARA PENINSULA

Back home, the **Niagara Peninsula** boasts the title of Canada's largest wine region. This highly seasonal cool-climate wine region is located just north of the 43rd parallel – placing it at a similar latitude to France's Bordeaux region (Shaw, 2005).

Despite what one might expect for an inland, mid-latitude region, the Niagara Peninsula never experiences extreme cold or hot temperatures throughout winter and summer. The region's characterizing mild climate is credited to two main geographical factors: the proximity to Lake Erie and Lake Ontario, as well as the presence of the nearby Niagara Escarpment.

Niagara Peninsula is actually a misnomer – the region is technically an isthmus rather than a peninsula.

Lake Ontario (Figure 7), with its average depth of 84m and small surface area, stores summer heat all throughout the coldest parts of the harsh Ontario winters (Shaw, 2005). Lake Erie – the shallowest of the Great Lakes with an average depth of only 19m – heats up quickly when the weather is warm and moderates the air temperature into late autumn, ensuring the grapes have enough time to ripen (Shaw, 2005). During the late spring and summer months, both Lake Erie and Ontario are cooler than the land. Warm

FIGURE 7: The Niagara Peninsula region sits between Lake Ontario and Lake Erie. Most of the vineyards are situated in the northern parts of the region, closer to Lake Ontario (Google Earth, 2018 [4]).

FIGURE 8: Ice wine grapes in the Niagara region grow throughout the typical April-October growing season but aren't harvested until later in the winter (Hatfield, 2007).

southwestern winds are cooled as they travel across the full length of Lake Erie, moderating the temperature in the southern part of the Niagara region. Offshore winds across Lake Ontario have the same effect for the northern areas (Shaw, 2005).

If you travel to the Niagara region, you'll be sure to spot the magnificent Niagara Escarpment rising up above the horizon. This characteristic geological feature has formed from over 400 million years of sediment deposition and erosion (Larson and Kelly, 1991). Sitting 30 to 50m above most vineyards in the Niagara Peninsula, the steep slopes of the escarpment shelter areas as far as 2.5km from its base from cold southwest winds (Shaw, 2005).

Although the Niagara region's generally temperate climate makes it suitable for the growth of a wide variety of grapes including those grown in famous areas like Bordeaux, the uniquely cold Canadian winters allow for the production of the region's signature ice wines. Canada is the world's largest producer of ice wine, with approximately 75% coming from Ontario (Pickering and Soleas, 2007). Ice wine is made from grapes which have grown throughout the warmer months of the year but are left unharvested until temperatures reach -8°C or less, as enforced by the Vintners Quality Alliance (Figure 8) (Pickering and Soleas, 2007). The grapes are pressed at such low temperatures to ensure that only the juices with the highest concentrations of sugar, aromatic compounds, and acids are extracted as a liquid. The end result is a very sweet dessert wine packed with flavours reflecting the climate and growing conditions of the Niagara region. Ice wines are typically made from hardy grape varieties like Riesling and Vidal, whose tough skins are able to withstand mechanically taxing freeze-thaw cycles (Pickering and Soleas, 2007).

The cold seasonal temperatures attributed to the Niagara region's northerly latitude influence the terroir of the ice wine – just as the altitude of vineyards in La Rioja, Spain affect wine tannin content, the clear skies and near-equatorial temperatures of the Elqui Valley can produce grapes rich in green pepper flavours from heat-induced pyrazine production, and the highly variable soils of Bordeaux yield wines of highly variable aromatic profiles.

TABLE 4: Prominent grape varietal and environmental statistics for the Niagara Peninsula region (Shaw, 2005; Cyr, Kusy and Shaw, 2008)

Prominent varietal	Riesling
Precipitation (over growing period)	536 mm
Temperature (over growing period)	Avg: 15.9°C Min: 7.2°C Max: 21.8°C
Elevation	90 to 180 m from Lake Ontario to the Niagara Escarpment
Latitude	43°N
Huglin Index Category	Cool-temperate

TO CORK IT OFF…

After having travelled around the world, you will have noticed that some characteristics are central to the success of the wine industry in Spain, France, Chile, and Canada. Although all four wine regions are distinguishable by various aspects of their natural environments, they still share the ability to successfully grow grapes. For example, every region falls within the previously defined 51°N and 45°S latitudinal range: La Rioja lies at 42.3°N, Haut-Médoc at 45°N, Niagara at 43°N, and the Elqui Valley 30°S. Consider also that most grape-growing regions require mild water scarcity to produce small berries with concentrated phenols (van Leeuwen et al., 2004). However, in Bordeaux and La Rioja the mechanisms by which this occurs are different. Rain in La Rioja is scarce, and as a result, vines are naturally exposed to low water intake. In contrast, rainfall in Bordeaux is much more abundant, but the gravelly soils that characterize the region do not allow for excessive uptake of water. The same is seen in the Niagara Peninsula and the Elqui Valley in regard to the warm temperatures observed during the growing season necessary for berry ripening (van Leeuwen and Seguin, 2006). While the Elqui Valley is exposed to higher temperatures due to its near-equatorial latitude and its clear skies, the Niagara Region attributes its warm seasonal temperatures to its proximity to two major bodies of water and the protection of the Niagara Escarpment.

Even though these regions have very similar climatic characteristics, the mechanisms that create them are never identical. It can easily be argued that the interaction between all these factors is responsible for the creation of wines with flavour profiles attributed to the unique climatic conditions that make up a wine region. The topography, soil, and climate of a grape-growing region has significant influence on the product, just as a region's cultural heritage and viticultural practices also influence the wine.

So next time you reach for a bottle of wine, be reminded of your adventure around the world and appreciate how the physical factors of a region manifest themselves so deliciously in your glass.

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Chasing the Sun & Following the Moon:

The Duality of Wine Flavour

Nicole Areias, Mehreen Butt, Yajur Iyengar, & Emma Tomas

Wine is all about chasing the Sun during production and following the Moon as we consume. The Moon cannot exist without the Sun, just as wine consumers cannot exist without producers. The natural, biochemical processes that contribute to wine creation and flavour profile are dependent on the Sun. Yet when a consumer drinks from their glass of wine, under the light of the Moon, there are many factors that contribute to its taste. Using the dynamic duality of the Sun and the Moon, this article will explore which processes contribute to wine flavour, and how those flavours are processed from chemical and psychological perspectives.

THE SUN

The taste of wine first arises from its production in the Sun. Before we can understand how we perceive its flavor during consumption, we need to be able to appreciate how various processes influence a wine's composition and flavour. By considering two critical processes of wine production, that occur under the Sun – maceration and barreling – we can begin to clarify the first aspect of the dual nature of wine flavour.

MACERATION

During its growth cycle, sunlight will influence a variety of the grapevine's qualities from height and health to chemical composition and taste. Ultraviolet radiation from the Sun will trigger the synthesis of phenolic compounds and influence their concentration in the berries (de Beer, 2015). With respect to wine, phenolic compounds are the principal determinants of colour, texture, and taste. Phenols are part of a family of chemical compounds that serve a variety of functions in nature and can be broadly categorized as a flavonoid or non-flavonoid. Flavonoids, like anthocyanins or tannins, influence color and texture, while non- flavonoids, such as the phenolic acids (e.g. caffeic and cinnamic acid, and vanillin), introduce the hints of vanilla or smoke that you may be familiar with (Polášková et al., 2008). Phenolic acids are concentrated in the pulp, anthocyanins in the skin, and other phenols can be found in both the skin and seeds.

The phenolic content must be kept within a range that enhances the wine's quality without compromising its acceptability by consumers. Accordingly, vinification techniques aim for a balanced extraction that maximizes colour and flavour, while minimizing the sensations of bitterness and astringency associated with certain phenols.

A deep red wine will be rich in phenols, such as anthocyanins, proanthocyanidins and flavonols, that originate from the skin and seeds. To extract these colour and flavour elements, the skins are left to soak with the berries' juice in a process known as maceration. Many of the phenolic compounds contributing to taste, colour and mouthfeel, are water soluble and will leach into the watery grape juice while in contact. Longer periods of contact will lead to a greater extraction of phenolic content. The skins can be 'cold soaked' in the unfermented must to encourage extraction by water and sulfur dioxide additives for fresher, cleaner wines (Lukic et al., 2017). Throughout the fermentation process, the must's increased alcoholic content acts as a solvent while the addition of heat decomposes the organic compounds within the skin, seeds and other materials. The skins can remain in the fermentation vat allowing maceration to continue for as long as 28 days post-fermentation (Grainger & Tattersall, 2007).

Must: the product of crushed grapes.

Unlike red wines, a bottle of white wine will get most of its flavour from the phenolic acids found in the pulp, with the skin providing little more than bitterness and astringency (Grainger & Tattersall, 2007). Approximately 60-70% of the available juice within the grape berry can be released by this process, while the remaining 30-40% is collected by pressing the berries using a variety of different mechanical methods (Robinson, 1994). Pressed juice can have higher phenolic content depending on the amount of pressure and tearing of the skins, and will produce more astringent, bitter wines.

Astringency: The dry mouth sensation felt when drinking wine.

The use of high pressure can scour the grape skins, increasing the phenolic compounds and tannins that are extracted. Higher pressures can also cause bruising and tearing of skins, causing damage to the cells and releasing greater proportions of phenolic content. This leads to the undesirable browning of musts, caused by activation of the catecholase enzyme--the enzyme responsible for the browning of damaged fruit in plants (Mayer, 2006). In the presence of catecholase, catechol is oxidized and converted to the melanin that is responsible for the dark brown color (Mayer, 2006). However, the enzyme's lack of specificity, which allows for the oxidation of a wide variety of phenols, has bitter/astringent consequences during wine production (Traverso-Rueda & Singleton, 1973). Increasing the pressure applied in the press will extract more of the enzyme's bitter effects, suggesting that the enzyme is primarily localized within the skins and pulp.

FIGURE 1: GRAPE COLLECTION Cabernet Sauvignon grapes at Rosewood Winery are placed on a conveyer belt to be cleaned and sorted before beginning maceration.

Following collection (Figure 1), winemakers employ processes like maceration and pressing to extract the phenolic content from the grapes. They can also use other techniques to introduce other phenols to diversify the wine's flavour profile. For example, the barreling process will also contribute to the phenolic composition of the wine, adding compounds such as vanillin to introduce vanilla aromas to wine.

BARRELLING

Many wines undergo a process called wine aging: a collection of chemical reactions that occur over a period of time to improve the taste and quality of wine (Gambuti et al., 2010). In order to eliminate intense sensory characteristics such as overpowering smells and harsh tastes, fine wines must be aged before consumption (Gambuti et al., 2010). Aging more commonly occurs through the use of Oak-barrels (Figure 2) with this method used in wine culture for over 2000 years (Li & Duan, 2018). Wine aging in barrels can be as short as three to five months or as long as three to five years (del Alamo-Sanza & Nevares, 2017), with a longer aging period creating more intense flavours (Gambuti et al., 2010).

Oak barrels contribute sensory characteristics to wine that are favoured by the general public. During barreling, aromas created by compounds such as sulphur are lessened, with new compounds appearing from the oak wood (Cerdán, Rodríguez Mozaz, & Ancín Azpilicueta, 2002). For example, particulates within the oak barrel that diffuse into the wine give rise to a smoky flavour (Gambuti et al., 2010). Barrels can also contribute volatile and phenolic compounds to the aging wine. Phenolic compounds such as tannins are extracted from the oak (Cadahía, Varea, Muñoz, Fernández de Simón, & García-Vallejo, 2001) and react with volatile compounds in turn affecting astringency levels (Li & Duan, 2018).

Phenolic Compounds: Compounds that affect the taste, colour, and mouthfeel of wine. For example: tannins.

Astringency is a large focus when aging wine in oak barrels. Wine makers can change certain aspects of their barrels to compensate for astringency levels in wine through wood seasoning and toasting (Tao, García, & Sun, 2014). Wood seasoning is used to reduce the moisture content within the wood, promoting wine maturation by reducing bitterness, astringency levels and increasing the aromatic properties of the wine (Tao, García, & Sun, 2014). Wood toasting involves changing the temperature of the wood before aging to produce different taste profiles of wine. It is used during the construction of barrels and provides specific oak characteristics to the wine depending on the type of toast (Tao, García, & Sun, 2014). A light toast provides fewer aromatic compounds but more tannins, while a medium toast provides a roasted character, whereas a heavy toast creates more volatile compounds and adds a smoky and spicy aspect to the wine (Tao, García, & Sun, 2014).

FIGURE 2: BARRELS AT ROSEWOOD WINERY (BEAMSVILLE, CANADA) Barrels with a red stained middle panel to indicate it is barrel for red wine.

Finally, barrel age is another aspect that is taken into consideration when preparing wine. Based on the age of the barrel, the intensities of astringency, and volatile compounds vary (Tao, García, & Sun, 2014). The older the barrel is the more exhausted the volatile and reactive compounds will be in the barrel itself, thus wine maturation would not be complete (Tao, García, & Sun, 2014).

Volatile Compounds: Chemicals that give wine their specific aroma (Liu & Duan, 2018).

There are many different factors involved in wine aging, ranging from the type of oak used and length of aging process, to the type of seasoning and toasting the barrel has. This all depends on the flavour profile winemakers wish to create for their consumers. As the Sun sets and the Moon rises, the bottled product moves from vineyard to table. We must next understand how these tastes arise during consumption. More specifically, how does wine interact within the body chemically and physiologically for one to be able to taste bitterness or sweetness?

THE MOON

Clearly, the processes of maceration and barreling are integral to creating the foundation for any wine's unique taste and flavor profile. However, as we bid adieu to the Sun and commence our chase of the Moon, we need to be able to understand how the components found within wine will be interpreted. This comes from first understanding how and why wines elicit the reactions that they do when consumed, on both a biochemical and physiological level as well as a more all-encompassing perception-based analysis.

THE BIOCHEMICAL COMPONENTS OF TASTE

Astringency

Much like how bitterness is related to polyphenols and the reactions, astringency is associated with tannin binding to salivary proteins present within the mouth (Obreque-Slier et. al, 2010).

Hydrogen bonding and hydrophobic interactions cause the tannins to bind to salivary proteins and attach to the surface of the mouth (Freitas and Mateus, 2001). The presence of these interactions causes formations of precipitates that prevent lubrication of the palate and lead to the common undesirable sensation of dryness when drinking wine (Freitas and Mateus, 2001).

Most red wines (like Merlot) are quite astringent.

Bitterness

This sensation can be derived from phenolic acid ethyl ester compounds and flavan-3-ols, compounds that can be extracted from the skins of grapes as tannins (Hufagel and Hofmann, 2008).

Bitterness arises from the activation of human taste receptors on the surface of the tongue, specifically the TASTE 2 Receptor (TAS2R) family (Soares et al., 2017). The compound (-)-epicatechin, a stereoisomer derivative of tannins, are one of the key substrate molecules that bind to TAS2Rs in order to initiate the bitterness response upon drinking wine.

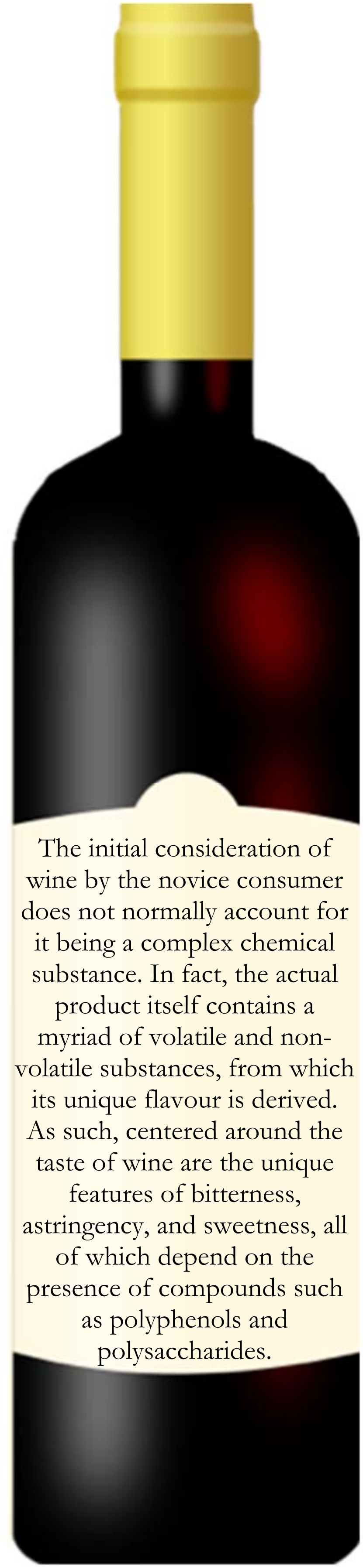
Cabernet Sauvignon is an example of a bitter wine.

Sweetness

The concentration of polysaccharides in grapes, which give rise to the sensation of sweetness, help to alleviate astringency in the mouth by inhibiting the formation of tannin-protein aggregates (Carvalho et. al, 2006).

The presence of polysaccharides in wine helps to alleviate the astringency sensation (Vidal et al., 2002). Polysaccharides will either bind the polyphenols present in the wine during consumption, or polysaccharides bind to the tannin-protein complex to decrease the sensation of dryness (Carvalho et. al, 2006).

Ice wine, which is fermented at very cold temperatures, is a very sweet wine.



By understanding the various chemical reactions that occur within wine, both expert and novice consumers can have a greater appreciation for the sensations associated with the taste of wine. The relationship between wine compounds and the sensations they create adds clarity to the diversity of wine flavor. We can use these concepts as a foundation to explore the immense subjectivity in wine taste perception.

TASTE SUBJECTIVITY

Flavour is not a simple concept; it is instead a psychological construct (Prescott, 1999). The immense subjectivity in wine flavour experience explains why your friend might not love a bottle of Shiraz like you do. There is a huge olfactory component to flavour; sensory information is integrated through multiple neural pathways yet perceived as one flavour 'entity' (Prescott, 1999). Flavour is also modulated by the time course of tasting and the location of sensory stimuli in the mouth (Smith, 2012). By holding your nose while you drink a glass of wine, you prevent odour particles (volatiles) from reaching the olfactory epithelium in your nose, leading to a more precise experience of pure taste (Smith, 2012). However, winemakers encourage savouring the smell and taste of wine to produce the full flavour experience. The individual threshold sensitivities to tannins, acid, sugar, alcohol, carbon dioxide, and sulphur concentrations further add to the subjectivity of wine flavour (Smith, 2012).

So, how do we determine, understand, or classify taste? Through practice, expertise, and knowledge (Smith, 2012). Experts have the distinguished palate and vocabulary to adequately describe the various flavour profiles within a variety of wines, including the acidity, sweetness, and tannin levels (Koone et al., 2014). Compared to novices, experts have the ability to perceive a proper food and wine match, primarily as a result of their experience with culturally acceptable and acclaimed pairings (Koone et al., 2014). However, there is more to taste than the integration of multisensory neural pathways and vast experience drinking wine. Higher levels of impulsiveness combined with lower openness have been attributed to sweet white wine preference (Saliba, Wragg, & Richardson, 2009). From an evolutionary perspective, sweetness was typically sought after as it symbolized high energy foods leading to an innately preferred flavour (Saliba, Wragg, & Richardson, 2009). However, the physical properties and sensory attributes of wine are not the sole determinants of consumption (Shepherd, 2001). Marketing and economic variables in addition to cultural, social, religious, or demographic factors will influence the wine you purchase (Shepherd, 2001).

WINE CULTURE

From religious ceremonies to champagne birthdays and housewarming gifts, one cannot deny that wine plays an important role in our societies. The earliest evidence of a grape fermented drink was found in China, dated to approximately c. 7000 B.C (Hames, 2014). The oldest winery existed not long afterwards in approximately c. 4100 B.C., where *Vitis vinifera* seeds, as well as wine presses, fermentation vats, and jars were found in the 'Areni-1' cave in Armenia (National Geographic News, 2011). Nowadays, wine culture dictates a multi-billion-dollar industry, that is driven by winemakers well-versed in a variety of scientific disciplines. The consumers of wine are equally invested in high-quality wine. While wine produces will utilize a vast array of practical and technical skills to produce their best wine, each individual consumer will experience the wine's flavour differently.

> ***Vitis vinifera*:** The species of grape vine most commonly used for wine production. There are over 5,000 varieties of *Vitis vinifera* grapes (National Geographic News, 2011).

THE SUN AND THE MOON

Having an appreciation for wine depends entirely on understanding the production that occurs in the Sun, and the consumption that occurs under the Moon. The Sun not only helps the vines to grow but further incites the production of key flavor compounds in the berries. Processes such as maceration and barreling are used to extract these compounds, giving rise to a wine's unique taste and flavour profile. A biochemical perspective provides a more concrete explanation for how we detect these flavours. However, a consumer's appreciation for taste can be influenced by previous social experiences with wine. These elements of perception coalesce, offering an interdisciplinary overview of taste as it is experienced under the light of the Moon. The Sun and the Moon work in tandem to create a duality of both the wine itself and how it is perceived. Hopefully, this relationship has inspired you to appreciate and savour in full the taste of wine.

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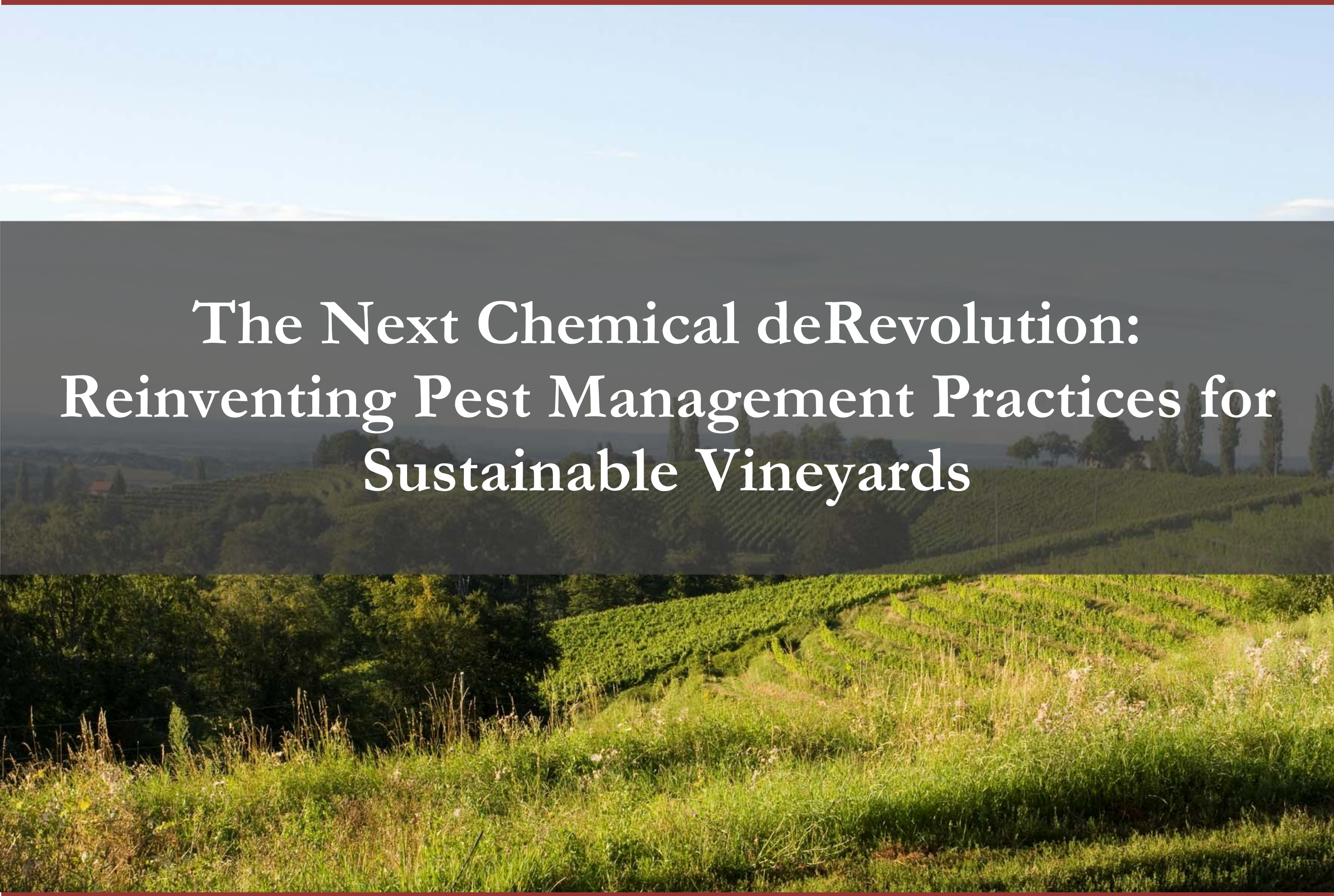


The Next Chemical deRevolution: Reinventing Pest Management Practices for Sustainable Vineyards

Authors: Sara Mar, Sam Marchetti, Sam Mills, Morgan Porteous, & Lauren Vamos

Sustainability, the assurance that a practice will not harm the environment, economy, or members of the global population, has become a buzzword in professional circles. Governments and corporations are setting sustainability goals, yet little regulation is in place to decrease accepted unsustainable practices such as pesticide use in viticulture. This article reviews the unsustainable nature of pesticide overuse and proposes alternative, sustainable solutions. These solutions work to prevent pest infestation of the vineyard, at minimal risk to the environment, economy, and the producers and consumers of the wine. The solutions, if tested properly, may not interfere with the taste of the wine and can be integrated into traditional viticulture practices. The article follows the life cycle of a grapevine and introduces pest management strategies at each level of succession. Both pre-emptive and reactive strategies are discussed, and can be used in conjunction, individually, or with other methods to create the most sustainable pest management strategy possible. The importance of these strategies cannot be stressed enough. Sustainability must become the primary focus at all levels of production and consumption of wine, to ensure the tenability of viticulture in the indefinite future.

THE PROBLEM WITH PESTICIDES

Have you ever considered what goes into that glass of wine you have on Friday night after the kids have gone to bed? The production of an economically, environmentally, and socially sustainable wine is a complex process. Wine growers today use a variety of integrated pest management (IPM) strategies such as the use of pesticides to increase the yield of their crop. The term 'pesticides' refers to herbicides, insecticides and fungicides.

The use of chemical pesticides impacts the local environment, ecosystems, and human health security. One of the main risks to human health is the direct exposure of an individual to high concentrations of pesticides when synthesizing or applying the chemical, and the indirect consumption of products with pesticide residue. This health insecurity mainly affects developing countries due to lack of health and safety regulations. Pesticide residue on the crops which are then ingested by the consumer is an even greater issue, especially to those in developing countries. A report from 1989 theorized that there are as many as 20,000 human deaths per year globally as a result of pesticide poisoning (Pimentel et al., 1992). However, this number is likely to have increased in recent years due to the growing population.

This article will propose alternative IPM strategies, using the Niagara region as a case study, to determine the sustainability of each strategy on a regional scale. In this case, sustainability encompasses economic, environmental and social viability in the long term.

Additional ramifications of pesticide use include a high price of application, clean-up of chemical residue, and environmental repair post chemical damage. For example, chemical drift occurs when a fraction of the pesticide is carried in the wind or through groundwater to other locations, which can damage or kill other species (Pimentel et al., 1992). This unintended death can affect other ecosystems in the region. Although new technologies are being implemented that reduce this waste, such as a recycling sprayer and vacuum set up, it would be advantageous to consider other methods that reduce or minimize the environmental impact.

These are just a few of the drawbacks associated with pesticide usage. A recent report stated that, when both the initial and the environmental repair costs are taken into account, the use of pesticides has cost the world $40 billion USD per year (Popp, Pető & Nagy, 2012). Clearly, sustainable alternative strategies to pesticide use must be implemented worldwide.

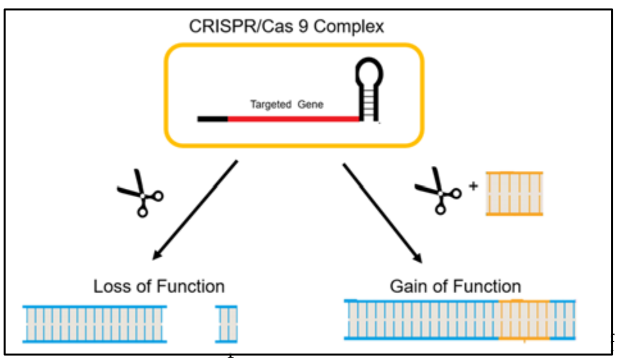
The Niagara region is a unique area for winegrowing in Canada due to its fertile soils and **mesoclimates**. Due to the colder climate, commonly grown varieties of grapes include Riesling, Chardonnay, Gamay Noir, Pinot Noir and Cabernet Franc (Vintners Quality Alliance Ontario, 2018). Two prominent pest species in the region are the grape berry moth (*Eupoecilia ambiguella*), and the fungus bunch rot (*Botryis cinerea*). The life strategies and environmental impacts of these species will be detailed in later sections. For the purposes of this article, we will use these two species as models to analyse the efficacy of the suggested IPM strategies in the region.

Mesoclimates:
The local climate in which the vineyard site is located.

This article will take you on a journey through the life cycle of a *Vitis vinifera* grapevine in the Niagara region, and outline promising IPM strategies at each stage. These methods will include pre-emptive, proactive and reactive strategies. These strategies are an important step in the creation of a more economically, socially, and environmentally sustainable winegrowing industry.

A PRE-EMPTIVE STRIKE: DOWN TO THE GENOME

The first step in the life cycle of a plant is fertilization. An IPM strategy that can be implemented pre-fertilization is gene editing, which can produce vigorous crops within the limitations of existing genotypes in a natural population. The main goal of gene editing technologies is to cause a loss or a gain of function within the organism to produce an ideal crop. Loss of function is usually achieved by cutting out or inhibiting a gene, while gain of function involves a gene mutation or replacement (Nature Plants, 2018). Currently the most accurate, time-efficient, and cost-effective gene editing technology is the CRISPR/Cas9 method.



CRISPR/Cas9. CRISPR/Cas9 can act like scissors and cut out or inhibit a specific gene to cause loss of function. It can also replace the cut-out gene with a novel gene. In the case of improving *V. vinifera* resistance to bunch rot, CRISPR/Cas9 would be "cutting out" the VvWRKY52 gene that reduces resistance to bunch rot (Kaidor, 2016; Levin, 2017; Wang et al. 2018).

The CRISPR/Cas9 mechanism alters a specific site in the organism's genome (Nature Plants, 2018). To improve the *V. vinifera* resistance to **bunch rot** using CRISPR, researchers must have two key pieces of information. First, *V. vinifera*'s genome must be sequenced to allow the CRISPR/Cas9 mechanism to target the appropriate site (Nature Plants, 2018). This has already been accomplished by The Grape International Genome Project (INRA, 2018). Second, the gene loci that are associated with bunch rot resistance must be identified (Nature Plants, 2018).

Dr. Xianhang Wang from the National Science Foundation of China has been spearheading research on a variety of gene loci that are responsible for improving the defense pathways of *V. vinifera*. The researchers were able to produce genetically edited strains of *V. vinifera* plants and infect them with *B. cinera*. After just five days, the genetically edited plants had a significantly reduced number of spreading lesions caused by bunch rot (Wang et al., 2017). This initial use of gene editing technology to increase grapevine resistance is a ground-breaking step in pest management. However, before genomic editing of *V. vinifera* is implemented on a large scale, the sustainability of the gene editing process must be considered.

Currently there is a negative public opinion surrounding the topic of Genetically Modified Organism (GMO) consumption (Wunderlich & Gatto, 2015). However, a recent study determined that educating wine consumers on genetic modification (GM) effectively reduces the fear of GM wine and increases customer disposition to buy GM wines (Lu, Rahman, & Chi, 2017). This study provides a positive outlook for the integration of GM wines into the market (Figure 2).

Economic feasibility must also be considered when assessing an IPM strategy. The National Institute of Health increased their investment into CRISPR research from $5.1 to $603 million between 2011 to 2016 (Harvard

Bunch Rot: Bunch rot is caused by the fungus *Botrytis cinerea*. It is a common grape fungal disease in the Niagara Region and it forms a layer of mould on the grapes which spoils them (Wang e.t al, 2018).

FIGURE 2. This is a series of hypothetical wine labels. How do you think consumer psychology is impacted by labelling a product as genetically modified? Research suggests that even though it may be higher quality, people are deterred by the GMO label (Hesed, 2018)

University, 2018). Public and private investment trends also indicate that the technology will become more accessible to agriculturists. Harvard University currently offers a price tag for CRISPR/Cas9 mediated gene knockout at $13 500 / gene (Harvard University, 2018). The use of CRISPR-Cas9 is a one-time payment because clones would be made from the successful transgenic seed. However, this price estimate doesn't include the cost of replanting an entire vineyard with the new, resistant crops. This process of uprooting the existing vines, planting new vines, and installing a new trellising system generally takes an average of 4-5 years (Jordan Vineyard & Winery, 2011). Moreover, considering the number of initial unproductive years, it might be 10-12 years before the crop starts producing fruitful grapes that yield high-quality wine (SARL Worldwide Vineyards, 2018b). For example, it would cost an estimated $3.6 million to plant a Cabernet Franc vineyard in the Niagara region from scratch (Ministry of Agriculture Food and Rural Affairs, 2014). This vineyard would pay an annual $114, 978 for fungicides. Thus, a genetically edited vineyard would have to last for 31 years without fungicides expenses to break even. This additional cost would decrease the economic viability of genetic editing for established vineyards. Other creative methods to consider would be to genetically edit a vine and subsequently graft it onto established roots, as discussed in the next section.

Acquired pest resistance should be taken into consideration when discussing the feasibility of genomic editing. A spore may produce a random mutation that could successfully infect a genetically modified vineyard. The resistivity of the vineyard would apply a selective pressure for the mutated fungal allele and result in the rapid proliferation of a novel strain of fungus, as demonstrated in Figure 3 (Dietrich Hermann, 2018). This never-ending battle of co-evolution between genetically modified plants and resistant pests would be a large risk that vineyard owners and investors would be taking when using gene editing technology.

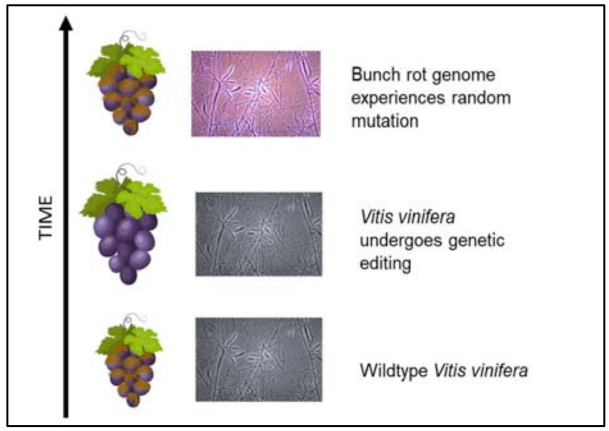


FIGURE 3. Depicts a simplified schematic of co-evolution occurring between *Vitis vinifera* and bunch rot. At time zero, the wildtype *V. vinifera* plant is infected with bunch rot. After genetic editing, it becomes resistant to the current strains of bunch rot. At the final timestep, the bunch rot genome experiences a random mutation which allows it to overcome the *V. vinifera's* resistance (Free Stock Photos, 2014; Shuttershock, 2018).

A PRE-EMPTIVE STRIKE: MOVING BEYOND THE NUCLEUS

The next step in a grapevine's life cycle is fertilization. Here, it is possible to use hybridization methods as an IPM strategy. Grape hybrids are the product of the process of cross-breeding two different varieties of wild, naturally evolved grape vines to produce a new variety of plant (Enjoy Hopewell Valley Wines, 2014). This hybridization is achieved by fertilizing one plant with pollen taken from another plant, such that the resulting offspring possess qualities from both parent plants (Muller, 1996).

The traditional European varietal grapes are considered to produce higher quality, more aromatic wines (Enjoy Hopewell Valley Wines, 2014), while the wild strains possess traits such as disease resistance and improved tolerance to abiotic stressors (Goto-Yamamoto et al., 2015). If a crop is more resistant, less money needs to be invested in pest and disease control mechanisms, thus conferring an economic advantage. Despite these advantages, hybrid species are still a cause for concern for traditional winemakers. In an effort to maintain the high-quality flavours and experience characterized by traditional single-species varieties of wine, it is pertinent to be rigorous in the selection of the most appropriate grape combination (Sabbatini & Howell, 2014).

Vitis species will easily hybridize when they are close enough to each other and there is sufficient overlapping of their bloom times. This trait is frequently exploited by breeders to make hybrid varieties which are hardier and more disease-resistant (Dangl et al., 2015). This ensures that vineyards will still have a successful harvest even during droughts or heavy rains (Enjoy Hopewell Valley Wines, 2014).

The interspecific hybridization of species within the *Vitis* genus arose in an effort to solve problems of chlorosis (i.e. loss of the green pigment in plants due to iron deficiency in soils) which became prevalent in certain grape species. Initially, they tried to solve this by grafting, but they found that the species they were trying to graft were incompatible and planting them was inefficient. The hybridization approach was an alternative method that created a fitter cultivar. Ultimately, this technique allowed for the creation of hybrid species that possessed the same disease tolerance as American species, but with fruit qualities that were consistent with traditional European cultivars (Sabbatini & Howell, 2014). Given this increased disease and pest tolerance, hybridization can be used as an effective means to battle pests such as the grape berry moth or bunch rot. This may be particularly useful in regions such as Niagara, where they currently pose a significant threat to crop yields.

Another IPM method that bears similarities to hybridization is a technique called top grafting, whereby the **scion** of a novel variety of grape is transplanted onto an existing **rootstock** (Jordan Vineyard & Winery, 2011). While hybridization mixes characteristics of two plants before sprouting, grafting mixes characteristics of two mature plants. Grafting is a common practice in viticulture as it confers several advantages to the health and quality of the grapevine, and thus the resulting wine (Figure 4).

Scion: The fruit bearing part of the plant.
Rootstock: The underground root system.

Normally if a winemaker wanted to grow a new type of grape in their vineyard they would have to go through a lengthy planting process. Instead, grafting allows a wine maker to utilize an already existing vine and root system that is productive in the given soil and modify it such that it produces a new grape variety. Since the vine/root system is already in place, the wine maker only has to replace the scion. Accordingly, they are able to produce a fruitful crop within 2 years, rather than having to wait nearly twice as long (Jordan Vineyard & Winery, 2011). For this reason, grafting is more economically feasible and sustainable for the winemaker (SARL Worldwide Vineyards, 2018a). For example, a cost analysis comparing the price to uproot and replant versus restructure via top grafting a typical 10-acre vineyard in France suggests that grafting can save the vineyard nearly $30,190 during its productive life (SARL Worldwide Vineyards, 2018a).

FIGURE 4. During the grafting process, the grafter removes the pre-existing buds on the grapevine, then cuts two slits in the vine and inserts two buds, which grow into scions, from the new variety of grape (Jordan Vineyard & Winery, 2011). As the vine begins to grow, it will incorporate these buds as the new growing points (Jordan Vineyard & Winery, 2011; Wieczorek, 2009).

One of the drawbacks of grafting is that it is a highly sensitive process and needs to be performed during specific climate conditions and only when the rootstock is in a physically optimum state. Grafting requires a great deal of skill, so there are inherent risks associated with this process and thus success of grafting can't be guaranteed (Bilderback, Bir & Ranney, 2014).

Grafting is also environmentally sustainable. It is a low-impact technique because the grafters and winemakers are able to preserve the natural vegetation, soil, and microorganisms in the surrounding areas (Jordan Vineyard & Winery, 2011). Additionally, certain rootstocks thrive in specific soils types. Part of the success of the vine comes from ensuring it is planted in the appropriate soil medium. Grafting allows the winemaker to maintain this successful root-soil relationship, while also growing a wide variety of grapes (Jordan Vineyard & Winery, 2011).

Grafting is also socially acceptable. It is already a common practice in vineyards all over the world and is actually one of the oldest techniques to grant disease resistance. The roots of grafting can be attributed to the ancient societies in China and Mesopotamia 4 000 years ago, and is still in common use today (Bilderback, Bir & Ranney, 2014). Similar to hybridization, grafting is an effective technique that is used in the Niagara region to combat pests, such as bunch rot and the grape berry moth.

A REACTIVE CONTROL

Once a vine has reached the mature stages of its life cycle, reactive IPM strategies must be employed to prevent pest damage after the pests are introduced. The first of these strategies is biological control, whereby a natural enemy of a pest is introduced to that pest's environment. The natural enemy controls and potentially eliminates the pest population in the area (Torres & Bueno, 2018). It is currently being investigated as an alternative to pesticide usage for a variety of different grapevine pests. However, rigorous research is needed before a new species can be released into an environment because the organisms could find new prey species; this could detrimentally affect their new ecosystem (Torres & Bueno, 2018). The following biological control agent will target the grape berry moth, *Eupoecilia ambiguella* (Box A). Many different biological control agents of the grape berry moth (GBM) have been studied, with varying results. Currently one of the most promising species is *Bacillus thuringiensis* (Bt), a microbial biocontrol agent

Box A: Meet the Grape Berry Moth

Figure A1. *Eupoecilia ambiguella*, the grape berry moth (Ustyantsev, 2018).

The grape berry moth (GBM) is a common grapevine pest in Europe that has migrated to the Americas over the last century (Ioriatti et al., 2012). The grape berry moth has 2-4 generations per year, depending on the climate. The first generation of eggs are laid on flower clusters, while later generations develop on the berries themselves. The GBM larvae feed on the berries, creating small holes in the crop and reducing crop quality (Ioriatti et al., 2012). This makes the plant more susceptible to secondary infection by agents such as grey mold (*Botrytis cinerea*), which is detrimental to crop yield and quality (Ifoulis & Savopoulou-Soultani, 2004).

commonly used on the European Grapevine Moth (Figure 5) (Ifoulis & Savopoulou-Soultani, 2004). Although there is a gap in the research on the efficacy of Bt as a biocontrol agent of the GBM, the many similarities between the two moth species (Ioriatti et al., 2012) mean that the EGM can act as an analogue species for the GBM. The two species have almost identical life histories and biological functions. One difference between the two is their climatic preferences: the EGM prefers warm, dry climates, while the GBM prefers colder, humid conditions. In very warm weather the GBM larvae will burrow into the berries seeking moisture, causing further damage to the crop. This is not characteristic of EGM larvae, which prefer hotter conditions (Ioriatti et al., 2012).

Bacillus thuringiensis was tested against the EGM on 11 cultivars in Greece and found to be 64-84% effective at reducing EGM presence, depending on the application strategy and cultivar in question. (Ifoulis & Savopoulou-Soultani, 2004). Used in conjunction with other IPM strategies, it may be possible to negate the effects of the EGM (Ifoulis & Savopoulou-Soultani, 2004). It is unlikely that these results will differ greatly in Niagara, where the GBM is common, due to the similarities between the species. Since Niagara is a colder region, the larvae will be less likely to burrow deeply into the grape; although, as yearly average temperatures increase due to climate change, this effect will need to be considered. The economic sustainability of biological control varies depending on the cost of breeding the parasitic organism. A 5lb bag of commercial Bt costs $84.00 ("BT AGREE WG 5 lb bag," n.d.). Considering that the application procedures in the literature suggest using 247g of Bt per hectare (Ifoulis & Savopoulou-Soultani, 2004), it would cost only $8.45 to apply Bt twice over four 22-row blocks, with 35 plants in each row to achieve the efficacy rates outlined above.

FIGURE 5. *Lobesia botrana*, the European grapevine moth (Gailhampshire, 2010). It has been studied more extensively than the GBM due to its larger presence in traditional European wine regions and will therefore be used as an analogue species to estimate the efficacy of Bt as a biological control strategy.

Box B: Meet the Winemakers

Figure B1. Jackson-Triggs Winery (left) and William Roman at Rosewood Estates Winery (right) (Simon, 2018).

Alan Jackson is one of the co-founders of Jackson Triggs Winery, left, in the Niagara Region. He is now 9 years into his retirement and produces D'ont Poke The Bear, a line of mixed-wine Ontario products. Jackson Triggs remains one of the largest-scale wineries in the region, and uses many traditional industrial techniques to produce common household wines. Will Roman, right, is the manager of Rosewood Estates Winery and Apiary in Beamsville, ON. He utilizes his apiary to make honey mead, as well as a variety of unconventional techniques to produce truly unique wine. His successful management of the vineyard in this way also shows this appeal of up-and-coming techniques, through his use of advanced and largely unexplored IPM strategies.

It is important to recognize some limitations of this procedure. Although protecting against GBMs has the double effect of increasing resistance to grey mold (Ioriatti et al., 2011), many other organisms can be detrimental to wine grape crops. Biological control is only effective against animals, and the success of that control can vary depending on the climate and species interactions within the ecosystem. Currently, no biological control studies have been implemented in the Niagara region on the GBM, so it is difficult to determine how effective the control will be. Since biological control involves the release of an invasive species into a new environment, some people may be less inclined to implement it. Therefore, to guarantee its social sustainability, the winegrowing population must be educated on all new research surrounding various biocontrol agents to eliminate that fear. More research needs to be conducted before this strategy is included in the IPM protocol for the Niagara region, however, it is a promising area of research in the continued effort to reduce pesticide usage.

THE NEW FRONTIER IN REACTIVE IPM

As the plants age and pests continue to parasitize the vines, alternative IPM strategies must be implemented. A new strategy is currently used by William Roman (Box B), who explained how he reduces the use of pesticides in his vineyards by using pheromone disruptors. Pheromones are a type of **semiochemical**, which are primarily categorized as either sex pheromones or necromones (Robin & Marchand, 2018). Although pheromones are the most commonly used semiochemicals in viticulture today, it is important to note that even this usage is a comparatively small amount next to traditional pesticides (Robin & Marchand, 2018).

Semiochemical: A compound that is naturally secreted by organisms for communication purposes (Robin & Marchand, 2018).

The pheromone disruptors used by Roman are small vials of chemicals that disrupt the mating patterns of pests such as the GBM. The volatiles in the disruptor confuse the male GBMs so they cannot find females with whom to mate. If the pests are unable to mate, their population will decline. These pheromone disruptors cost around $1/vial, and Roman suggests an application of about 100-200 vials per acre for full coverage (2018). Using these disruptors in conjunction with other biocontrol methods, according to Roman, allowed his vineyard to eliminate pesticide spraying last summer (2018).

Conversely, necromones signal the presence of deceased individuals of the same or similar species (Aksenov & Rollo, 2017). Unlike sex pheromones, necromones have yet to be used in large or small-scale viticulture. This category of semiochemical has only very recently been mentioned in scientific literature. However, research has shown that insects that detect the presence of necromones will avoid the affected area (Aksenov & Rollo, 2017). Some pests, like cockroaches, require direct contact with the necromone-affected surface whereas others, like crickets, will respond to airborne necromones. Female crickets have also been shown to avoid laying eggs in affected areas, which could have a detrimental effect on the population. Much like pheromone traps, necromones are a cost-effective alternative to pesticides, as they can be produced using nothing more than dead insect samples and ethanol (Aksenov & Rollo, 2017). Both Roman and Jackson indicated that they as winemakers would not be opposed to trying this as a potential method of pest control and believe most other winemakers would feel the same way (2018).

A Sustainable Life for a Sustainable Future

As the plant's life cycle comes to an end, we may review the many different IPM strategies that have been implemented along the way. Although not all these strategies may be used in the same vineyard, some combination thereof can be implemented as an effective means of reducing pesticide usage and minimizing plant damage. This ideal combination may be determined by factors such as climate, soil type and native species. IPM strategies, whether pre-emptive or reactive, provide interesting, novel alternatives to traditional pesticide use. Although many have yet to be employed in viticulture on a large scale, their economic, environmental, and social sustainability potential cannot be ignored.

This article can be used as an example to evaluate methods based on their appropriateness for a specific region, to create the ideal combination of IPM strategies in any region in the world. Pest management is not one-size-fits-all, and it may require significant trial and error before pesticides are eliminated from the industry. Despite this, the benefits associated with eliminating pesticides far outweigh the costs. It just may be sooner than you think that you'll be drinking a glass of wine from grapes grown pesticide-free.

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Here's to your health!

The Potential for Wine Consumption to Attenuate Neurological Disease

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What could pair better with a nice bottle of red wine than neurological health? In an increasingly health conscious market, the wine industry may reap great benefits from a consideration of the health implications of red wine and the balance that can be reached between its beneficial and harmful components. Red wine has high quantities of antioxidants called phenolic compounds. These molecules can reduce damage caused by oxidative stress which is common in many neurological diseases such as Alzheimer's disease. The phenolic concentration in wine can vary greatly according to a number of environmental factors involved in grape growing and can also be further modified through post-harvest treatments and vinification techniques. However, where does the alcoholic component of wine come into play? Is drinking more red wine really the answer to combating neurodegenerative disease? This article will tackle these questions, and more.

PHENOLIC COMPOUNDS IN WINE

Deep, violet-red liquid swirls within its glass container, running down the side like tears from where it splashed. Wine evokes feelings of culture and sophistication, but perhaps it should also be more widely recognized for its health implications. Wine, specifically red wine, is an important source of a group of molecules known as polyphenols, or phenolic compounds, which are largely responsible for the colour of wine and its astringency – the drying nature (Minussi, et al., 2003). However, the role of these phenolic compounds goes far beyond what wine consumers can directly perceive. These molecules are powerful antioxidants which can reduce oxidative stress common in neurodegenerative diseases, and can potentially attenuate Alzheimer's Disease (Martín, et al., 2011). But when do these potential benefits outweigh the negatives, and how is the wine industry involved?

HEALTH: A SOCIETY ENTHRALLED

In an aging society, particularly one that is becoming increasingly health conscious, the promise of health benefits may be impacting the sales of wine. In recent years, wine, particularly red wine, has been receiving considerable attention in the media for its potential health benefits. Evidence of these benefits are largely popularized by the idea of "the French paradox". This suggests that red wine might allow individuals in France, and other European countries, to consume more foods that are high in saturated fats while maintaining lower incidence of heart disease (Chang, Thach and Olsen, 2016).

In 1991, the hosts of *60 Minutes* interviewed researchers from France and the US. This episode explained "the French paradox" and how moderate wine consumption may be beneficial to overall health. In the months following the broadcast, red wine sales increased by 40% in the U.S. (Chang, Thach and Olsen, 2016). In addition, there have been studies that reviewed the impact of health perceptions on wine sales and found that consumers who are interested in the health benefits of wine are more likely to purchase wine in higher quantities and at higher prices if they believe it will enhance their health (Higgins and Llanos, 2015).

As more research about the health benefits of wine emerges and appears to impact wine sales, one may question whether the wine industry should capitalize on the idea of wine as a healthy beverage. Indeed, there have been studies that observe the consumer response to wines that have been advertised as "healthy". For example, at the beginning of the 21st century, there was a heavy research focus on wine and health, particularly the health benefits of the phenolic compound resveratrol. In 2008, a paper was published that analyzed consumer responses to wines that were enriched with resveratrol. The authors found that advertising wines as "resveratrol enriched" showed a strong positive correlation with consumer red wine purchase (Barreiro-Hurlé, Colombo and Cantos-Villar, 2008).

If health appears to impact wine sales, then why are wines not marketed as healthy? According to a review paper published in Wine Economics and Policy by authors Kathryn Chang, Liz Thach and Janeen Olsen (2016) the most significant restriction with advertising wine as "healthy" is that wine advertisement is highly regulated. The paper explains how all products must be thoroughly examined by government officials for any misleading or false statements to avoid promoting public overindulgence. Regardless of the potential health benefits, wine contains ethanol, which is known to have toxic effects if abused. In many cases, wine producers would rather choose to avoid advertising health benefits of their wines than risk fines or loss of business permits. But, is there any truth to the potential health benefits of wine? The answer lies in the role of phenolic compounds, their general health effects and antioxidant properties.

ANTIOXIDANTS, OXIDATIVE STRESS, AND PHENOLS, OH MY

Antioxidants are compounds which protect molecules in the body from damage caused by free radicals - molecules with an unpaired electron in their outer shell (Young and Woodside, 2001). An excess of free radicals can cause damage to DNA, protein, lipids, and other components of the cell (Martín, et al., 2011).

Oxygen is highly susceptible to losing an electron from its outer shell to become a free radical, inducing further radicalization to produce reactive oxygen species (ROS) as seen in Figure 1 (Kim, et al., 2015). A low amount of ROS is required for cellular communication, pro-survival signals, and other processes. Although the body has a natural ability to reduce and detoxify ROS, there can be surplus production of these molecules, known as oxidative stress, which causes cellular damage (Kim, et al., 2015). The brain is particularly sensitive to oxidative stress due to its high consumption of oxygen and relatively low concentration of proteins that reduce free radical reactions (Gómez-Serranillos, et al., 2009). Therefore, it is not surprising that oxidative stress is implicated in many neurodegenerative diseases, such as Parkinson's, amyotrophic lateral sclerosis (ALS) and Alzheimer's (Martín, et al., 2011).

Antioxidant molecules have received great attention for their potential to reduce oxidative stress and delay the onset of some neurodegenerative diseases. These antioxidant molecules, such as vitamin E (Kim, et al., 2015), can remove free radicals by receiving or donating an electron to create a stable product that will not cause damage (Young and Woodside, 2001). Additionally, antioxidants can augment the action of enzymes, proteins which increase the speed of reactions, that are naturally involved in reducing ROS.

Phenolic compounds, essential to the sensory experience of wine, are natural antioxidants. This is confirmed by the very close relationship between total phenolic content in wine and the total antioxidant potential (Minussi, et al., 2003). There is also a high correlation between antioxidant activity and several of the common individual phenolic compounds, such as gallic acid, epicatechin, and catechin. These phenolic compounds, as well as caffeic acid and quercetin, are those at the highest concentration in red wine (Gómez-Serranillos, et al., 2009; Martín, et al., 2011; Minussi, et al., 2003). However, a single phenolic compound cannot account for the beneficial effects seen with wine in cells and in animal models. Instead, many scientists believe that the benefits are a result of the interaction between several phenolic compounds (Gómez-Serranillos, et al., 2009; Minussi, et al., 2003; Xiang, et al., 2014).

These substances can permeate the **blood brain barrier** and exercise their effects on the brain (Basli, et al., 2012), removing free radicals or increasing the activity of several enzymes which help to reduce oxidative stress (Martín, et al., 2011). When treated with red wine, cells exposed to conditions causing oxidative stress were seen to have increased viability and survival (Martín, et al., 2011). Red wine was used in this study because red wines have higher overall concentrations of phenolic compounds than white wines (Minussi, et al., 2003). The reduction in oxidative stress observed after red wine treatment may be beneficial in

Blood brain barrier: A selectively permeable lining of the blood vessels in the brain that keep the brain isolated and protected from substances in the blood throughout the rest of the body.

fighting against neurodegenerative diseases, as oxidative stress is often a significant characteristic of these conditions (Xiang, et al., 2014). This is apparent in Parkinson's disease, amyotrophic lateral sclerosis (ALS), and Alzheimer's disease (Martín, et al., 2011). However, the majority of research investigating wine and neurodegenerative diseases has focused on Alzheimer's disease.

ALZHEIMER'S DISEASE: IS WINE REALLY THE ANSWER?

Alzheimer's disease is a neurodegenerative disease characterized by memory loss, confusion, as well as personality and behavioural changes (Alzheimer's Disease International, 2018). With a short life expectancy for those afflicted, as well as high incidence rates and medical costs, Alzheimer's is devastating on a global scale (Alzheimer's Disease International, 2018).

Currently, there is no cure for Alzheimer's, primarily because the mechanism of the disease is not well understood. However, there seems to be a relationship between Alzheimer's disease and the aggregation of protein plaques which can interfere with neurological functions. Although the brain normally accumulates plaques with age, this process occurs much more rapidly in individuals with Alzheimer's disease (Basli, et al., 2012). In a healthy brain, neurons communicate with each other through a signalling network that is responsible for controlling all aspects of the body. The signal continues to be transmitted until it reaches the intended location, or dissipates. In those with Alzheimer's disease, connections between neurons are lost because the extent of neuronal death ends the transmission path prematurely. The cause of neuronal death may be due to the accumulation of protein aggregates known as beta-amyloid plaques (Basli, et al., 2012).

Amyloid precursor protein is a long protein strand whose fragments are believed to assist in neuronal health. Proper cleavage into fragments is regulated by alpha-secretase (Basli, et al., 2012). When cut improperly, the fragments will adhere to form protein aggregates- beta-amyloid plaques (refer to Figure 2). Though the complete mechanism is unknown, the aggregates are believed to cause the release of free radicals that are toxic to neurons (Basli, et al., 2012). Additionally, in a mechanism resembling a positive-feedback loop, beta-amyloid plaques tend to release more free radicals in the presence of free radicals (Christen, 2000).

Currently, there are several treatments for Alzheimer's disease. These involve increasing cell-to-cell communication through improving the stability and flow of chemical signals between neurons, but this has no effect if the neurons

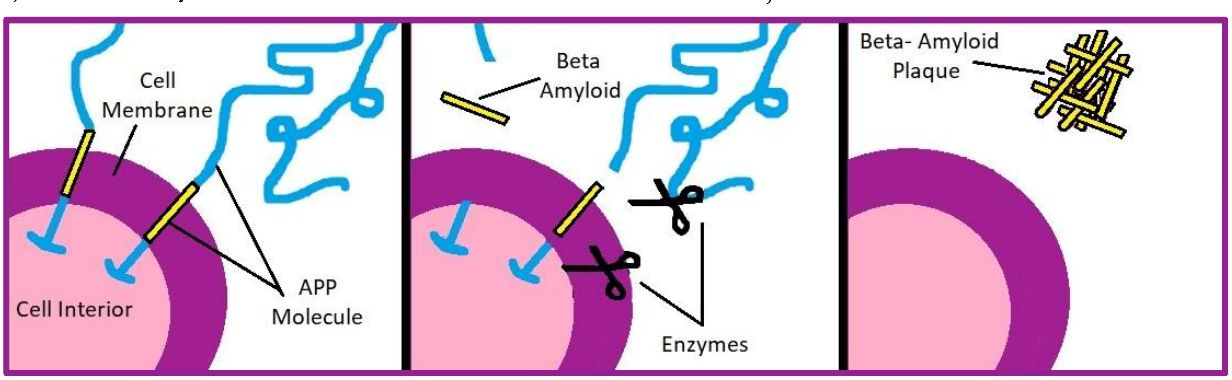

FIGURE 2: Formation of Beta-Amyloid Plaques Beta secretase is an enzyme which improperly cuts the APP protein strand into fragments. These fragments stick together to form protein aggregates known as beta-amyloid plaques that are responsible for producing the free radicals and oxidative stress associated with the onset of Alzheimer's disease (adapted from National Institute on Aging, 2008).

themselves are dead (Alzheimer's Association, 2018). But what if plaque accumulation prevention could easily be incorporated into your daily routine? Surprisingly, the answer may be red wine.

In mouse models exhibiting the progression of Alzheimer's symptoms, red wine has been shown to delay the onset of the disease (Ho, et al., 2009; Wang, et al., 2006). In these studies, mice were given a moderate dose equivalent of 2.3 glasses of wine per day for 7 months. Scientists determined there was a delay in decline of spatial memory (Wang, et al., 2006) and a delay in general cognitive deterioration in these mice (Ho, et al., 2009). Both studies analyzed brain sections and determined there was a reduction in formation of amyloid plaques due to increased alpha-secretase activity, which cuts the precursor of amyloid plaques and prevents the formation of these harmful aggregates (Ho, et al., 2009; Wang, et al., 2006). Therefore, drinking a moderate amount of red wine attenuates Alzheimer's disease in mouse models of the disease as seen through biochemical pathways and behavioural effects.

This result is mirrored in human cohort studies where up to 3 glasses of red wine a day was correlated to a reduced incidence of Alzheimer's disease in a population of individuals over 65 followed for 4 years (Luchsinger et al., 2004). However, the extent of a red wine's effect may vary, as phenolic content is not necessarily consistent between wines.

VINES, VARIANTS AND VINIFICATION TECHNIQUES: THE PLOT THICKENS

This variation in phenolic content between wines is due to factors involved in grape-growing such as grape variety, climate, and soil content (Paissoni, et al., 2017; Ortega-Regules, et al., 2006; Wang, Sun and Chang, 2015). These factors can greatly affect the phenolic content of the grape, and hence the amount present in the wine. For instance, the concentration of anthocyanins, a class of polyphenols with high antioxidant capacity, can vary up to 30% depending on grape variety and wine production techniques (Ageeva, et al., 2015).

Furthermore, anthocyanin content of grapes from the same vine can exhibit even greater variance between years differing in climate than between two varietals from the same year. This indicates that climate fluctuations also impact polyphenolic content (Ageeva, et al., 2015). Indeed, many aspects of climate can alter the phenolic content of the grapes. One study demonstrated that maximum anthocyanin concentration occurs during the driest and hottest years. As phenols are accumulated primarily in the grape skins, it follows that reduced water availability decreases grape size, increasing the grape skin to pulp ratio and thus the anthocyanin concentration in the wine (Ubalde, et al., 2010).

Highly permeable soils rich in phosphorus and calcium, but low in organic matter, generally produce grapes with higher phenolic content and quality (Wang, Sun and Chang, 2015). These soils also increase phenol accumulation in grape skins (Yuan, et al., 2018) yielding higher total phenolic composition in the resulting wine (de Andrés-de Prado, et al., 2007).

Additionally, the wine industry has found several ways to augment the phenolic content of both grapes and wine. For example, resveratrol content is related to the stress experienced by the grapes (Hasan and Bae, 2017; Sun, et al., 2015). By imposing additional stresses on the grapes during pre-harvest maturation, such as microbial infection, LED and UV light, or fungicides, winemakers can increase resveratrol content (Hasan and Bae, 2017). Furthermore, several treatments before fermentation, such as freezing grapes with dry ice, can increase total phenolic content and quality in the finished wine. Freezing ruptures the cell walls of the grape skins, facilitating polyphenol transfer into the juice. The carbon dioxide gas from the dry ice displaces the oxygen in the juice and inhibits enzymatic degradation of polyphenols (Río Segade, et al., 2014). Another treatment involves applying ozone after harvesting to control the organisms related to adverse flavour formation in wine. For some red grape varietals, this ozone treatment can stabilize the grape anthocyanins to maintain their quality and increase the resveratrol content four-fold (Paissoni, et al., 2017).

Phenolic content also changes through chemical reactions that occur during **vinification**, a process encompassing **maceration**, fermentation, and post-fermentation treatments. As the phenols are transferred out of the grape skins and into the juice, chemical reactions increase the structural complexity of these phenols, and form new compounds (Li and Sun, 2017). Attempts to augment the phenolic content of wine during vinification involve maceration in cold or hot conditions, and may incorporate UV light to amplify the effects (Tahmaz and Söylemezoğlu, 2017). Low temperatures (4-15ºC) reduce organism and enzyme activity in an attempt to limit the break down of the phenolic compounds while the higher temperatures (60-85ºC) damage skin cell walls and allow phenols to transfer more readily into the grape juice (Tahmaz and Söylemezoğlu, 2017). Both treatments were found to increase total phenolic content, total anthocyanin content, and antioxidant capacity, while producing a more favourable flavour and colour profile (Tahmaz and Söylemezoğlu, 2017). Furthermore, yeast strains have been genetically engineered to encourage resveratrol production, with reported resveratrol concentration increases of 36% (Song, et al., 2018) and 100% (Sun, et al., 2015) as compared to wine fermented with the non-engineered yeast.

Vinification:
The process by which grape juice develops into wine.

Maceration:
The crushing and soaking of the grape seeds, flesh, stems, and skins in the juice.

While there are methods to increase phenolic content, how effective are the augmented concentrations present in wine? Resveratrol has received much attention from the media and wine growers (Barreiro-Hurlé, et al., 2008) due to its

FIGURE 3: A STANDARD DRINK A standard drink is different in many countries, but for Canada and the USA it refers to approximately 14g of pure alcohol which is equivalent to the values represented in the diagram (National Institute on Alcohol Abuse and Alcoholism, n.d.).

potential use as a therapeutic. It boasts antioxidant, **anti-apoptotic** and anti-Alzheimer's effects (Savaskan, et al., 2003). Naturally, it is present in wine at such low quantities that its pharmacological effects are likely negated (Basli, et al., 2012). In fact, one study has shown that resveratrol has no significant contribution to antioxidant capacity of wine, even when the resveratrol concentration was increased ten-fold (Xiang, et al., 2014). Despite this seemingly negative result for this molecule, its broad potential uses are still being explored and more information could determine unknown effects at low quantities or in combination with other phenolic compounds. However, resveratrol is not the only phenolic compound in wine. It has been shown that the other phenolic compounds have significant antioxidant effects in wine (Minussi, et al., 2003), with great potential for reduction of oxidative stress in cells and animal models (Martín, et al., 2011). Furthermore, wine has demonstrated anti-Alzheimer's effects in vivo (Ho, et al., 2009; Wang, et al., 2006) and through epidemiological studies (Kim, et al., 2015; Xiang, et al., 2014). So, why not indulge in a guilt-free bottle of red wine tonight? There is still one other component of wine still to consider.

Anti-apoptotic effect: An effect resulting in the mitigation of apoptosis, which is programmed or organized cell death.

ETHANOL: THE GOOD, THE BAD AND THE UGLY

Despite its bad reputation, there is some evidence that suggests ethanol has neuroprotective effects and can even reduce the risk of dementia. Many studies and meta-analyses conclude that these effects are only seen with low to moderate alcohol consumption (Brust, 2010; Piazza-Gardner, Gaffud and Barry, 2013; Ridley, Draper and Withall, 2013). In Canada, low to moderate ethanol consumption is defined as 10 standard drinks (Figure 3) per week for females and 15 standard drinks per week for males (Canadian Centre on Substance Abuse and Addiction, 2018).

The unique relationship between the dose of ethanol and its impacts can best be described as a J-shaped curve (Brust, 2010), as shown in Figure 4. This description is used because low to moderate doses have been observed to reduce the risks of cognitive impairment, dementia and Alzheimer's, compared to no alcohol consumption, whereas heavy drinking increases these risks (Brust, 2010). Heavy drinking is not beneficial since ethanol is a direct neurotoxin which can alter the brain and mental activity in many ways (Brust, 2010). Ethanol alters **neurotransmitter** systems by inhibiting excitatory receptors and activating inhibitory receptors (Brust, 2010). Additionally, it decreases the volume of **white matter** in the brain, causes oxidative stress, kills neurons by breaking DNA, and disrupts neuron formation (Brust, 2010; Ridley, Draper and Withall, 2013).

Neurotransmitter: Chemical signal that binds to the receptors of neurons so they can communicate with each other.

White matter: Parts of the nervous system, where the neurons are coated in a fatty insulating layer called myelin.

Furthermore, chronic drinking can result in 'alcoholic dementia' which is described as dementia that lasts for 60 days after ceasing ethanol intake (Brust, 2010). The neurotoxic burden that precedes this lasting impairment is caused by a minimum weekly consumption of 35 standard drinks for males, or 28 for females, over five or more years (Brust, 2010; Ridley, Draper and Withall, 2013). Alcoholic dementia is one of the main types of cognitive impairment caused by alcohol over-consumption and represents about 10% of all dementia cases, although it is expected that alcohol is a contributing factor for many

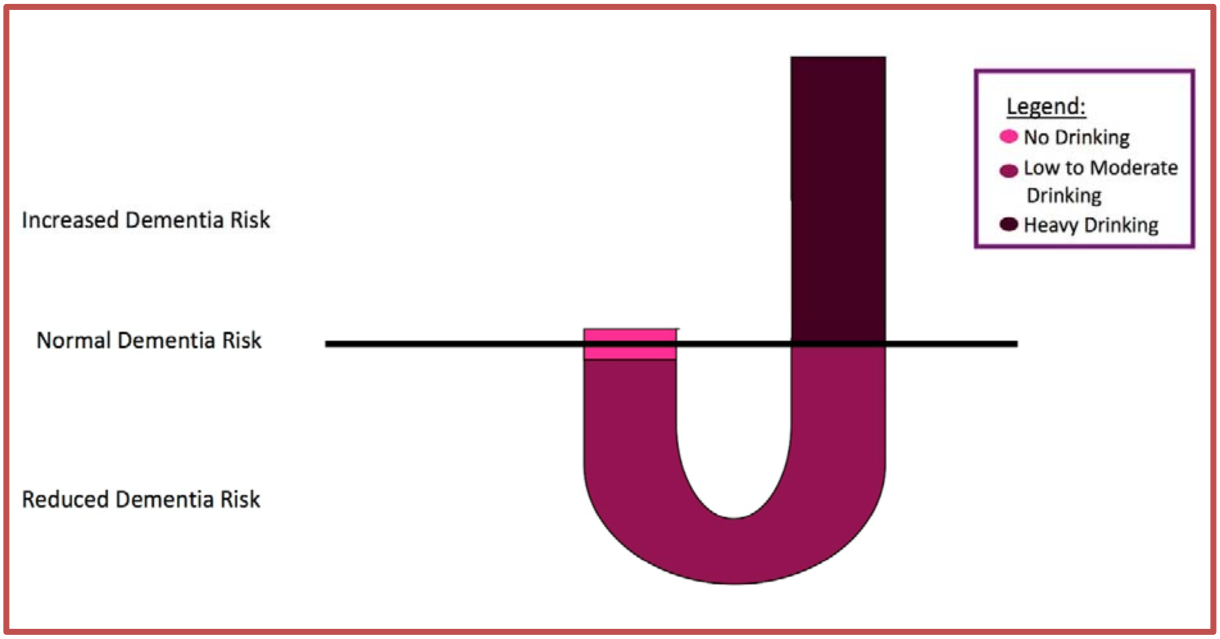

FIGURE 4: THE J-SHAPED CURVE The different shades of maroon represent drinking levels as explained in the legend. The black horizontal line represents the normal risk for dementia, which is approximately the risk level for people who abstain from drinking. Those who consume a low to moderate amount of ethanol have a lower risk of dementia shown by the curved part of the J beneath the black line. Once consumption transitions to what is considered heavy drinking, the risk of dementia increase well above the normal risk. Heavy is defined as any drinking more than the guidelines.

other dementia cases (Brust, 2010; Ridley, Draper and Withall, 2013).

In conjunction with the neurological effects, heavy drinking impacts other parts of the body and increases the risks of alcohol associated cancers (National Institute on Alcohol Abuse and Alcoholism, 2018). Ethanol causes irregular heartbeats, stretching of the heart muscles, stroke, and high blood pressure. Additionally, the pancreas is affected since it releases toxic compounds in response to ethanol which can lead to dangerous inflammation and expansion of pancreas blood vessels. Liver cancer is strongly associated with ethanol, since heavy drinking is the main cause of this condition. Finally, breast and colon cancer risks are related to alcohol consumption because regularly exceeding the recommended drinking levels by 10g increases cancer risks by 7-12% for breast cancer and 7% for colon cancer (National Institute on Alcohol Abuse and Alcoholism, 2018).

The overconsumption of alcohol seems to increase cancer risk, and has potentially dire consequences on the brain and other organs. However, wine has been demonstrated to have positive health effects. Where does this leave the confused consumer?

SUMMARY

The benefits of wine are part of a delicate balance between its components. With low to moderate wine consumption, the phenolic compounds in the wine work synergistically to reduce oxidative stress and overpower the negative aspects of ethanol. However, the balance tips at heavy wine consumption as the neurotoxic effects of ethanol exceed the benefits of the phenolic compounds. Although the wine industry employs multiple techniques to increase the phenolic content of wine, it is intended to enhance the flavour profile, and cannot be used to promote health benefits without a confirmed correlation. All things considered, the key to the benefits of wine can be summarized by the phrase, 'moderation is key'. Drinking a moderate amount of wine (a weekly amount of 10 glasses for females and 15 glasses for males) may reduce the risks of negative neurological conditions. However, more research needs to be performed before wine can be recommended to benefit neurological health. Until then, drink to your health, not for your health. Cheers! Santé!

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You Better Be-leaf It:

The Impact of Defoliation on Red Grapes, *Vitis vinifera*

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Wine is one of the world's most widely consumed beverages, and one of the most intricate to create. Many winery owners would argue that the production of high-quality wine is akin to a calculated artform, and that the final product is a carefully synthesized blend of both technical and environmental influences.

Many of these influences are implemented at the start of the wine-making process: at the vineyard. From the sunlight that streams through the leaf canopy, to the breeze that blows across the clusters, the exposure of grapes to the elements shapes the wine that they will finally become.

To fine tune the conditions of the canopy to ensure the highest quality of wine, grape growers will utilize various leaf pruning techniques. Much like a sculptor, a viticulturist brings out the beauty from within the fruit through pruning. Using variations in the number of leaves left on the vine, the mechanism of removal, and even the timing of defoliation, impactful changes may be made to the intricate painting that is the composition of the grape and its chemical balance. It is these changes that result in the full-bodied mouthfeel of your favourite Cabernet Sauvignon, or in the strong astringency you taste from sipping a Barolo.

Therefore, with a better understanding of the art of canopy management, we can better understand the story behind the grape-wine growing process and develop a greater appreciation for what is consumed.

PRUNING AND DEFOLIATION 101: WHAT IS IT, AND WHY DO WE DO IT?

Why is it so important for winegrowers to practice proper pruning techniques? Pruning significantly contributes to overall vine health, as well as to the developing grape and eventual wine quality. While it may seem logical that a sprawling vine or a large quantity of grapes is desired in the winemaking industry, the reality is quite the opposite. Instead, viticulturists aim to produce just the right amount of grapes and leaves so that vines do not lack the energy and nutrients that are required to fully ripen berries to the highest quality (Barth, 2016). In fact, a vine that is too lightly pruned and that bears too many clusters may produce larger grapes of an immature character and diluted flavour. Overcropping a vine also weakens the vine itself, and shortens its lifespan (Freeman, 1983; Thomas, 2015).

In 1985, Smart et al. developed a scoring system to help viticulturalists keep a closer and more calculated eye on their vineyard. This system analyzes the number of leaves, leaf layers, canopy gaps, and grape clusters on both the interior and exterior of the vine. Ultimately, this analysis assesses the balance of a vineyard and the potential quality assurance of its grapes. Canopies possessing leaves and fruit that were well-exposed to sunlight often scored the highest in taste panels evaluating wine quality (Smart et al., 1985; Smart and Robinson, 1991). So why exactly were these particular vine characteristics investigated?

The factors studied are all indicative of the microclimate of a grapevine. The microclimate refers to the environmental conditions of a very small area, and in the case of vineyards, to the area immediately surrounding the grape clusters. Primarily, the microclimate is affected by the amount of sunlight intercepted by the vine, which in turn influences plant photosynthetic capacity and the partitioning of resources between vegetative growth (the development of the leafy elements of a vine), and reproductive growth (the development of the grape) (Pereira et al., 2006). One of the main goals of grape growing is to maximize the production of certain chemicals that would achieve the desired quality of grapes, and thus the wine they produce (Kliewer and Dokoozlian, 2005). During the ripening period, important chemicals accumulate in the grape, giving it a distinctive character. The accumulation of these chemicals occurs during the ripening stage and is greatly influenced by the microclimate. Viticulturists can artfully manipulate the microclimate, and consequently, the character of the final wine, through defoliation. Defoliation denotes the removal of leaves from the fruiting zone of a grapevine (Figure 1). The aim is to achieve the correct balance between carbon sinks - the grapes which consume carbon dioxide (CO_2) - and carbon sources - the leaf area which takes in CO_2. This optimizes the production of quality fruit (Martinson, 2017).

FIGURE 1: THE FRUITING ZONE. The area immediately around the grape clusters is known as the fruiting zone, which plays a large role in determining the grape microclimate and is the region where basal leaves reside.
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When a viticulturist is defoliating a vine, they are 'opening up the canopy', ensuring that the density of the surrounding leaf canopy is not shading and preventing the grapes from ripening, nor smothering vines around it (Marrison, 2011; Barth, 2016). Currently in the industry, the most common method of defoliation is the removal of basal leaves (Smart and Robinson, 1991). As the larger and older leaves of the vine, and the closest to the grape clusters, basal leaves play an important role in shaping the grape microclimate (Palliotti and Poni, 2011). When properly applied, basal leaf removal not only opens up the lowest canopy, allowing greater exposure to sunlight, but also facilitates improved air circulation around grape clusters, reducing the incidence of fungal disease (Percival et al., 1994). With fewer leaves, pest and fungal sprays are also more effective, as they may penetrate a larger surface area of grape clusters (Percival et al., 1994). These factors contribute to a better microclimate in which grapes are grown and harvested.

IT'S ALL ABOUT TIMING: TRADITIONAL VS. ALTERNATIVE DEFOLIATION

The type of leaf that is removed from the vine is an example of one among many important variables that must be considered when it comes to defoliation. Another is timing. The time that basal leaf removal is applied has profound impacts upon the grapevine microclimate and thus, the physical and chemical profile of the grape. The grapevine goes through various changes as it flowers. Beginning with fruit-set (when the fruit starts forming), the vine matures into veraison - the transitioning point from grape formation to ripening (Figure 2). Throughout this process of fruit development, basal leaves provide necessary sun protection and sources of carbohydrates for young grapes, while they undergo many chemical changes that will eventually contribute to important wine characteristics (Jackson, 1997). Therefore, removing basal leaves at different times can significantly alter grape composition. The importance of performing appropriate treatments at the right time can be clearly shown in the differences between two kinds of defoliation: traditional and alternative.

Traditional leaf removal is one of the most commonly practiced defoliation methods amongst viticulturists. Typically applied to high density canopies, traditional leaf removal involves the partial or complete removal of basal leaves from the fruiting zone, between the developmental stages of fruit-set and veraison (Figure 2). This achieves the primary objectives of leaf removal - improving air circulation and disease tolerance around the clusters, as well as opening up the canopy to allow better light distribution. In turn, this helps to enhance pigmentation of the grapes, and eventually the red wine character (Palliotti and Poni, 2011). That being said, substantial leaf removal is not necessarily the answer to quality wine. Severe or complete leaf removal from the fruiting area can have damaging impacts on the fruit, as excessive light exposure increases grape temperature, leading to sunburn and unfavourable chemical imbalances. This ultimately results in a poor-quality wine (Palliotti and Poni, 2011). In 2013, researchers demonstrated that Sangiovese grapes of vines that were defoliated during veraison achieved the highest temperatures, compared to vines that were left alone or defoliated with an alternative technique (Pastore et al., 2013). These same veraison-defoliated vines had the lowest concentration of pigments in the grape skin, a characteristic that results in a muted or unfavourable red wine hue. Similar results support the conjecture that the concentration of these pigments is reduced at approximately 30°C, possibly due to temperature degradation, alongside inhibition of the genes responsible for their synthesis (Mori et al., 2007). In addition to reduced colour and sunburn, excessive veraison defoliation can stunt fruit maturation through the removal of too many sugar-producing basal leaves just as the grapes are beginning to ripen.

This reduces the amount of sugars that eventually accumulate in the fruit.

As improvements in canopy management continue to advance the grape industry, an alternative defoliation method has attracted the interest of viticulturists in recent years: early leaf removal. Also referred to as pre-bloom defoliation, early leaf removal is the practice of removing leaves prior to flowering, and provides a possible solution to addressing both the common goals of defoliation (i.e. enhanced air circulation and reduced disease susceptibility) while avoiding the potential pitfalls of traditional leaf removal. Early leaf removal is centered around controlling fruit-set size by adjusting the carbohydrate supply available (Palliotti and Poni, 2011). Removing the most photosynthetically active leaves in the fruiting zone prior to fruit-set deprives flowers of carbohydrates, which reduces the number of immature grapes that ultimately develop and limits the size to which they will grow. Although having fewer grapes may seem counterintuitive, the trade-off between quality and quantity is apparent. After defoliation, resources are divided amongst a smaller number of grapes, so compounds such as sugars and pigments become concentrated to levels sought by viticulturists. In addition, reactive processes in the flowering vine result in higher photosynthetic rates through elevated activity in the remaining leaves, and through compensative lateral leaf growth just as the grape enters veraison (Palliotti and Poni, 2011). This has been demonstrated in several scientific studies, including a 2008 investigation where scientists found that the CO_2 exchange rates per yield of early defoliated Sangiovese vines were 38% greater than the non-defoliated treatment group during veraison. It was concluded that these greater CO_2 rates reflected enhanced sugar production (Poni, Bernizzoni and Civardi, 2015). Ultimately, a younger, less-dense canopy created by early leaf removal provides the air circulation, sun exposure, and nutrients necessary for optimal growth just as the grapes begin to ripen. This timeline would be unattainable with traditional defoliation, in which leaves are removed at veraison.

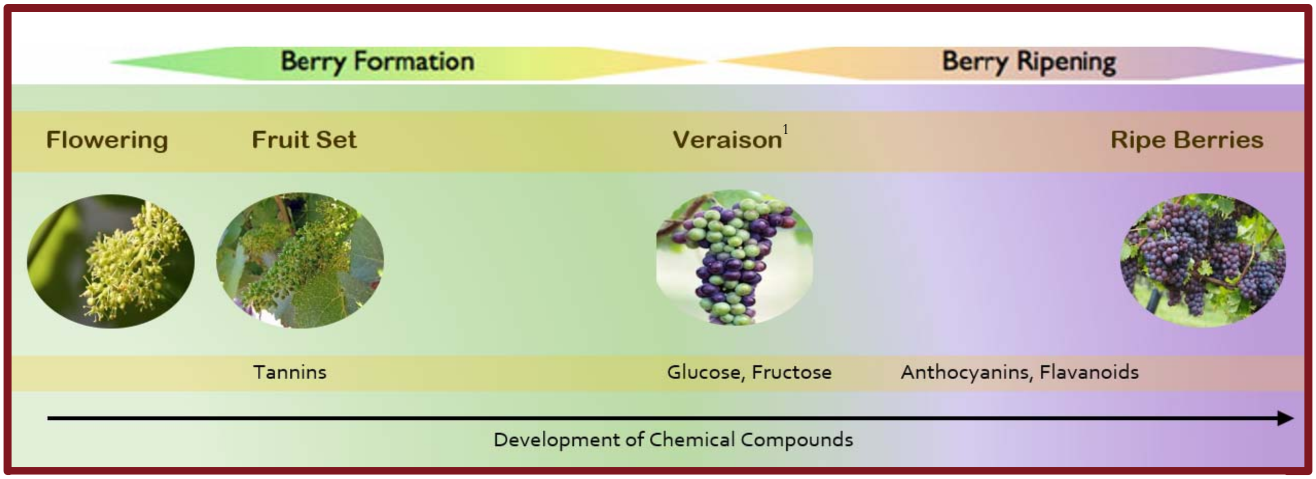

FIGURE 2: CHEMICAL PRODUCTION OVER GRAPE LIFESPAN. A visual representation of the time of wine grape compound production and accumulation. [1]Veraison image (Wikimedia Commons, 2015).

The application of defoliation techniques allows viticulturists to manipulate the interactions between the leaves and fruit in the vine microclimate, and is guided by an important concept of vineyard management: vegetative versus reproductive growth (Smart and Robinson, 1991; Palliotti and Poni, 2011). It is the goal of each viticulturist to achieve the optimal balance between growth of the vine and development of the fruit. Without the leafy infrastructure to provide services like sugar production and sun cover, grapes will not reach sufficient maturation. However, if the vine is allowed to grow without constraint, resources will be stretched thin across many leaves and clusters, resulting in unfavourable consequences like reduced colour and flavour from the dilution of pigments and sugars (Palliotti and Poni, 2011; Pastore et al., 2013).

WHICH LEAVES TO LEAVE? OPTIMIZING LEAF REMOVAL

Along with the 'when' and 'where' to defoliate, there comes the question: how does one determine exactly how many leaves to remove? Although experience makes it a matter of intuition amongst some grape growers, scientific research has narrowed it down to a calculable quantity, depending on the region and cultivar of *Vitis vinifera* (Smart and Robinson, 1991). Through attempts to understand the optimal leaf area-to-fruit ratio, a formula was developed. This ratio can be determined by comparing grape cluster characteristics to the variable leaf surface area in the fruiting zone. Factors such as cluster weight, average grape weight, and sugar content are examined, and the leaf area resulting in the highest values for each category is generally desirable. The resulting ratio has been narrowed down to a range of 7-12 cm^2/g (Kaps and Cahoon, 1991; Smart and Robinson, 1991). Viticulturists can use this range to determine the amount of defoliation required, typically leaving at least 15 leaves per cluster (Jackson, 2014).

With recent technological advancements in viticulture, some vineyards now have the option of using machines to carry out defoliation instead of by hand, which is costly in terms of both money and time. Ideally, mechanical leaf removal would be capable of faster defoliation rates at the same expected quality, but at a lower cost. So far, the use of mechanical leaf defoliation has been shown to typically maintain the same grape quality observed as with manual defoliation, or to have minimally negative effects (Tardaguila et al., 2010; Percival et al., 1994). These techniques can, however, present hefty upfront costs and bring the risk of malfunctions. Currently, it is a matter of cost-benefit analysis, left to the discretion of the vineyard (Jackson, 2014).

Pruning practices are changing as we speak!

Our changing climate has resulted in some regions experiencing increased sunlight and higher temperatures, and in turn, grapes are ripening earlier than expected! Consequences of these changes include: increased sugar and alcohol concentrations (Keller, 2010), delayed pigment accumulation, and in some cases, grape degradation (Sadras and Moran, 2012).

Wineries in areas such as Spain, the United States, and even Bordeaux are already seeing the effects of the changing climate (Schultz and Jones, 2010).

In response, viticulturists are changing the way they prune to compensate for these climatic differences and keep their wine tasting the same.

Researchers are suggesting a reduction in pruning and the removal of apical (top) leaves rather than basal (bottom) leaves, in order to preserve quality (Zheng et al., 2017; Palliotti et al., 2013).

The decision of a viticulturist to remove either one single leaf or ten, by hand or by machine, has profound effects on the internal processes of a vine. The consequence of these processes may be a reallocation of nutrients or a shift in the distribution of sunlight. However, the most important repercussions may be observed in one small vessel: the grape.

THE METABOLITES BEHIND THE MADNESS

Here, we arrive at the microscopic centre of defoliation practices. It is difficult to imagine that the simple act of pulling a few leaves off of a vine can result in fundamental changes to a growing grape and the corresponding wine character.

Yet, it is the chemical composition of a grape that a viticulturist is ultimately manipulating.

One of the most important groups of compounds one will come across when considering wine and grape composition is the polyphenols. Three polyphenolic groups of particular interest to viticulturists are the flavonoid groups, flavonols

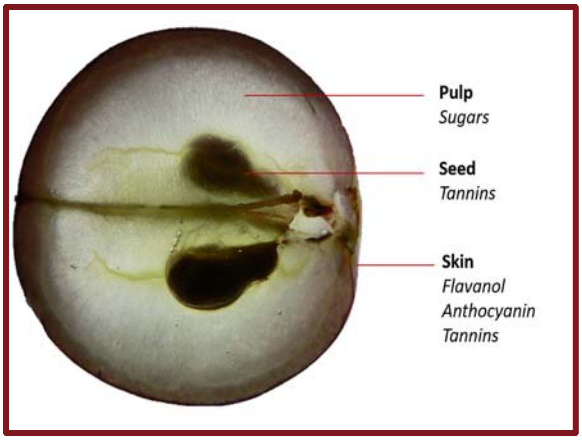

FIGURE 3: COMPOUNDS IN A GRAPE. A visual representation of where sugars and polyphenols, compounds altered by defoliation, are found.

and anthocyanins, and tannins (Figure 3). Each of these groups serve many functions in a grapevine and should also be of special interest to consumers, as they contribute to the unique characteristics of wine we know and love. These characteristics, which include colour, mouthfeel, and dryness, can be manipulated through changes in the microclimate via defoliation. The use of alternative or traditional leaf removal techniques can establish distinct ratios of compounds within the grape.

For instance, flavonoids are found in nearly every fruit and vegetable are naturally synthesized in plants (Aherne and O'Brien, 2002). They are commonly attributed to grape skin colour and relatively resistant to modification when facing stressors like oxygen, heat, or water shortages (Panche, Diwan and Chandra, 2016; Aherne and O'Brien, 2002). That being said, variations in light exposure, which can be brought on through defoliation, will have significant impacts on the pathways responsible for flavonoid synthesis. This in turn changes the balance between compounds present in the grape.

Specifically, flavonols are mainly produced in the leaves, but they can also accumulate in the skin of the grape. Wines made from thicker-skinned grapes will have a higher flavonol concentration, and thus a more bitter flavour (Harwood, Ziegler and Hayes, 2013). Another significant flavanoid group found in the grape skin are anthocyanins. Anthocyanin biosynthesis begins at veraison, as the berries begin to ripen. Anthocyanins contribute to the darker, more purple pigmentation found in red wine grapes, and the subsequent wine produced. In contrast, grapes used to make white wines often contain little to no anthocyanins (Boulton, 2001).

The final group of compounds, which should be of notable interest to consumers, are the tannins. Known to wine and tea drinkers alike, tannins are responsible for the predominantly bitter flavour in both beverages. Produced primarily in the grape seed and skin, they also contribute to what has been described as the "body" and "mouthfeel" of a wine. Although we know that the main production of tannins occurs in the seeds following fruit-set, with maximum levels observed around veraison, scientists do not truly know the biological importance of tannins. However, a possible reason may be that the compounds act as a deterrent to herbivorous feeding (Robbins et al., 1987). All that is known with certainty is that tannins do not deter humans from enjoying wine.

Understanding how these compounds and flavours arise in the leaves and grapes can provide insight into the significance of defoliation on the microscopic scale. The primary factor responsible for flavonoid synthesis is the harmful ultraviolet radiation (UVR) that accompanies sun exposure. While humans turn to sunscreen and clothing to block UVR, plants are self-sufficient. When UVR strikes the vine, grapes respond with an increase in the synthesis of flavonoids, which can minimize mutation and disease (Cohen and Kennedy, 2010). This duality is a testament to the multi-functional nature of flavonoids, as alongside their roles in herbivory defense and UVR stress, they are also responsible for producing the colours of flowers that attract pollinators and allow for the spread of eventual offspring.

Once flavonoid synthesis is induced in the grape skin through sun exposure, the chemical pathway to its flavourful product begins. While flavonoids are often considered a secondary metabolite of some of the more commonly known metabolic pathways (e.g. photosynthesis), there are two distinct metabolic processes that work in tandem to synthesize this group of compounds: the phenylpropanoid and shikimate pathways. The phenylpropanoid pathway is responsible for producing flavonoids from an alternative form of malonic acid, and the essential amino acid phenylalanine. These compounds are obtained from the shikimate pathway (Herrmann and Weaver, 1999). Thus, the shikimate pathway acts as the link between carbohydrate metabolism and aromatic compound synthesis in plants, taking in the sugars produced by the vine, and transforming them into the metabolites that ultimately provide wine its unique taste.

The phenylpropanoid pathway is equally significant to viticulturalists. Exclusive to plants and microorganisms, this pathway is responsible for converting metabolic intermediates into an important amino acid precursor. These intermediates are obtained from glycolysis and the Krebs cycle, two of the most fundamental pathways in all organisms (Fraser and Chapple, 2011). With the polyphenols often seen as a byproduct, their importance in wine production are clearly linked to these essential processes.

Ultimately, these minute processes of biosynthesis are brought about when sunlight strikes the surface of a grape. Although they may be overlooked, these chemicals play a vital role in the flavours of the final wine. It is for this reason that the practice of defoliation is so important, and why viticulturists strive to apply the most appropriate, and timely, of removal methods.

CONCLUSION

Defoliation is only one part of the story sculpted into a vine, but an enjoyable chapter nonetheless. As the leaves of a vine are removed, whether by traditional or alternative methods, the grapes undergo subtle chemical changes, resulting in a distinct wine character. Having a greater understanding of the importance of defoliation on a macroscopic to microscopic scale hopefully provides you with some appreciation for the effort invested in a vine, and with proper ageing, grape growing as complex and flavourful as the wine itself. So, the next time you find yourself settling in for the night with a glass of Shiraz or go out with friends with a bottle of Pinot Noir, consider the story and science behind the wine.

MORE TO EXPLORE

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Manipulating Wine Colour

Taste the Wine Rainbow

Nicole Cappelletto, Hannah Hosein, Michael Pasquariello and Jess Speedie

Wine is a colourful topic. The hue of wine attracts us to the bottle and influences taste; therefore, colour is an important characteristic of wine to both the consumer and winemaker. There are distinct processes that occur to manipulate wine pigmentation throughout the production line that ultimately lead to a wide colour spectrum of wines. This colour journey that wines partake in can be described through a narrative of what, how and why: ***what*** pigments are responsible for wine colour, ***how*** do various chemical and physical processes alter pigmentation and ***why*** does the wine industry go to so much trouble to perfect wine colour? From a marketing perspective, colour and taste have strong psychological associations and this relationship can be exploited to maximize consumer appeal. Recently, the interest of millennials in untraditional wine colours has opened the floor for winemakers to experiment with pigmentation, broadening the wine colour spectrum.

MANIPULATING COLOUR: WINE NOT?

Red or white? This seems to have been the question on every wine drinkers' mind for the past several thousand years. Traditionally, wine has been produced in various red and white shades. This narrow colour spectrum has been the result of limited technological methods to alter wine colour, the natural limitation of white and red grape varieties and the lack of demand in wine variety. Technologies used to manipulate colour are now both abundant and complex, and oftentimes colour alterations have effects on other properties of a wine, such as taste and aroma (Cheynier et al., 2006). Colour also induces various psychological responses in humans and thus, the hue of a wine can be used to maximize buyer appeal. Colour can also be used to indicate a wine's tendency to maintain its organoleptic (sensorial) properties over time (Zoecklein, 2005). Therefore, colour is of great interest to both the consumer and producer.

It seems as though the era of a red- and white wine-dominated market is coming to a close, however. Serving rosé, once considered a faux pas, is now all the rage. Some new wine brands have even gone so far as to introduce dyes to their wines in order to create new wine colours (Cannon, 2018). The need to create novel niches in the competitive wine market by budding wineries, coupled with the demand by millennials for 'something new,' seems to have pushed the wine industry to expand its traditional colour horizons.

PIGMENTS OF REALITY

Grape varietals can be broadly divided into two categories: red and white. However, these classifications do not refer to the colour of the juice the grapes produce. All grape varietals (with the exception of the *teinturier* variety) produce clear or white juice (Cheynier et al., 2006); the red and white grape categories correspond to the skin pigment of the grape. Pigment molecules present in the grape skin, seeds and stems are ***what*** give wine its initial colour (Cheynier et al., 2006).

These colour molecules are known as anthocyanins, hydroxycinnamic acids, flavan-3-ols and tannins (Reynolds, 2010). All of these molecules are referred to as phenolic compounds because they contain aromatic rings and hydroxy groups in their chemical structure (Klein, 2015). Anthocyanins are plant pigments that consist of

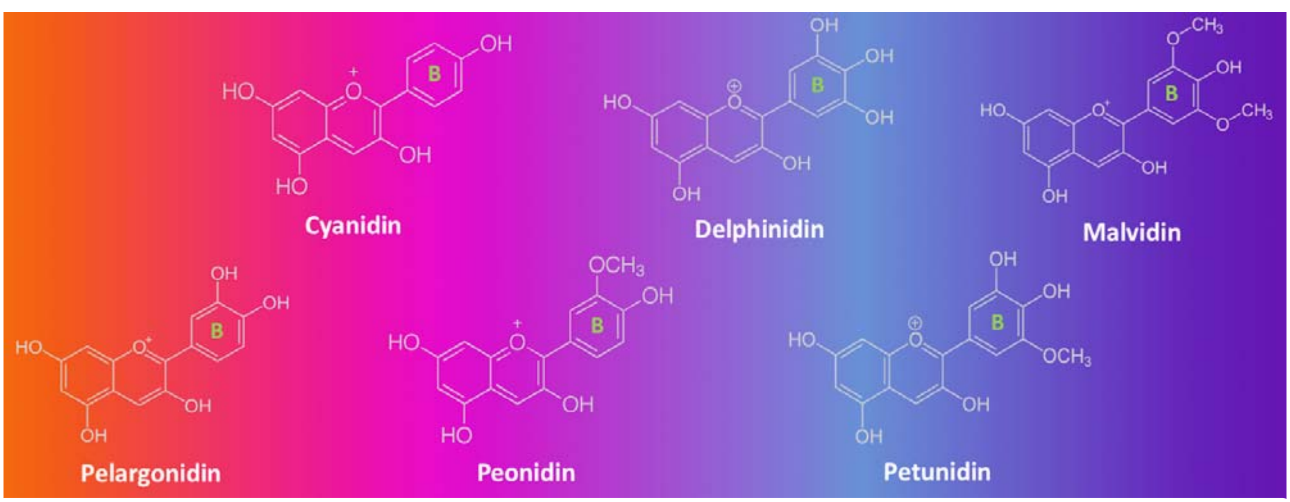

FIGURE 1: COLOUR COMPOUNDS. Small changes to the ring structure of anthocyanidins produce a range of colours (adapted from Dai and Wein, n.d.). Blueness increases with the number of hydroxyl groups (-OH) attached to the B-ring (labelled in green) while red intensity increases with the degree of methylation. These anthocyanidins bind to a sugar (not shown) to become anthocyanins.

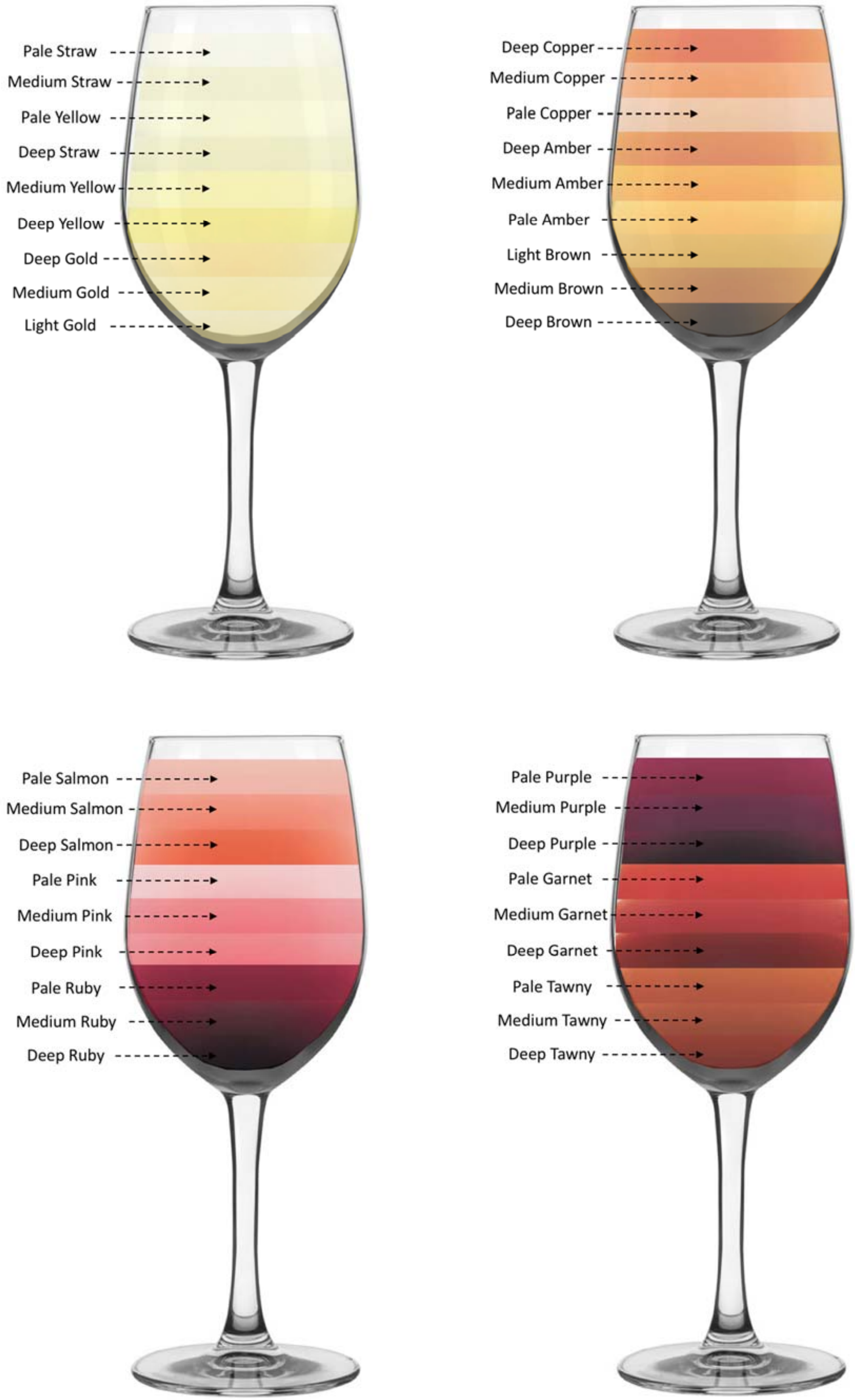

FIGURE 2: WINE COLOUR SPECTRUM. Colour identifications for various hues of red, white and rosé wines.

an anthocyanidin bonded to a glucose. These produce scarlet, magenta, purple and blue hues in wine as shown in Figure 1 (Glover and Martin, 2012). The wide variety of colours produced by anthocyanins is attributed to minor changes in ring structure. Tannins are bitter molecules found in plants (Ma et al., 2014). Both anthocyanins and tannins are found in red grapes whereas hydroxycinnamic acids and flavan-3-ols, on the other hand, are the molecules that contribute to white grape colour (Reynolds, 2010).

Though there are only a few molecules responsible for wine colour, a broad spectrum of colours can be produced through meticulous colour manipulation techniques imposed by winemakers (Figure 2).

FROM GRAPE TO GLASS: WINE THROUGH THE STAGES

Winemakers encounter ample opportunities to make choices from the moment the grapes are harvested to the moment a glass of the vintage is poured. It is by these choices at each step of the vinification process that the winemaker can customize the colour of their wines and achieve their desired product. Before entering the stage of fermentation, choices in temperature and the contact time between the grape skins and juice can alter wine colour. During fermentation, winemakers can employ yeast strains to tailor the wine's chromatic nuance. Finally, once the juice has fermented, colour-altering choices in pH, barrel type and oxygenation level need to be made. Precisely ***how*** winemakers' choices during each of these three stages influence the colour of wine will be explored in the following sections.

Quick Terms: Vinification

The overall process of the conversion of grape juice to wine.

Pre-fermentation

Before the wine must even encounters its first ethanol molecule, winemakers have the colour profile of the final product in the front of their mind. Upon harvesting, grape berries are distributed to large steel tanks where they are either pressed or left to be crushed under their own weight. Pigment extraction and colour development begins when the skin and berry flesh soak together in a process known as maceration (Figure 3) (Freitas et al., 2017; Cheynier et al., 2006). Maceration enables the pigment molecules from the grape skins, seeds and stems to enter the clear juice (Robinson, 2006). Curiously, a larger berry will not always produce more colour; the concentration of pigments produced by a grape is determined by the grape's skin to flesh ratio (Roby and Matthews, 2004). Winemakers have noticed that if non-severe water deficits occur during the growing season, then the growth of mesocarp tissue, the fleshy part of the grape, will be inhibited (Roby and Matthews, 2004; Roby et al., 2004); the skin to flesh ratio will consequently increase, and ultimately result in a more intensely pigmented wine (Balint and Reynolds, 2014).

How long the grape skin and juices are in contact, if at all, determines the wine's colour identity. Immediate removal of the skins from the pulp and juice will produce white wine, the intrinsic colour of grape berry flesh (Reynolds, 2010). Red wine is created by allowing the skins, seeds, pulp and juice, collectively known as must, from the red grapes to steep together for several days during maceration (Jackson, 2008). Varying skin contact time between the flesh and the skin is how winemakers produce the colours in between red and white, such as rosé and amber.

Skin-contact wines, otherwise known as amber or orange wines, are a variety of white wine made from white grapes (Reynolds, 2010). Steeping the

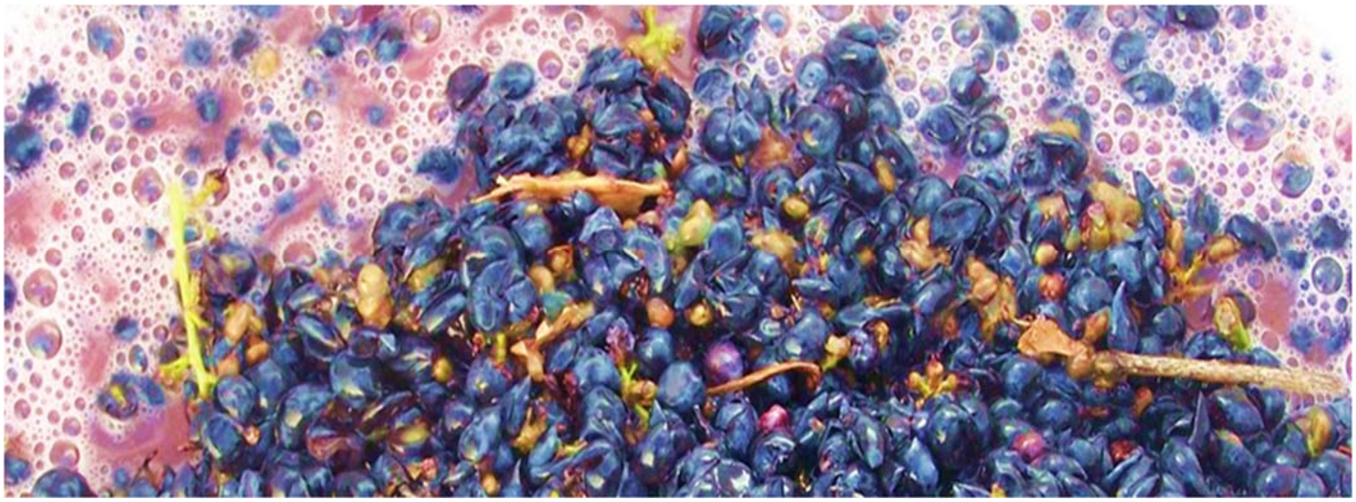

FIGURE 3: MACERATION. During maceration, the skins, stems and flesh of red grape berries come into contact with the juice, initiating the extraction of pigments from the berries into the previously clear juice (Wikimedia Commons, 2007).

skins of white grapes together with the white juice from the berries results in an orange to amber colour due to higher concentrations of hydroxycinnamic acids and flavonoids (Gomez-Mıguez, 2005). Conversely, rosé wines are typically made from a process known as saignée, where the white juice from red grapes is allowed to steep with red grape skins for a short time in order to develop a pinkish colour (Jackson, 2008).

Taking this to the extreme transforms the outcome to red wine, dictated by diffusion of anthocyanins from the berry skins (Reynolds, 2010). The longer the red grape skins are allowed to steep, the deeper the pink or red hue becomes. The temperature at which this occurs must be considered by the winemaker, as it greatly affects pigment extraction. In an effort to extract more than the standard 30% of anthocyanins from grape skin tissue, winemakers employ a method known as thermovinification (Jackson, 2008). This process involves flash heating and hot pressing the must (up to 80°C) so winemakers can develop a rich red colour in their wine product.

The opposite extreme, whereby the winemaker immediately removes grape skins, seeds and stems, results in a clear, crisp juice ranging in colour from white to pale yellow. In contrast to the diffusion-dominated colour development in red wine must, white grape must colour is instead dictated by the process of oxidation. It is common practice to process the must as soon as possible after harvest, as white wine must is acutely vulnerable to oxidation (see Box 1). Phenolics in the must react with oxygen in the air, yielding a distinctly yellow product. If winemakers find this effect undesirable, they can tighten the tank lid and add sulfur dioxide (a process known as sulfur dioxide bleaching) to inactivate the oxidative enzyme, polyphenol oxidase, and thus minimize the extent of oxidation. If a yellow hue is desired, winemakers can keep the tank lid open and delay the start of fermentation.

During Fermentation

Grape berries naturally host strains of yeast on their skins throughout the growing season (Morata, Loira and Suarez Lepe José, 2016). They are retained during harvesting and eventually infiltrate the must. These 'wild types' of yeast, if left alone will initiate the fermentation process – and, in fact, some commercially available wineries employ this technique (e.g. Rosewood Estates 2016 Unfiltered Pinot Noir). However, for reasons predominately concerned with enhancing

FIGURE 4: AGED VS. YOUNG RED WINE. The colour profile of red wine changes with age. The addition of some strains of yeast by the winemaker during fermentation results in the formation of vitisins, which mimic the aged-wine colour profile (adapted with permission from Paula, 2016).

fermentation rates, winemakers often choose to add other yeast strains manually. The consequences for wine colour, though, are not to be overlooked.

Certain metabolites of these wild-type yeast strains react with grape anthocyanins and form secondary pigments: pyranoanthocyanins, otherwise known as vitisins. These pigment molecules are more stable than anthocyanins and have slightly more nuanced chromatic properties, including immunity to sulfur dioxide-bleaching (Morata, Loira and Suarez Lepe José, 2016). Their red-orange hue is characteristic of aged wines, in subtle contrast to the red-bluish colour of young wines (Figure 4). The presence of vitisins, remarkably, can thereby allow the colour profile of young wines to parallel the tawny, brick red or brown colour profile of aged wines.

Box 1: Oxidation vs. Oxygenation

Oxidation has a negative connotation. It is a naturally-occurring reaction between molecular constituents of white wine must that winemakers generally wish to minimize because it results in a distinctive yellow hue to the wine. Oxygenation, on the other hand, is a technique purposefully implemented by winemakers whereby they introduce small and measured amounts of oxygen into red wine in order to improve taste, aroma and, most importantly, colour.

Post-fermentation

The fermented product can finally be deemed wine and thus winemakers can enter the final steps of vinification wherein wine colour can continue to be altered. Aging is typically only desirable for red wines, and will be left to do so in oak barrels for several months to years (Reynolds, 2010). During the aging process, young red wines transition from a red-purple-blue colour into a tawny-brown, brick-red hue (Perez-Prieto et al., 2003), facilitated by the barrel's porosity and the resulting oxygen exposure. The amount of oxygen received by the wine inside is directly related to the barrel surface area to volume ratio, porosity, and the number of times the barrel has been used previously (Perez-Prieto et al., 2003). Each of these factors are taken into consideration by the winemaker.

The tannins and anthocyanins present in red wine are chemically unstable, and thus will undergo polymerization reactions during their time in the barrel (Basalekou et al., 2017). Products of these reactions include stable polymer pigments that contribute to a tawny colour (Basalekou et al., 2017; Gómez-Plaza and Cano-López, 2010). In the presence of oxygen, however, this polymerization is facilitated by acetaldehyde. Products of this reaction exhibit special chemical structures, known as ethyl bridges, that are able to protect anthocyanins from colour alteration and bleaching (Jackson, 2008). Thus, increasing oxygenation by using newer, more porous barrels aids in the development and stabilization of an aged red wine colour. All in all, the winemaker can choose from various oak barrels and alter storage time to control how the aging process, and consequently oxygen exposure, affects the colour of their wines (Perez-Prieto et al., 2003).

Although pH is typically associated with taste (owing to wine's acidic pH, which ranges from 3.1-3.6), it plays a large role in the stabilization of red wine colour (Gómez-Plaza and Cano-López, 2010). Winemakers closely monitor the pH post-fermentation, and make adjustments accordingly.

Broadly speaking, there are three important molecular structures of anthocyanins in red wine (Kontoudakis et al., 2011). The flavylium cation and quinoidal base structures are associated with red and blue colour, respectively, while the third conformation is completely colourless. Changing the pH of the wine changes the relative abundances of each conformation, enabling the colour associated with the conformation to dominate the colour profile (Cheynier et al., 2005). Incredibly, the colourless anthocyanin conformation would in fact dominate at typical wine pH, if not for the process of co-pigmentation. In this naturally-occurring process, the formation of conglomerates decreases the abundance of the colourless anthocyanin conformation, and allows for the deep colours of red wine to persist (Jackson, 2008).

WHY BOTHER?

Clearly, winemakers make many efforts to create a wine that looks beautiful. The myriad of colour-altering processes that occur throughout vinification is impressive, but manipulating them does not come without cost. ***Why*** does the winemaker go through such trouble to change the colour of their wine? Why not save the time and money needed to make such changes and simply focus on another aspect of the beverage, like branding or bottling? The answer lies in market analyses and psychology research.

As with any other product on the market, consumer appeal is crucial. According to consumer choice theory, consumers tend to purchase goods that will maximize their utility, or satisfaction (Thaler, 1979). Consumers would rather continue purchasing a good with which they are satisfied than try something completely different and run the risk of being less satisfied. As a result, winemakers tend to produce traditionally-coloured wines, the reds and whites, knowing that those wines have dominated the market for centuries and will likely continue selling. In fact, most market analyses often consider any non-red, white or rosé wine to be part of the 'other' category (Zion Market Research, 2018). Simply by producing a red, white or rosé, winemakers give themselves a better chance of selling their beverage, demonstrating that colour itself can be enough to persuade a customer to choose one wine over another.

Interestingly, wine colour also has a profound impact on the consumer after they have made their purchase. Colour and taste play off each other to create a truly multisensory experience, which ultimately will help increase the consumer's utility and encourage them to purchase the product again in the future. According to Charles Spence, a researcher at Oxford University's Psychology Department, colour is "the single most important product-intrinsic sensory cue when it comes to setting people's expectations regarding the likely taste and flavour of food and drink" (Spence, 2015). In other words, our brain makes colour-flavour associations that allow us to predict the flavours we will taste simply based on the product's colour.

One of the first studies on this topic was done nearly five decades ago by André et al. (1970), where rosé wines were tested in three different rounds. The wines were ranked solely on their colour, then by their taste when the colour was visible, and finally by their taste when colour was not visible. The results showed that the first two groups produced nearly identical outcomes, while the third group had significantly different rankings; the most preferred wines when ranked by colour were the least preferred when tasted blindfolded. Wine tasters tended to rank the wines differently when they we able to see the colour of the wine itself, which shows that colour influences a consumer's opinion of a product. In this case, the colour of some wines more than made up for their taste.

In a more recent study done by Spence et al. in 2014, researchers examined the effect colours of the environment had on wine tasters. Participants tasted red wine served in a black drinking glass under white, red, and green lighting (Figure 5). Participants rated the wine as fruitiest and most intense under red lighting, and freshest and least intense under green lighting. The wine was preferred more under red lighting, due at least in part to the fact that people tend to enjoy sweeter wines. These results align with the findings of a psychological study done by Pangborn (1960), which found that when eating or drinking, the brain tends to associate red with sweetness and

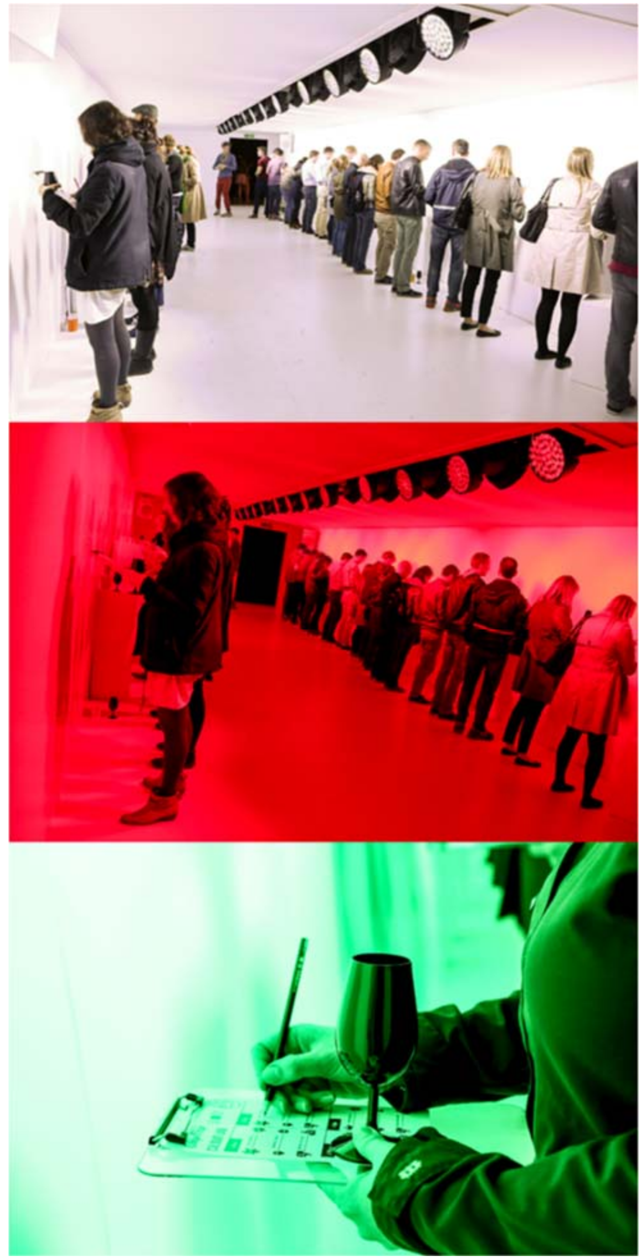

FIGURE 5: EXPERIMENTAL LIGHTING. Ambient lighting (top: control; middle and bottom: experimental) used to assess colour-flavour associations while wine was rated and sampled from a black glass - making the beverage's true colour impossible to identify (Spence et al., 2014).

ripeness, while green is associated with freshness, sourness and bitterness. Interestingly, these associations depend heavily on the culture and norms of particular regions. Shankar et al. (2010) found that participants from the UK associated a blue drink with raspberry flavour while participants from Taiwan associated the same drink with a mint flavour. Therefore, depending on the demographics of the consumers, winemakers may see a variety of colour-flavour associations being made solely based upon where the product is being sold. Evidently, a number of variables come in to play when analyzing how the brain responds to certain colours. Researchers from the 2014 Spence et al. study suggested that the changes in the ambient lighting could have caused the brain to trigger a change in salivation, a potential chemical reason as to why the same wine was ranked differently. Although the study by Spence et al. (2014) does not specifically examine the influence of wine colour on the brain, it illustrates the fact that certain colours are often associated with certain flavours, even if that colour comes from a source other than the food or drink itself. Winemakers employ this information while meticulously working to generate the perfect colour for their wine, knowing that they can tease certain flavours just by careful colouration.

WINE PRIDE: BRANCHING OUT

While red and white wines are sure to remain staple wine colours, other wine colours are gaining in popularity. The wine industry is transforming, and much of this change can be attributed to millennials reaching the drinking age. Wine purchases by millennials increases each year; so much so, in fact, that millennials are expected to become the largest fine wine consuming generation by 2026 (McMillan, 2018). The social media craze often associated with the generation has caused rosé, which once barely had single shelf to its name, to gain popularity. Its

FIGURE 6: #WINEPRIDE. Samples of Instagram posts celebrating rosé, blue, orange and green wines (Yes Way Rosé, 2018; GIK LIVE!, 2018; Proper Natural Wine, 2018; Haikal, 2018).

pink hues are a hit on social media platforms such as Instagram (Figure 6), and the slew of hashtags that accompanied the photos of the pink wine have garnered much exposure for rosé. Experts are predicting that the rosé trend will persist (Jacobs, 2018).

The millennial interest in sustainability is also pushing the colour envelope. The 'natural wine movement' seems to be gathering momentum, popularizing amber, yellow and cloudy wines (McNevin, 2016). The intriguing colour profiles of these natural wines, combined with the concern of millennials to consume fewer processed products, is driving this change in the wine market (Maida, 2017) - and winemakers are responding. Wineries such as Rosewood Estates pride themselves in providing an organic product with a pure, natural colour profile. This effect is widespread; the global organic wine market is expected to grow at a rate of 9.98% per year until 2021 (Maida, 2017).

By being open to new ideas and rejecting stigmas around untraditional wine colours, the modern consumer is giving winemakers the freedom to experiment with wine colour and in turn evolving the wine industry. No longer do yellow or brown wines have a negative connotation; instead, these colours can be celebrated alongside the traditional red and white - and even new colours like green and blue. Wine-drinkers and winemakers alike are taking pride in the colours of wine they produce and consume and that is something we can all say cheers!

MORE TO EXPLORE

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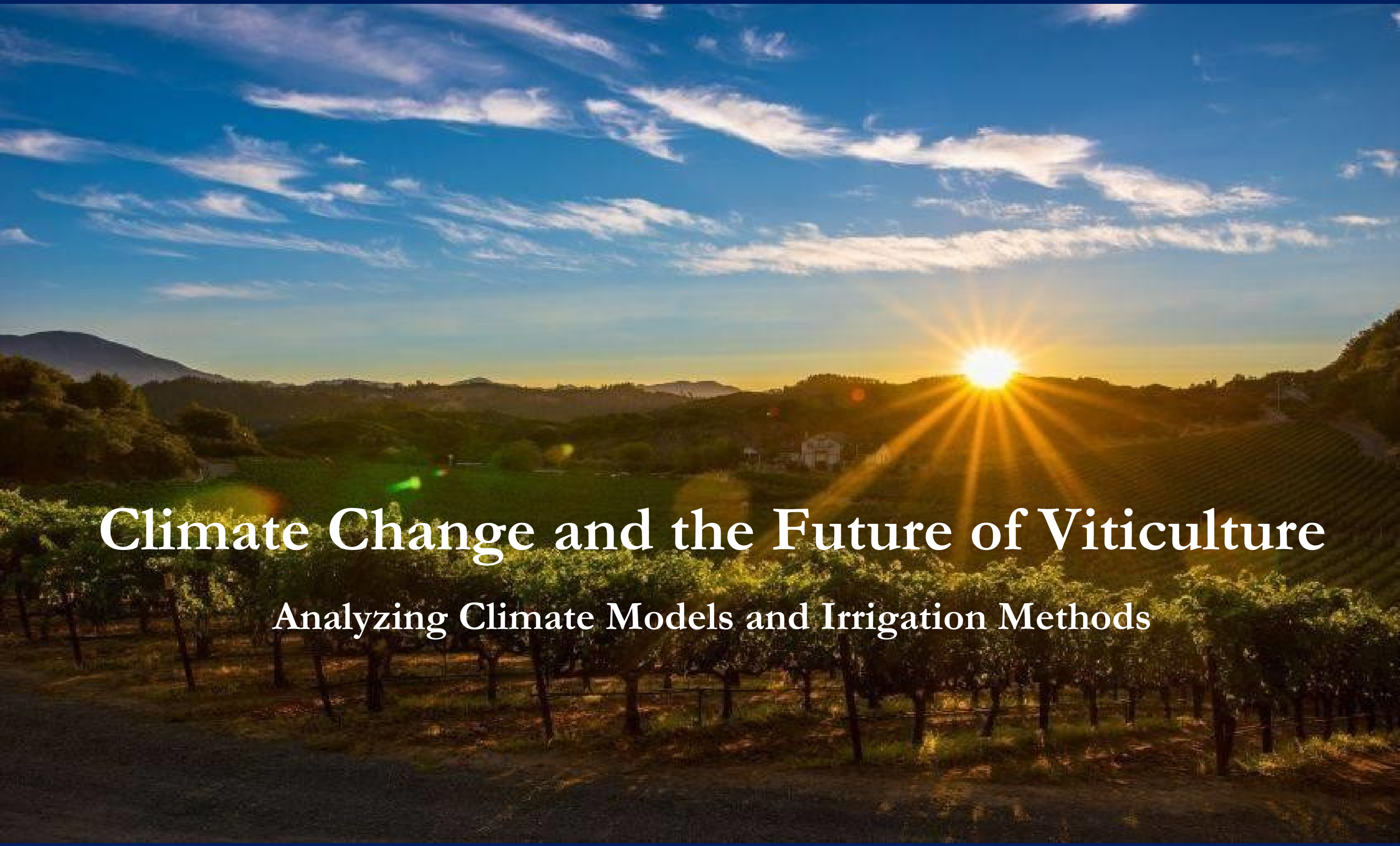

Climate Change and the Future of Viticulture

Analyzing Climate Models and Irrigation Methods

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From the cultivation of the land to the consumption of the product, the tips, tricks, and techniques involved in the winemaking process are complex and abundant. The one variable in particular that is becoming increasingly concerning for wine growers and wine consumers alike, is none other than climate change. With the help of climate change models, scientists have been able to predict how the effects of this phenomenon will impact winegrowing regions over the next few decades. However, climate change affects different regions in various ways and magnitudes, so it is important to look at more than one region to gain a better understanding of the future of water availability in viticulture. As such, this article investigates climate model outputs for future precipitation levels in the Niagara and Napa Valley regions, located in Ontario, Canada and California, U.S.A. respectively. In addition, it will examine the connection between soil conditions and precipitation levels as well as the impact of this relationship on grapevine growth. Although the predictions made by these climate models suggest a reduction in water availability, there are many strategies available to combat this issue. This article will review different irrigation methods and their implementation to determine effective strategies for preserving quality wines for generations to come.

WATER IN GRAPE DEVELOPMENT

To better illustrate the role of water in grape development, it would be helpful to segment and identify its effect at the different growth stages including before ripening, after ripening, and after maturation (Zhang and Hansen, 2018). Before ripening, the xylem, the plant transport system for water and solutes, distributes most of the water to the grapes through a process known as transpiration (Zhang and Hansen, 2018). This growth stage is imperative for grape development because during ripening, the grape size is dependent on soil water availability which is basically excess moisture present in the soil (Zhang and Hansen, 2018). Generally, water stress induced in the ripening stage forces the plant to adapt by distributing water more sparsely, preventing grapes from growing too large (Mirás-Avalos, 2017). Most wines use smaller grapes because the skin-to-flesh ratio is preferable (Roby and Matthews, 2004). Therefore, it is ideal to cause water stress during this stage if the goal is to produce vintage or high-quality wines (Roby and Matthews, 2004).

FIGURE 1: SHRIVELLED GRAPES. The red arrows demonstrate the shriveling of grapes that are a result of a lack of hydration during the post maturation growing stage (Zhang and Hansen, 2018).

After reaching its ripening point, the phloem, the plant transport system for glucose and amino acids, begins to supply most of the water to the grapes through translocation (Zhang and Hansen, 2018). However, water at this stage only affects sugar accumulation instead of grape size (Zhang and Hansen, 2018). This suggests that at this stage, water is now more involved with sugar accumulation through processes like photosynthesis, and higher water content is preferred. Lastly, after the maturation point, sugar accumulation ceases completely, but hydrating the grapevine is still important in order to prevent grapes from shriveling, as seen in Figure 1 (Zhang and Hansen, 2018). In drier conditions, the before ripening stage will reap the rewards, but the other two growth stages will need more help. As climate conditions continue to change, the role of water in grape health and development needs to be further examined, taking special consideration for influencing factors such as precipitation levels and soil conditions.

INFLUENCE OF SOIL ON WINE QUALITY

Ask a winegrower what affects the quality of their wine and more often than not, the predominant answer is terroir. This concept describes the relationship between environmental and cultural conditions in which grapes are grown and their resulting sensory characteristics when made into wine (Leeuwen and Seguin, 2006). One of the largest contributors to the terroir of a region is soil composition (Vaudour, 2002). Although further research needs to be done in order to determine the empirical relationships between terroir and sensory attributes of wine (Maltman, 2008), it is universally known that healthy soil leads to a healthy plant.

One soil condition that has a definite impact on grape development and morphology is the availability of water in a vineyard (Medrano et al., 2015). In most areas, and especially semi-arid regions, the soil layer is the main source through which grapevines have access to water (Maltman, 2008). Water behaves differently depending on the soil type and its characteristics (Maltman, 2008). For example, porous soil material like deep gravel allows soil to drain easily resulting in strong root growth and a decrease in the risk of dehydration (Jackson and Lombard, 1993). On the contrary, denser soil consisting of clay allows slow absorption of water after rainfall and prevents over-watering, since clay is an aquitard and excess water becomes runoff (Jackson and Lombard, 1993). This showcases how different soil types have their own advantages when it comes to successful grape growth and how the impact of precipitation might vary significantly between regions. A great example of this contrast between regions can be seen in Niagara and Napa Valley, with each region exhibiting unique soil and climate conditions.

THE NIAGARA VITICULTURE REGION

Home to 55% of wineries in Ontario, Niagara is a prominent wine region renowned for the diversity and distinction of its vinicultural areas (VQA Ontario, 2016). The cool-climate appellation, which boasts rich and fertile soils, spans thousands of acres growing over 46 different varietals including Chardonnay and Pinot Noir (VQA Ontario, 2016). What makes the Niagara wine region climate so unique is the wind circulation that occurs between Lake Ontario and the Niagara Escarpment, moderating the seasonal temperatures during the growing season (Telfer, 2000). During autumn in particular, energy is transferred from water bodies acting as heat-sinks to overflowing winds which blow onto to low-lying vinicultural areas, extending the growing season. Conversely, breezes from the winter-cooled water decrease the magnitude of early warming effects in the spring (Telfer, 2000). Regarding precipitation levels, the Niagara region is considered to experience adequate rainfall with growing season outputs ranging from 534 mm to 578 mm (Shaw, 2005). Since the source of precipitation for this region comes for multiple frontal and convective systems, moisture over the growing season tends to vary monthly (Shaw, 2005). In July and August specifically, high temperatures and evapotranspiration rates can cause drought-like effects on the top layers of soil (Shaw, 2005). This can be especially concerning for grapevines that have not yet reached maturity because they are more susceptible to stress from a lack of water (Shaw, 2005). However, the region's current geology was formed from glacial events which have paved the way for beneficial soil conditions that help reduce drought-like effects (Greenough, Mallory-Greenough and Fryer, 2005). The Niagara region has soil compositions developed on glacial till and lacustrine sediments ranging from sandy loams to silty clays (Shaw, 2005). In general, these soils have high water retention capacities, meaning they are able to store moisture well and can provide sufficient water to crops during the summer months when adequate water availability becomes essential. In the winter, the Niagara region receives light to moderate amounts of snowfall with averages ranging from a low of 100 cm to a high of 177 cm for inland areas and regions close to Lake Erie respectively (Shaw, 2005). Having moderate snowfall levels can be quite beneficial for vineyards. This is because snow helps add moisture back into the soil and it also provides insulation for newly planted vines and mature vine trunks, protecting them from extremely low temperatures (Shaw, 2005).

THE NAPA VALLEY VITICULTURE REGION

Not only known for its beaches and luxurious properties, the state of California is also home to a prosperous wine-growing region. Labelled as the Golden State, the region is responsible for 89% of all American wine production (Hira and Swartz, 2014). This geographically diverse region continues to be a dominant force in the wine industry and is renowned for its premium quality grapes that strive in its warm climate conditions. In California, Napa Valley is a wine sub-region famous for its hillside-style vineyards, complemented by high-end restaurants that feature these wines. This region experiences cool, wet winters and hot, dry summers with climate conditions including temperature and precipitation levels strongly influenced by the El Nino Southern Oscillation and the Pacific Decadal Oscillation (Pathak et al., 2018). These atmospheric and oceanic factors have actually benefited Californian vineyards over the last few decades because of the asymmetric warming they cause, resulting in a lower frost frequency and longer growing season (Nemani et al., 2001). Historically, the majority of precipitation that California receives on a yearly basis is predominantly in the form of snow, meaning rainfall during the summer months is minimal (Pathak et al., 2018). The diverse environments in which these vineyards are situated consist of varying soil compositions, allowing many different grape varietals to flourish. Soil formation in Napa Valley is greatly associated to the complex geological history of the region and its past tectonic activity (Elliott-Fisk, 1993). Due to the active geology of the region, there is a diverse topography ranging from clay to clay loam soil types (Elliott-Fisk, 1993). In the surrounding regions of Napa Valley, many vineyards consist of more gravelly and alluvial soils that drain well, making them ideal for many different varietals (Hannah et al., 2014). Napa Valley also consists of mountain slopes made of volcanic soils and valley floors consisting of rock-strewn sites and clay soils, further exemplifying the diverse environments found in the region (Hannah et al., 2014). Because of the unique climate systems, soil conditions, and precipitation levels exhibited in Napa Valley, the region appears to have benefited from recent climate change effects. However, producing wine is definitely a long-term affair meaning it is essential to understand how climate change trends may affect water availability in this environment in the future and what we might be able to do to mitigate impacts.

> **Fun Fact**: Prior to the 1940s, the primary fruit crop in Napa Valley was actually prunes, not grapes!

MODELLING CLIMATE CHANGE

With the impact of soils, precipitation, and regional variability established, the next step is to look at what the future has in store. To our benefit, science has given us a way of anticipating what the future may hold through the use of climate models based on current observations and past recordings.

They use what is already known, like past temperature or precipitation levels, and mathematical equations to predict the unknown. These models identify and quantify Earth's processes, such as evaporation and freezing, by using variables that affect climate (Pindyck, 2013). However, a phenomenon as broad as climate change gets affected by many other variables and relationships external to the environment. The biggest drive for determining the future of climate change relies on human impact (Wiedmann and Minx, 2008). Unfortunately, human activity is vastly unpredictable since there are many influential variables that factor into determining their actions. As such, climate change models must use specific scenarios to outline different possibilities accounting for a wide range of variables. These scenarios are referred to as RCPs which stands for Representative Concentration Pathways (van Vuuren and Rihahi, 2011). There are four scenarios, RCP 2.6, 4.5, 6 and 8.5 with the numbers indicating the future of our planet through values of greenhouse gas concentrations (van Vuuren and Rihahi, 2011). In RCP 8.5, there is predicted to be a slow income growth, increase in population and average technological advancements. Unfortunately, based on recent population projections and economical predictions, it seems most likely for humans to follow this scenario (Gerland et al., 2014). As such, this article will solely focus on the most aggressive scenario; RCP 8.5. The HadGEM-2 ES climate model was used to study this scenario. There is a decrease in precipitation levels in the years 2050 and 2070 for the Niagara region (Figure 2) and California region (Figure 3) compared to current levels. Niagara seems to have a sufficient amount of precipitation, dropping from around 950 mm a year to less than 900 mm. This may seem like an insignificant change posing miniscule consequences for viticulture, but during the grape growing season, the precipitation levels drop and during the winter months, there is an increase in precipitation. However, the precipitation levels now decrease The change in precipitation over the years can be visualized on various climate model maps represented by Figures 4 to 7.

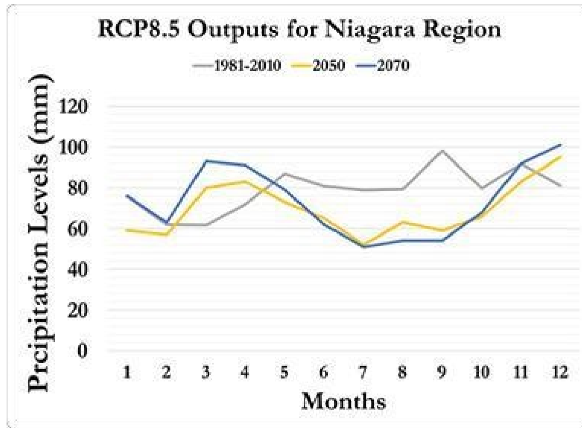

FIGURE 2: NIAGARA PRECIPITATION TRENDS. Using the HadGEM2-ES climate data and the Canadian government websites for precipitation values, this graph illustrates the changing trends in precipitation for the RCP 8.5 scenario in the Niagara region. The year 2050 is depicted by the yellow line & the year 2070 by the blue. The current and previous trends are shown in grey.

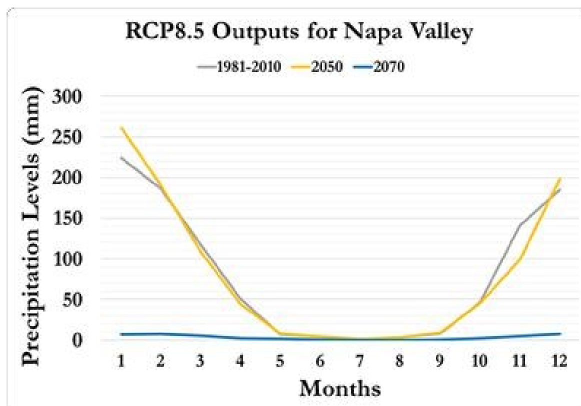

FIGURE 3: NAPA VALLEY PRECIPITATION TRENDS. Using the HadGEM-2 ES climate data and the United States government website for precipitation values, this graph represents the precipitation levels changing from 1981-2070. The yellow line represents the predictions for 2050, blue for 2070 and the grey for the current and pasta data.

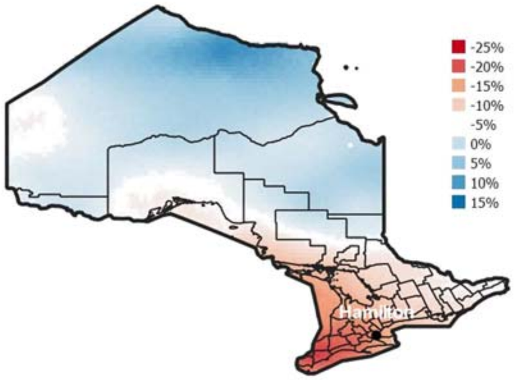

FIGURE 4: PRECIPITATION MAP OF ONTARIO IN 2050. Using the HadGEM-2 ES climate data for precipitation values, this map represents the percent change in precipitation levels changing from right now to 2050 for RCP 8.5. In general, the northern regions of Ontario appear to have increases in precipitation, whereas the southern regions of Ontario appear to have significant decreases.

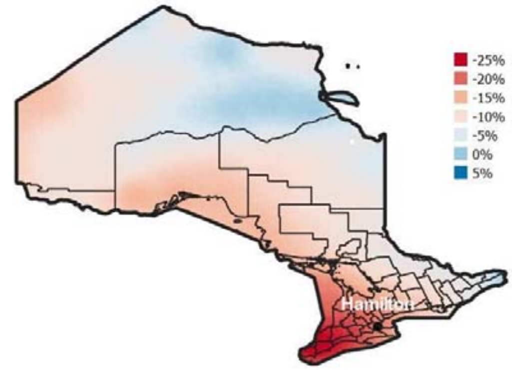

FIGURE 5: PRECIPITATION MAP OF ONTARIO 2070. Using the HadGEM-2 ES climate data for precipitation values, this map represents the percent change in precipitation levels changing from right now to 2070 for RCP 8.5. In general, the northern regions of Ontario appear to have increases in precipitation, whereas the southern regions of Ontario appear to have significant decreases. Overall, precipitation levels have decreased compared to 2050.

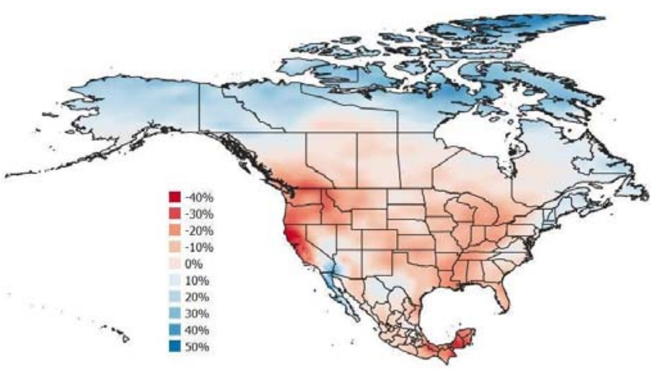

FIGURE 6: PRECIPTATION MAP OF NORTH AMERICA IN 2050. This is a HadGEM2-ES climate model map showing the percent change in precipitation over the wine grape growing season for North America comparing current to 2050 outputs in the RCP 8.5 scenario. When comparing the outputs across the continent, the states near the west coast of the United States, and California especially, have drastic decreases in precipitation amounts.

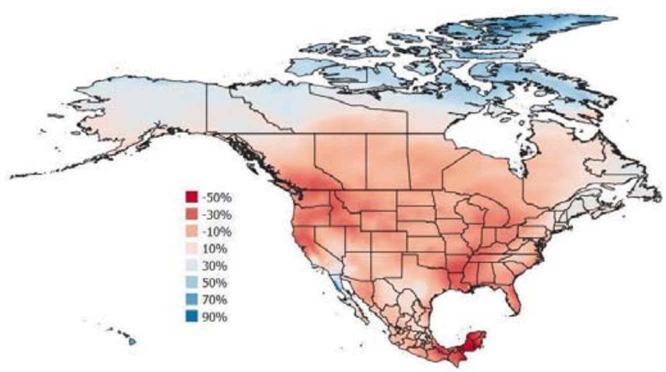

FIGURE 7: PRECIPTATION MAP OF NORTH AMERICA IN 2070. This is a HadGEM2-ES climate model map showing the percent change in precipitation levels over the continent of North America comparing current to 2070 precipitation outputs. In comparison to 2050, the decreases in precipitation are much more drastic and intense throughout North America.

Figure 4 is a representation of precipitation levels changing from current data to the year 2050 and shows a decreasing trend throughout the southern regions of Ontario in comparison to its northern counterparts. Whereas, Figure 5 represents the trends in 2070 which demonstrates the similar trends, albeit more prominent. By 2070, California is predicted to have almost zero precipitation throughout the year including the growing season. However, Figure 3 shows some alarming realizations requiring avid wine growers to start considering the security of their crops. Figure 6 shows the change in precipitation levels throughout North America for the year 2050. As the figure illustrates, the precipitation levels experience a substantial decrease in precipitation levels throughout the central regions of the United States and lower regions of Ontario. As shown, California seems to be a region that will likely experience a severe decrease in precipitation levels. Figure 7 shows the changes amongst the North American region in the year 2070 and displays a decrease in precipitation throughout the entire continent, with a minor increase towards the northern regions.

Any change in the environment can be consequential for growing the best quality of grapes. Based on future predictions, the changes don't seem to favour the future of wine. However, don't lose hope just quite yet. Along with lowering our carbon footprints, there are also some methods wine growers can use to mitigate the effects of climate change.

MITIGATING CLIMATE CHANGE EFFECTS

In the wake of increasingly hot and dry conditions suggested by the current climate models, implementing self-watering systems could be beneficial (Diffenbaugh, et al., 2011). According to the International Organization of Vine and Wine, grapes are one of the highest acreage crops in the world (IOVW, 2017). As a result, implementing a self-watering system for them would be very expensive and would require sufficient planning to determine which method is required, shown in Figure 8. There are many different irrigation methods available, each designed for different regional characteristics with their own associated benefits. Which type should each region use? To answer this question, it is important to show how each irrigation method works and the associated benefits.

Deficit Irrigation

"You can never have too much of a good thing." It is a common saying often associated with many things, but is this true with water for crop growth? Deficit irrigation (DI) is a self-watering system that focuses on using less water as opposed to fully hydrating the grapevines. DI is designed to keep some moisture in the soil to prevent the plant from wilting, but not enough for the soil to be thoroughly damp (Anderson et al., 2009). Specifically, it allows the grapevines to undergo water stress during its growth period leading to possibly a lower crop yield, but gets compensated through improved grape composition (Anderson et al., 2009). Why might DI be an effective strategy? Irrigation uses so much water worldwide that every bit amount conserved is money saved, especially when water stress can induce higher wine quality. Water conservation is becoming so increasingly relevant, that utilizing less water is both more feasible and beneficial to viticulture (Ritchie and Roser, 2018). The Niagara region could benefit from DI as the precipitation rates are expected to decrease, but still has rainfall during the growing season.

FIGURE 8: EXAMPLE IRRIGATION SYSTEM. This irrigation system controls water stress by limiting water availability in attempts to achieve higher grape quality.

Partial Root Drying

Similar to DI is a technique called partial root drying (PRD), which works by supplying one half of the grapevine with full irrigation while drying the other side, and then alternating. This method is designed to dehydrate the roots allowing them to release a hormone that is called abscisic acid (De la Hera et al., 2007). Essentially, this compound is transported to the leaves of the plant and trains the plant to be more efficient with the water it is allotted (Jovanovic and Stikic, 2018). Thus, this further increases yield and water use efficiency while not affecting grape weight or wine quality (De la Hera et al., 2007). Instead of increasing wine quality and possibly sacrificing yield with DI, this method might be the ideal balance between the quality and yield. As mentioned before, this increasing demand for irrigation water will likely occur and with a rise in demand, an increase in price will follow (Beattie et al., 1985). By implementing irrigation methods that use less water, the overall sustainability of the wine industry can be ensured. Again, the Niagara region would fit the criteria for this irrigation method given the climate models. It is hard to say whether PRD is better than DI as this irrigation method is very new. However, with the developing research, it looks like a promising method (De la Hera et al., 2007).

Full Irrigation

What if the grapevines were watered all the time? In arid regions, full irrigation (FI) could be a more preferable method as a consistent and high-volume water supply would prevent crops from drying out. Some of the disadvantages presented with FI is that it cannot induce water stress missing out on the positive benefits associated with it. Also, FI can lead to a higher chance of crop spoilage either through too much moisture in the soil or absorbed water in the plant itself. Over-watered soil can result in rotting and the development of mold, making the grapes unusable for wine (Corison et al., 1979). Even if the soil is adequate, the grapes could grow too large due to the excess water content and causing the grape skin to split (Barbetti, 1980). At a glance, this may not seem like a big issue, but this creates an entry point for insects and pests, leading to more crop spoilage (Christaki and Tzia, 2002). Furthermore, if not removed from the wine fermentation, it would produce unwanted bitter and vile flavours (Christaki and Tzia, 2002). Now generally, it would not be recommended to commit to FI, but it might be the most appropriate method for extremely dry regions. According to our models, by year 2070, Napa Valley could have little to no annual precipitation and will require irrigation regardless of the method. This would be the best method because of how dry the climate will be and depending on low water retention soil conditions, this will likely be needed.

No Irrigation

Another option is to not invest in an irrigation system entirely. This option basically leaves the watering up to the weather and if sufficient, saves a lot of needless spending. Especially in a high rainfall region, irrigation would be excessive and these vineyards could possibly consider setting up a drainage system instead. The disadvantage of having none of these systems set in place is inevitably having less control in water levels. Investing in an irrigation system, even if only used during droughts, could still be beneficial because it gives the vineyard tools to combat weather variations if they do occur.

Irrigation can be thought of as an insurance policy that ensures a net profit gain from the vineyard, as it is a business.

Ultimately, each irrigation method has its own benefits based on regional climate conditions. In respect to the Niagara and Napa Valley wine growing regions, implementing DI/PRD and FI methods, respectively, could help mitigate the predicted precipitation fluctuations. It is important for wine growers and interested parties to be wary of the effects of climate change and how this cultural novelty may need to adapt to the world's constant changing state.

SUMMARY

Viticulture is subject to many shifts and changes in the next few decades depending on how climate change pans out. As a consumer, it is important to understand the complications that will arise in the wine industry. There are many steps with each their own intricacies that play into a finished bottle of wine. From the maintenance of the grapevines to the ripening process of the grape, water is shown to be a key player in this overall development. Although the effects of climate change may vary by region, generally it will lead to drier conditions for crop growing regions, which is a glaring issue in need for solutions. With the world's changing climate, it is vital that the world's finest vineyards prepare themselves for the future we are headed towards. Although some may argue the validity in the use of the RCP 8.5 climate change model, it sets the grimmest future where solutions could still be applied and help sustain the wine industry. For the love of wine and preserving a cultural novelty, understanding how climate change may play a role in its downfall is important, regardless of one's background. Whether or not climate change models accurately predict what the future has in store, we'll be prepared, even for the worst.

MORE TO EXPLORE

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What Makes a Wine Expensive?

Abby Lindzon, Natasha Singh, Matthew Speciale & Ciara Zogheib

The concept of luxury is not one that is easily defined. Marketing theorists would argue that the concept of luxury is a result of customers wishing to be perceived in a certain way, while manufacturers would argue that luxury comes from a physical difference in the integrity of the product (Fountain, Wolf and Morrish, 2016). Applying the idea of luxury to wine further complicates the matter.

The idea that some wine is better than others is ubiquitous, as evidenced by the existence of both thousand dollar bottles of champagne and ten dollar boxed wines, but what is the source of this difference in price and perception? What makes a wine luxury?

This article will explore history, marketing, psychology, and chemistry, as well as the intersection of these factors, to search for the truth about luxury wines, beginning thousands of years in the past.

Wine in general has historically been associated with luxury. Unlike beer, which was enjoyed in antiquity by people from across social strata, research from around the world suggests that wine was likely an upper class phenomenon from fairly early in its inception. This was probably due to wine production being limited by the availability of grapes, harvest times, and the time necessary for fermentation (McGovern et al., 2003).

Records from ancient Egypt and Mesopotamia establish that wine was available only to the elite, often as an imported good, while Babylonian records suggest that at the absolute lowest price, one litre of wine would cost almost two days' labour (McGovern et al., 2003; Joffe, 1998). References to wine as a luxury good appear again and again throughout time, everywhere from records of Greek Symposia to medieval Church manuscripts (Bynum, 1988) to poetry about early Hebrew 'wine parties': "Wine is the herald that promises joy; it banishes untoward thoughts" (Scheindlin, 1999).

The ceremonial use of wine in religious and ritual contexts set a cultural precedent that can still be seen today in rituals such as the Christian Eucharist. It also had major ramifications for the early wine industry. Public or publicized events such as Symposia, Mass, and wine parties meant that, over time, the exclusivity of wine was eroding (McGovern et al., 2003). As wine was incorporated into more and more rituals, it became accessible (in some contexts) to those of lower socioeconomic class. Consuming the same goods as their servants and slaves was anathema to the elites of early societies; thus, while wine in general was becoming more accessible, stratification within the wine industry began to occur for the first time.

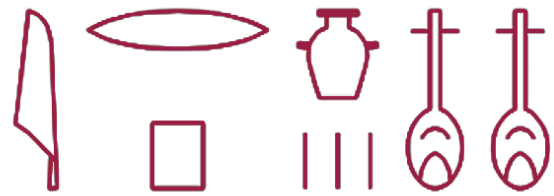

FIGURE 1: INSCRIPTION ON A WINE LABEL FROM THE TOMB OF AMENHOTEP III. It reads 'very good wine'/'good, good wine' (Wahlberg, 2012).

There are indications of a hierarchy of wines developing as early as 1350 BCE, in the Theban palace of the Pharaoh Amenhotep III. Archaeologists have excavated wine jars with labels showing the date, the vintner's name and location, and even the quality of the wine: 'good', 'very good', or 'very, very good' (Figure 1) (Hayes, 1951). The Roman poet Horace wrote in his Odes (23 BCE) of "true" and "ancient" wine being reserved for special occasions and celebrations such as the death of Cleopatra, while "last year's wine" could be used for everyday occasions such as picnics. Here, the foundations of concepts such as manufacturer reputation and wine age as metrics for superior quality began to appear.

Where wine had once been a status symbol in itself, as it became more accessible, winemakers were presented with a new challenge: that of differentiating their wine from the rest. How could they convince the rich that their 'very, very

Luxury: Literature on wine is divided between the terms 'luxury wine', 'premium wine', and 'expensive wines', at times using them interchangeably and at times defining them as distinct things. In this article, we use 'luxury wine' to refer to wine in a high price bracket, but also to the qualitative experience of luxury.

good' wine was worth a premium price, and that 'very, very good' wine even existed?

SELLING LUXURY

The winemaker's attempt to market their bottle as a luxury item is grounded in the consumer's perception of a luxury wine. The basics of marketing consist of knowing the needs and expectations of your customer and target audience.

Marketing wine is no exception. Exploring the wine drinker's expectations of a luxury wine might reveal the reasons behind price differences in the wine market. So what do consumers look for in luxury wines?

Champagne: **Authenticity is an important market tool for producers and is valued by consumers. An interesting example of the strength of this type of marketing involves the history of champagne, an iconic wine consumed on special, celebratory occasions. The bubbly effect in wines produced in the Champagne region of France were originally viewed as flaws by winemakers of the 16th century, but the unique quality of the fizziness piqued the interest of French consumers, and the market grew (Rokka, 2017). Champagne was used in the coronation of various French kings, especially King Louis XIV, who popularized the drink in high society and art (Rokka, 2017), and far from a flaw, the bubbles became a sign of luxury. The historical branding of this wine over centuries has resulted in its exclusive nature: any sparkling wines produced outside of the Champagne region cannot be labelled champagne (Rokka, 2017).**

Surveying wine purchasers has revealed the qualities they seek out when buying luxury wines. In a study of 509 Australian consumers, participants were asked to rank a list of elements according to the appropriateness of using each element to describe luxury wines and categorize the list of elements into four different price ranges (Sjostrom, Corsi and Lockshin, 2014). The elements that had the highest probabilities of being associated with luxury wines and the most expensive price bracket were "good brand reputation", "authentic/trustworthy brand", "premium quality", "old (back) vintage", "limited production/edition", and "premium price" (Figure 2) (Sjostrom, Corsi and Lockshin, 2014, pp.69). In contrast, the study found that "suitable retail location", "promotional activities (advertisements)", and "machine made" were the elements most closely associated with the least expensive price bracket (Sjostrom, Corsi and Lockshin, 2014, pp.69). Brand reputation appears to be an integral component of consumer perception of luxury wine in the market. In order to project the image of a luxury wine producer, wine companies must craft a good reputation as a trustworthy brand that does not need to rely on advertisements and machine-made products. These companies could market their products as antique and exclusive to strengthen an association with luxury.

The concept of establishing authenticity in a brand to uphold its status as a luxury producer applies to brands from across the wine world. Beverland (2005) conducted a study of 26 luxury wine companies from Australia, France, Lebanon, New Zealand, and Portugal, with the purpose to identify how these brands construct images of authenticity. The study consisted of interviews with employees, observations from tours of the wineries and production facilities, external reviews and media, consumer focus groups, and interviews with international luxury wine retailers (Beverland, 2005). Analyses of these case studies found that brands often employed strategies geared towards protecting their status and crafting a sincere story of their winery in order to appear authentic and differentiate their products from commercial goods (Beverland, 2005). Luxury brands frequently reference their commitment to quality, which helps to maintain and protect their luxury status by upholding consumer trust in their brand (Beverland 2005). Emphasis is often placed on their attention to detail in harvesting and production practices, like the types and quality of barrels chosen for aging (Beverland 2005). A common strategy used to convince consumers of the brand's attention to detail is releasing multiple labels from the same crop or selling a large part of the crop's yield to third parties as non-labelled wine (Beverland, 2005). This is because purposeful selectivity of the crop (i.e., seemingly selecting only the finest grapes for the finest label) demonstrates deep understanding of the differences between premium and lesser quality grapes (Beverland, 2005).

Another marketing technique used by luxury brands is emphasizing the culture and history that the brand is steeped in, their commitment to traditional production techniques, and their rejection of mass advertising, commercialization, and modern production techniques (Beverland, 2005). Consumers may be more willing to pay for wines produced in Old World countries than in New World countries because Old World wines are perceived as more authentic due to the hundreds of years of winemaking history and heritage in those countries (Babin, Moulard and Griffin, 2015; Spielmann and Babin, 2011). Wine marketers that capitalize on their region's history likely understand that authenticity starts with the consumer's pre-existing expectations and standards of the product (Grayson and Martinec, 2004), and in the case of wine, this standard is often set and dictated by the winemaking history of Old World countries. Even wine producers that are new to the luxury field, who lack a rich winemaking history, are still able to build trust in their consumer base. They promote their pioneering legacy and chronicle their individual stories, which often involve themes of overcoming hardships or striving to be unique (Beverland 2005). Furthermore, Beverland (2005, pp.1023) found that although large luxury brands use modern technology to efficiently meet output

FIGURE 2: QUALITIES OF LUXURY WINE. Continuum of wine traits ranked based on association with high or low price. Luxury wines are associated with being antique, limited edition, and available at a premium price. Image based on information from Sjostrom, Corsi, and Lockshin (2014).

demand and incorporate new winemaking and marketing practices based on scientific studies, they will downplay this modern involvement, instead choosing to focus on their traditional methods. Luxury brands frame their marketing in a non-commercialized context in order to prevent consumers from associating their products with mass produced, low quality items.

Even the presentation of wine itself has been shown to have an influence on a consumer's perception of its quality. Something as simple as the type of bottle closure can have a quantifiable effect on the consumer's perceived taste and assessment of wine quality. A study of U.S. wine drinkers found that participants were more likely to give a lower liking and quality score to Chardonnay samples when they knew they were bottled with a screwcap than when they did not know the bottle closure type, but this trend did not apply to naturally corked wine samples (Marin et al., 2007). Furthermore, the quality rating of Merlot samples significantly increased when participants learned that the sample had been naturally corked (Marin et al., 2007).

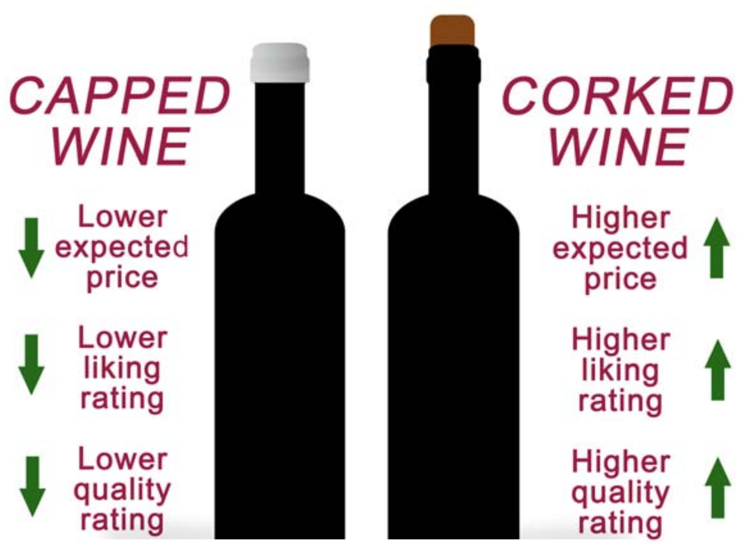

FIGURE 3: PRESENTATION OF WINE MATTERS. Differences in consumer perception for wines bottled by screwcap versus cork (natural or synthetic). Image based on information from Marin et al. (2007) and Marin and Durham (2007).

These results suggest that U.S. wine consumers associate naturally corked bottles with higher quality wines, and screwcap closures with lower quality wines (Marin et al., 2007). The experiment also assessed participants' expectation of price for each sample: the prices that participants expected to pay for samples from bottles closed by screwcap were significantly less than bottles closed by natural or synthetic cork (Figure 3) (Marin and Durham, 2007). However, these results may differ by wine type and country (Marin et al., 2007). In the Australian wine market, screwcap use has historically been more prevalent than in the U.S., especially for premium white wine brands (Marin et al., 2007). If a wine producer wanted to establish their product as a luxury item in the U.S. market and justify their expensive selling price, they should avoid screwcaps, but this consideration may not be as important in the Australian market. Such regional differences in consumer perception of luxury wines make it difficult to completely generalize the marketing required to establish a bottle of wine as a luxury item. Investigating more general trends requires delving further into the consumer's mind, shifting our focus from the world of the manufacturer to the inner workings of the wine consumer's mind.

ALL IN YOUR HEAD?

After examining how marketing affects an individual's perception of wine quality, it could seem as though there are only external factors at play. Far from merely altering purchasing habits, however, current research suggests that perception of luxury has a tangible neuronal effect. While at the moment, not much is understood about how marketing truly affects physical interactions within the brain, it is believed that the effects are derived from individual expected results originating from preconceived perceptions.

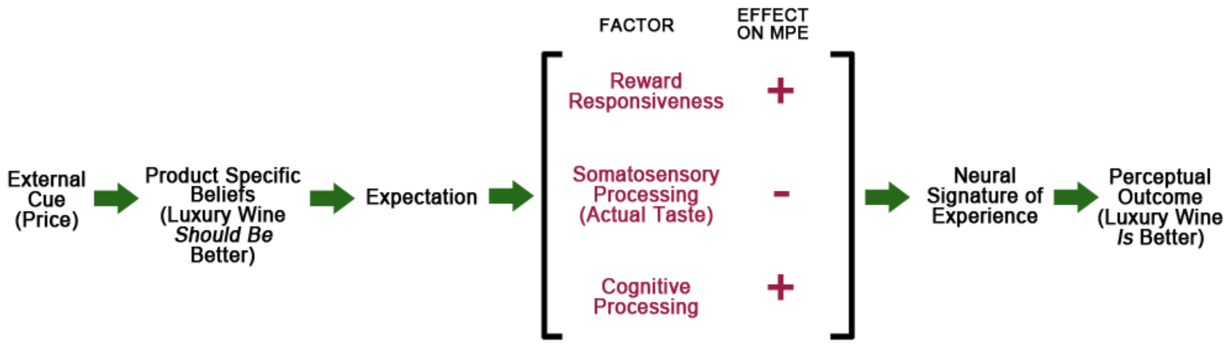

FIGURE 4: THE MARKETING PLACEBO EFFECT (MPE). The MPE causes enhanced enjoyment of identical products with higher prices. The neural process by which the MPE influences perception of luxury wines; the MPE can be strengthened or weakened by different factors. Image based on information from Plassmann and Weber (2015).

Several studies have examined how the brain responds to tasting differently priced wines (Schmidt et al., 2017; Plassmann and Weber, 2015; Plassmann et al., 2008). The methodologies of these studies differ slightly, but always involve the tasting of a single wine at multiple prices. This is done to compare how the brain is affected by certain external cues, given identical wines. Specifically, in a study conducted by Plassmann et al. (2008), participants believed they were tasting five different priced wines, when in fact they were only trying three. In the study, two of the wines were duplicated and presented to the subjects at prices higher or lower than their market value (Plassmann et al., 2008). As expected, the more "expensive" wines were preferred in all trials. To understand what occurred in the brain, functional MRI (fMRI), a technique used to analyze the activation of brain regions through monitoring blood oxygenation, was used (Lebreton et al., 2009). Researchers discovered that while people sampled wines they thought were more expensive, some regions - the medial prefrontal cortex (mPFC), the medial orbitofrontal cortex (mOFC), and the ventral striatum (vS) - experienced greater activity (Plassmann et al., 2008). The activation of these three regions in particular is important, as they are commonly associated with reward seeking and expectation evaluation (Barbas, 2009; Tremblay, Worbe, and Hollerman, 2009). Thus, when we see a higher price (regardless of the wine), our brain links the price to the expectation of a reward, which changes our perception of the experience, in this case, improving the taste.

Ultimately, the brain's reward and motivation centre plays a trick on us, leading to enhanced enjoyment of identical products that simply possess different prices. The researchers established this phenomenon as the marketing placebo effect (MPE), due to its similarities with the medical placebo effect (Plassmann and Weber, 2015). If someone thinks that a pill will alleviate their pain, there's a high likelihood that it will, regardless of whether the pill is nothing but sugar. The same trick is seen here: the expectation of pain relief is related to what we think we know about the pill, just as the belief of a better taste is linked to what we think we know about the wine. Though the MPE can help researchers begin to understand why certain areas of the brain 'light up' with expensive wines, the concrete mechanism and subjective contributing elements are still a topic of debate. The first individuals to model the MPE were Shiv, Carmon, and Ariely (2005), who propose a three part method for how this phenomenon works. They suggest that the MPE is initiated by an external stimulus (in this case price), which leads to anticipatory activation of certain areas of the brain in preparation for an expected result (Shiv, Carmon and Ariely, 2005). This expectancy results in a behavioural change, where one alters their actions to suit the anticipated outcome. However, this model failed to recognize the other neural factors at work, leading to current research meant to extend the theory. In the paper by Plassmann and Weber (2015), three important processes emerged that can be used to predict the effect of MPEs (Figure 4). These are reward seeking behaviour, bodily awareness, and emotional regulation related to cognition (Plassmann and Weber, 2015). Based on the study's findings, it is revealed that the external stimulus (price) promotes reward seeking (as seen by the activation of the mPFC, mOFC, and vS) such that people who are more responsive to reward seeking behaviours respond more to MPEs (Plassmann and Weber, 2015). Another finding is that there is a negative correlation between the somatosensory system, which is linked to touch and sensation, and MPEs (Plassmann and Weber, 2015). Essentially, people who are more aware of their body react less to MPEs. Areas of the brain associated with emotional regulation are also affected by expectancy, thus, emotional state can also influence susceptibility to the MPE (Plassmann and Weber, 2015).

Marketing/consumer research tells us that people perceive expensive wines differently; neurobiological research shows that this difference has a physical manifestation in the brain. Together, these factors seem to confirm that, at least on a conceptual level, luxury wine is distinct from cheaper wines. To determine whether this difference is a product of our own expectations or if it has a physical basis, we can examine the chemical composition of luxury wines.

WINE CHEMISTRY

It has been concluded in multiple studies that there are significant differences in the chemical compositions of differently-priced wines. These compositional differences suggest that factors involved in viticultural practices and winemaking techniques influence commercial quality and pricing of luxury wines.

One of the most important of these factors is the presence of phenolic compounds in red wines. There are two main groups of phenolic compounds: non-flavonoids (hydroxybenzoic and hydroxycinnamic acids, and phenolic alcohols) and flavonoids (anthocyanins and flavanols). These compounds contribute to many of the characteristics of wine including colour, astringency, and bitterness, and they are beneficial to human health since they have anticarcinogenic and antioxidant properties (Fanzone et al., 2012). All are desirable traits in a luxury wine - and sure enough, Fanzone et al. (2012) found that there was a higher amount of total phenols in higher priced wines than in lower priced wines. It was also observed that the degree of polymerization and molecular weight of one of the specific anthocyanins, called proanthocyanidins, was greater in higher priced wines compared to lower priced wines. This means that the compounds found in higher priced wines were bonded together and formed chains more frequently than in lower priced wines. This suggests that more expensive wines are produced from riper grapes with higher density or from vines subjected to viticultural practices that reduce berry size, thus increasing the amount of proanthocyanidins extracted from the berry skins. (Fanzone et al., 2012).

Tannins are another type of phenolic compound that are responsible for wine mouthfeel, body, and astringency (the dry sensation that is experienced after tasting some wines). Different enological practices prior to aging will cause different extraction of compounds from grapes, which will influence the concentration and composition of tannins in the wines. Gómez-Plaza, Olmos and Bautista-Ortín (2016) found a positive trend in the concentration of tannins as the commercial value of wine increased (Figure 5). The increased presence of skin tannins could be due to longer maceration, with solid parts, or in other words, soaking the crushed grapes seeds and stems with the wine for long amounts of time (Gómez-Plaza, Olmos and Bautista-Ortín, 2016). Phenolic compounds are not the only distinguishing factor for luxury wines: Fanzone et al. (2012) also found that the molecular weight of

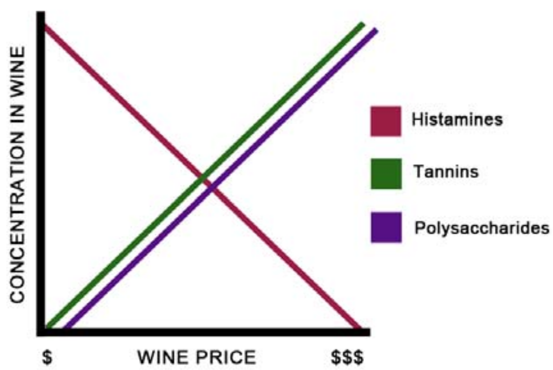

FIGURE 5: TRENDS FOR THE CHEMICAL COMPOSITION IN WINE. Displays the general trends for how the amount of histamines, polysaccharides and polyphenols increase or decrease as the price of wine increases. Image based on information from Preti, Vieri and Vinci (2016) and Gómez-Plaza, Olmos and Bautista-Ortín (2016).

polysaccharides is greater in higher priced wines, and another study by Preti, Vieri and Vinci (2016) found that high priced wines exhibited the highest level of antioxidant-related compounds such as resveratrol. Essentially, it seems that luxury wines generally come from riper grapes that are macerated for longer amounts of time with skin and seeds during fermentation, increasing the extraction of these compounds into the wine.

The chemical characteristics of expensive and cheap wines do not just impact taste and colour - some can even impact human health as mentioned briefly before. It was reported that histamine was found in statistically greater concentrations in low price wines, whereas other biogenic amines, cadaverine and putrescine, were found in higher priced wines (Preti, Vieri and Vinci, 2016). Histamine is the most dangerous amine and can cause many adverse effects to human health whereas cadaverine and putrescine have no documented adverse health effects (Preti, Vieri and Vinci, 2016). The presence of histamine in wines can likely be traced to production: Most inexpensive wines are typically younger and undergo shorter maceration time, with fermentation taking place in a purely liquid phase (Preti, Vieri and Vinci, 2016). This differs from more expensive wines, where the fermentation of the wine is carried out in the presence of grape solids and in oak barrels, a much more costly process. A decrease in histamine content has been reported during aging in oak barrels and wines stored in bottles, primarily due to the action of histamine-degrading enzymes present in various organisms (Bach et al., 2012; Jiménez Moreno, Torrea Goñi and Ancín Azpilicueta, 2003).

It is evident that there are chemical differences between wines of different commercial values. This seems to support the conclusion that luxury wines are in fact different, in a quantifiable way, from non-luxury wines, not only in terms of marketing and perception but in terms of physical quality. The question now becomes: How do all of these influencing factors fit together?

IN VINO, VERITAS

A method of mathematical modelling has been applied to the luxury wine market in an attempt to quantify the contribution of all of these factors – reputation, sensorial, or objective – to wine's market price. The technique is called hedonic regression, and its underlying assumption is that the various characteristics or attributes of a product can be segregated based on their contribution to the product's market price. Manipulating certain features of a product can raise or lower the price that it may be sold at. Several studies have been conducted using the hedonic regression technique to determine which factors of wine contribute the most to market price, with each study looking at particular growing regions (Combris, Lecocq, & Visser, 1997, 2000; Benfratello, Piacenza, & Sacchetto, 2009).

Modelling wine prices from the Bordeaux and Burgundy regions of France revealed that the objective characteristics of wine usually noted on bottle labels (producer, ranking, colour, vintage, region) contribute more to the determination of market price than sensorial characteristics (e.g., aroma, acidity, finish, etc.), whereas sensorial characteristics contribute more to the determination of quality (as judged by professional wine tasters) (Combris, Lecocq, & Visser 1997, 2000). For the Italian wines of Barolo and Barbaresco, all variables (objective, sensorial, reputation) contributed significantly to market price determination; however, a model that only included reputation of the wine/producer and objective characteristics more accurately correlated with market price than a model that only included sensorial and objective characteristics (Benfratello, Piacenza, & Sacchetto, 2009).

So where does this leave our question of what makes a luxury wine? It appears that the taste and quality of wines are less important than the characteristics noted before the bottle is opened, at least in terms of price. It is therefore understandable why luxury wine producers use history, culture, and tradition to market their wines to consumers, because these attributes help craft and set up a particular image of luxury in the consumer's mind before purchase. The consumer's mind then congratulates itself on purchasing the more expensive bottle, playing into the Marketing Placebo Effect of luxury status. Technically, the consumer is paying more for a wine that has increased levels of tannins and antioxidant effects, but are these physical differences the reason why certain wines are seen as luxury?

Roman philosopher Pliny the Elder famously wrote "in vino, veritas"; that is, "in wine, truth". When the question is what makes a luxury wine, however, and when wine is at once a historical phenomenon, a trick of perception, and a product of chemistry, the truth might be, in spite of our best efforts, out of our reach.

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It's the Little Things in Life:

The impact of microbial communities on wine

Angela Dittrich, Sara Lemire, Coulter Montague, Maryanne Oketch

Wines from various regions around the world are known to possess unique characteristics. The concept of terroir – environmental factors which impact the quality and taste of wine – is thought to contribute to these geographic differences. More recently, the impact of microbial communities on wine has been investigated. Microbe populations are both plant organ and region specific, although there seem to be worldwide 'core' microbial species. Microbial communities impact grapevine health through nutrient acquisition, disease suppression, and regulation of plant growth hormones. Climatic conditions such as precipitation and temperature heavily influence which microbes are able to survive. Yeasts such as *Sacchromyces cerevisiae* have a profound influence on the final taste and scent profiles of wine. Factors such as nutrient availability, temperature, and grape variety can determine which metabolic reactions yeast undergo, producing final products which have either unpleasant or desirable tastes and smells. While many winemakers choose to sterilize grapes and remove the natural microbial community, the increased knowledge of the microbiome's role in wine quality may persuade them allow the regional characteristics to shine through in their wine, producing a traditional and truly unique product for consumers.

INTRODUCTION

Signature wines represent famous viticultural regions throughout the world, such as Champagne, which may only bear its name if it comes from Champagne, France. The concept of terroir is largely used as a means of explanation for why such renowned wines possess unique and distinct characteristics. Terroir was first coined in 1844, when viticulturists observed that small areas of land could change the quality and characteristics of the harvest planted in that location (Lavaud, 2003). Today, it aims to explain how a particular region's climate, soil, and terrain influence the **organoleptic** qualities of wine. Each aspect of terroir has a direct influence on grape growing, and subsequently, wine making, however it is also important to understand the interactions between these factors. While regional and climatic characteristics have been recognized as major influences on terroir, the influence of **microbes** has only been recently considered (Knight et al., 2015).

Organoleptic: relating to the stimulation of sense organs, such as taste and smell.

Microbe: a microscopic organism, such as bacteria, fungi, and viruses.

Microbial populations are extremely diverse and highly susceptible to environmental pressures. On a global scale, one of the most significant influences on microbial biodiversity is climate. On a more regional level, soil characteristics and interspecies interactions yield the most significant effects on diversity. Recent studies have sought to quantitatively examine microbial populations surrounding a single grapevine, between vineyards within the same or nearby regions, and between vineyards across the globe. Through the use of DNA sequencing techniques, researches have identified taxa associated with different plant tissues, as well as drawn comparisons between vineyards, and used these to explain regional distinctions in wine character. The presence and influence of microbes can be traced from the initial stages of grapevine planting all the way through to the final stages of fermentation, with distinct chemical remnants remaining in the finished wine.

LOCAL DIFFERENCES IN MICROBIOME POPULATIONS

It has already been established that microbial populations differ regionally, and it is also apparent that microbes are also organ specific – that is to say, microbial populations found on the leaves of the vine will differ greatly when compared to populations on the grape, and to those within the soil (Figure1) (Junker and Keller, 2015). Belowground bacterial populations differ significantly more than those aboveground, and yet the communities associated with the leaves, grapes, and flowers of the vines share a greater abundance of taxa with soil populations than with each other (Zarraonaindia et al., 2015). This suggests that soil may serve as a bacterial 'reservoir', from which organ-specific microbial populations originate.

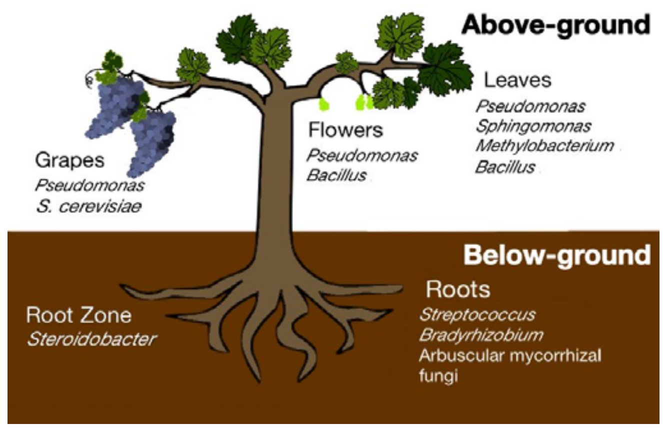

FIGURE 1: Examples of microbial species found on various grapevine organs (Gilbert, van der Lelie and Zarraonaindia, 2013).

It was also found that despite significant variations in populations, some epiphytic bacteria (bacteria residing on the plant) were common both on above ground organs and in soil. This suggests that physical proximity within the vineyard might facilitate microbial transfer through natural occurrences such as rain splash, high winds, and insect movement. It is also likely that microbial transfer occurs during harvesting practices, such as placing grape crates on the ground (Trouvelot et al., 2015).

A study of organ-specific microbial communities showed that although microbial communities associated with leaves and roots shared many of the same taxa, the corresponding communities differ in structure (Bodenhausen, Horton and Bergelson, 2013). Aboveground microbial communities are less diverse than those belowground, and similarly, communities found in the rhizosphere (root zone) are less diverse than those in bulk soil (Philippot et al., 2013). Intuitively, each grapevine organ yields a specific physical and chemical environment, which in turn selects for the survival of different microbial species. Soil characteristics have an extensive influence on microbial communities in the rhizosphere, and these factors are influenced by a multitude of environmental conditions and symbiotic relationships with plant species (Figure 2).

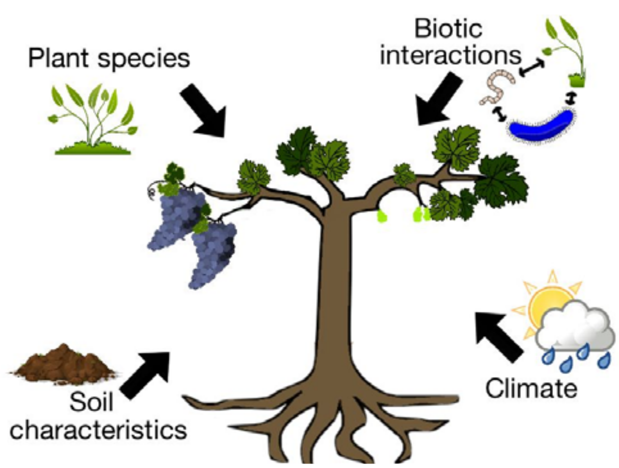

FIGURE 2: Environmental characteristics which influence the soil microbiome populations (Philippot et al., 2013).

The decreased microbial diversity present among the aboveground epiphytic populations may be explained by the nutrient poor conditions and ever varying conditions of temperature, UV radiation, and humidity (Zarraonaindia et al., 2015). Conversely, belowground communities are significantly influenced by soil pH, the ratio of carbon to nitrogen, as well as the natural flora residing in the soil and the rhizodeposits (proteins and sugars) which these flora release (Philippot et al., 2013). The lack of – or rather the diminished influence of biotic and abiotic and biotic factors within the bulk soil – explains why microbial diversity is highest here; there exists limited environmental selection, thus allowing for greater microbial diversity. Aboveground and belowground communities however, show organ-specific adaptations. For instance, genes associated with nitrogen metabolic pathways are most prevalent in taxa found within the soil, especially the root zone (Zarraonaindia et al., 2015). These adaptations are of significant importance when considering symbiotic relationships between microbes and the grapevine.

INTERACTIONS BETWEEN THE MICROBIOME AND THE VINE

During fermentation, bacteria and fungi have a direct and even quantifiable influence on the organoleptic qualities of wine, and as such, much research has been focused on grape microbiota and associated metabolites during fermentation (Trouvelot et al., 2015). Due to the diversity and complexity of microbial populations, it is still not precisely known how the microbiome influences the terroir of wine, nonetheless, it is understood that the microbiome could indirectly contribute to terroir. The phenotype and quality of the grape used in the winemaking process depends upon the growth, health, and behaviour of the vine - factors which are impacted by bacteria and fungi (Junker and Keller, 2015). These complex symbiotic interactions between the microbiome and the grapevine can result in both negative and beneficial outcomes for the plant. These interactions are also dependent on the surrounding microbial communities and the organ-specific adaptations these communities possess.

Microbial populations can impact the fitness of the grapevine by stimulating growth hormones, facilitating the acquisition of nutrients, and actively suppressing disease. The epiphytic bacteria *Pseudomonas spp.*, *Sphingomonas spp.* and *Methylobacterium spp.* aid in stimulating plant development through **phytohormone** production

Phytohormone: signal molecules produced by plants that regulate factors such as plant growth.

(Innerebner et al., 2011; Kutschera, 2007). *Steroidobacter spp.* also stimulate vine development, but specifically impact seed germination, fruit ripening, and leaf expansion - all of which are vital to the development of harvestable grapes (Yin-Ru Chiang, 2011). The acquisition of nutrients is also vital to the growth of the grapevine (Philippot et al., 2013). Nitrogen is essential for vine metabolism and ensures the rapid growth of young vines as well as shoot growth in the spring. In fact, low nitrogen acquisition has been shown to be very unfavorable in the production of white (sauvignon) wine (Trouvelot et al., 2015). Arbuscular mycorrhizal fungi (AMF) are a group of mutualistic biotrophs which facilitate plant nutrition through the acquisition of phosphorus and nitrogen in exchange for photosynthetically fixed carbon (Philippot et al., 2013). These fungi, which are present in the rhizosphere, form an extensive branching network beyond the root depletion zone, thus shortening the diffusive distance for phosphorus and nitrogen and increasing vine absorption (Trouvelot et al., 2015).

Rhizosphere microbiota are the first line of defense against soil pathogens. Pathogenic bacteria, fungi, oomycetes, and nematodes all negatively impact the health of vines (Philippot et al., 2013). Grapevines are especially susceptible to downy mildew, which results in yield loss and expensive antifungal treatment (Trouvelot et al., 2015). Disease suppressive bacteria can protect the vine by inhibiting the growth of pathogens at a particular life stage or by directly competing for nutrients and/or space within the rhizosphere (Philippot et al., 2013). In addition to facilitating nutrient acquisition, AMF has even been shown to induce systemic resistance in vines; initiating a response against multiple pathogens and insect pests (Zamioudis and Pieterse, 2012).

PHYSICAL MICROBES PRESENT IN SOIL ACROSS VARYING GEOGRAPHIC REGIONS

The grapevine associated microbiome is very diverse. Throughout 22 wine growing countries and among 49 grape varieties, there are 93 known yeast species and over 50 bacterial species - each with thousands of unique strains and genotypes (Figure 3) (Liu et al., 2017). On grapes specifically, there is typically a higher population of yeast species, but there is a greater species diversity of bacteria.

Although the microbiome has a significant effect on the plant, it is important to consider the factors that can change its composition. Bacteria is especially affected by the developmental stage of the grape. Bacterial populations rise as the grapes begin to ripen, and accordingly, the highest levels of bacteria are present on overripe grapes (Liu et al., 2017). In addition, as the grapes mature, gram-negative bacterial populations decrease, whereas the gram-positive communities increase (Liu et al., 2017). This alters the bacteria present during the fermentation process, thus influencing the resulting product.

In all varieties of grape, *S. cerevisiae* is the most prevalent yeast species present, however other yeast species are found on the grapes which likely result in interactions during fermentation (Capozzi et al., 2015). In a study looking at yeast diversity in Italian grapes, 13 known varieties of yeast were identified (Capozzi et al., 2015). Six different grape varieties were sampled, and yeast DNA was identified from the must of grapes harvested from two vineyards in the Apulia and Sicily regions, which are 610 kilometers apart (Fig. 3). The results demonstrated that not only was variation in yeast population dependent on grape variety, but also the location of the grape. These results suggest that regional factors have a large influence on the grape-associated microbiome, and that even minute differences in soil composition and microclimate affect microbial structure and subsequent metabolic influence during fermentation.

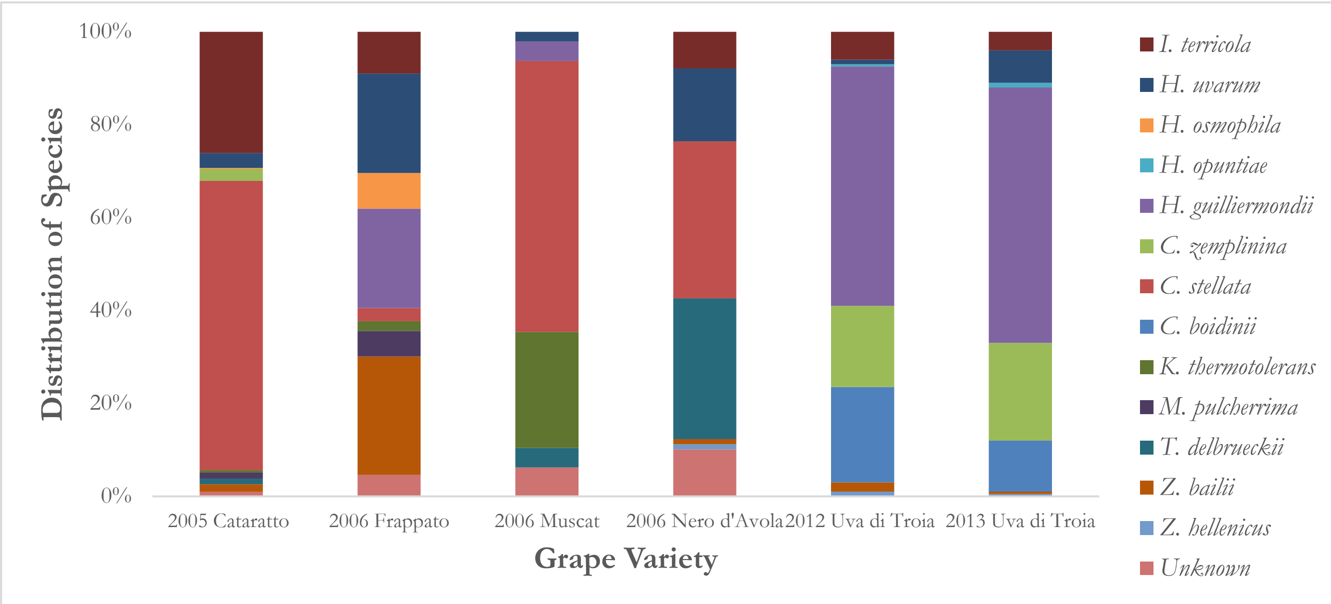

FIGURE 3: Meta-analysis of Yeast Species in Italian Grape Must. The Uva di Troia varieties were grown in Apulia, the rest of the grapes were grown in Sicily.

Microbial Terroir Varies Geographically

The microbial contribution to terroir is unique in that the types of microbes present in soil are chemically represented in wine character, but their diversity is immensely variable by region, and also extraordinarily sensitive to the effects of climate (Bokulich et al., 2014). Through the use of high-throughput DNA sequencing techniques, researchers have been able to record the microbial taxa within a region, and compare it to other mapped sites in close proximity, and around the world.

Grape must: juice prior to fermentation containing freshly crushed grapes, seeds, and skins.

After collecting and sequencing microbial samples of grapes at four sites in Cannonau, Italy, it was found that while rich in microbial diversity, all epiphytic populations sampled shared a core composition of microbiomes. This was characterized by the presence of *Enterobacteriales*, *Pseudomonadales*, *Bacillales*, and *Rhodospirillales* (Mezzasalma et al., 2017). As well, DNA sequencing of bacteria in **grape musts** of Merlot grapes in Suffolk New York, Bordeaux France, and California revealed a conserved group of microbial phylogeny that existed independent of growing region, climate, or sample collection method (Zarraonaindia et al., 2015).

While similarities are apparent in microbial communities between local and international sites, product distinction is based on the phylogeny and metabolic products unique to each region, and in some cases, can differ from vineyard to vineyard. The exact microclimatic, viticultural, and geophysical factors could explain variation among vineyard sites have thus far been beyond the scope of any investigation into microbial population variations between regions (Bokulich et al., 2016). Some of the broader aspects of climate, however, such as temperature and precipitation, have been studied and can be used to explain more general variations between regions, such as the abundance and function of bacterial soil communities, as well as their variation in physiology, temperature sensitivity, and growth rate (Classen et al., 2015). Some microbiota may not survive under certain conditions that are the result of a sudden, or even gradual changes to climatic conditions. This is especially important to understand when evaluating the potential threat climate changes poses to viticulture internationally. Such changes may translate to alterations in soil conditions, leading to the eradication of certain species either intermittently after sudden or seasonal changes in conditions, or permanently following the continuation of a trend negatively affecting certain microbial species (Alkorta, Epelde and Garbisu, 2017; Classen et al., 2015).

Evaluations of microbial population growth has demonstrated positive, but exceedingly variable relationships between microbial biomass and temperature. This is presumed to be the result of variations in the optimal temperatures for microbial species across different geographical regions (Wardle, 1992). Essentially, this means different bacteria thrive under different thermal conditions, and variations between regions, or even seasonal changes, lead to unique selective pressures on microbial populations. This ultimately generates diversity in the microbial taxa between regions.

The grapevine associated microbiome, and particularly that of the soil, is extremely susceptible to the conditions of the soil (Wardle, 1992). While pH and nutrient levels are substantial mediators for microbe population variation and survival, they are characteristic of the soils themselves, and not dependent on climate. However, the environment does dictate soil moisture as a result of precipitation. This greatly influences surface and subsurface conditions, and therefore dictates bacterial diversity and survivability. The microbial biomass in soil has frequently been shown to decline during dry periods and increase with substantial precipitation (Lovieno and Bååth). Studies have also shown that microbial responses to moisture variations can be extremely rapid, and that a significant portion of carbon and nitrogen in the microbial biomass may be released during these cycles. Positive responses to moisture are, however, not universal. Some bacteria respond negatively to moisture levels, and even more positively to dry conditions. Another potential factor affecting microbial reaction to soil moisture is their response to osmotic pressure related to precipitation and soil salinity. Due to the diversity that exists amongst microbiota, many may be capable of surviving even extreme soil-moisture potentials. These microbial species are potentially what comprise core bacteria associated with multiple geographic regions, however this has yet to be explored. Seasonal variations may also eradicate certain bacteria that can't survive in extreme conditions, leaving only the more vigorous microbes to thrive and create a regionally unique microbiome composition that is nature made, and non-replicable (Wardle, 1992).

THE INFLUENCE OF YEAST ON TASTE AND SCENT PROFILES DURING FERMENTATION

Yeasts are responsible for converting sugars into alcohol and carbon dioxide during fermentation, which is thought to influence the scent and taste profiles of wine. The primary yeast involved in wine fermentation is *Saccharomyces cerevisiae*, also known as "brewer's yeast" (Figure 4) (Moyad, 2007). This microbe is present on the skin of grapes, and thus in the grape must. Commercial strains of *S. cerevisiae* are also commonly added to the **grape must** prior to fermentation.

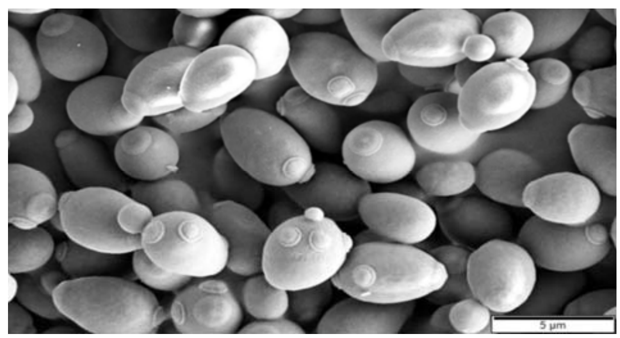

FIGURE 4: *Saccharomyces cerevisiae* A common yeast found naturally on grapevines, imaged through scanning electron microscopy (Das Murtey and Ramasamy, 2016).

There are over 9000 strains of *S. cerevisiae,* which can each undergo a variety of metabolic processes depending on nutrients or chemicals available, temperature, and grape variety (Moyad, 2007). Each pathway has its own final product(s) which can contribute to the aroma or taste of wine. While some of these flavour profiles are considered unpleasant, others are considered desirable by consumers.

As mentioned, nitrogen concentration is important in maintaining plant health. However, nitrogen also produce highly undesirable flavours within the wine.

In fertilizers and natural soils, there are a variety of nitrogenous compounds, including total nitrogen and yeast-assimilable nitrogen (YAN). YAN is the only form of nitrogen that is able to be utilized by yeasts, and so the presence, absence, or excess of YAN will determine what metabolic products will be produced. If the YAN concentrations in the grape must are too low, thiols such as hydrogen sulfide will be produced, leading to odours commonly described as rotten eggs. Excessive amounts of YAN in the grape must leads to the production of acetic acid, commonly referred to as vinegar (Bell and Henschke, 2005).

While narrow ranges of nutrient concentrations are required to produce a quality wine, improper concentrations of the final metabolic products themselves can result in a poorer product. Acetaldehyde is a compound commonly found in wine. At low concentrations, it can provide a pleasant fruity scent profile. At higher concentrations, acetaldehyde produces deterring odours described by some as grassy or overly ripe fruit (Liu and Pilone, 2000). Acetaldehyde levels in wine can increase in two different ways: during alcoholic fermentation or through oxidation of the wine. *S. cerevisiae* produces pyruvate during the conversion of sugars to ethanol, which is then converted to acetaldehyde. To resolve the overproduction of acetaldehyde, winemakers can minimize oxidation, or more commonly, utilize lactic acid bacteria such as *Lactobacillus* which can break down acetaldehyde (Liu and Pilone, 2000).

Yeasts are also responsible for producing a variety of desirable floral and fruity flavour profiles in wine. Two of the most attractive chemical compound groups are ethyl esters and damascenones. Ethyl esters are a family of compounds found to add fruity tones to the wine, such as apple or peach flavours. It was discovered that ethyl ester production decreases when there are high levels of unsaturated fatty acids present during fermentation.

Grape varieties have varying levels of unsaturated fatty acids, for example, cabernet sauvignon tends to have higher levels of fatty acids than pinot noir (Yunoki et al., 2004). As well, increased temperatures during fermentation can result in larger concentrations of ethyl decanoate and ethyl octanoate produced by *S.cerevisiae*. It is thought that nitrogen and carbon levels may also influence ethyl ester concentrations (Saerens et al., 2007).

Damascenone is a compound known for producing honey or floral tones within a wine. Notably, when placed in fermentation conditions, it was found that *S. cerevisiae* produces high levels of damascenones from the conversion of the ketones megastigma-4,6,7-triene-3,9-dione and 3-hydroxymegastigma-4,6,7-trien-9-one. However, each yeast strain has varying conversion efficiencies (Lloyd et al., 2011). One study tested damascenone concentrations with two different *S. cerevisiae* strains and their two ketone precursors, finding that the highest damascenone concentrations were produced when the common commercial strain AWRI 796 was used to convert megastigma-4,6,7-triene-3,9-dione (Lloyd et al., 2011). Overall, yeast strains and fermentation conditions should be carefully selected and manipulated in order to maximize the quality of the scent and taste profiles of wine.

NATURAL VS. COMMERCIAL MICROBES – IS THERE A RIGHT CHOICE?

While native microbial communities can have a profound impact on the overall taste and quality of wine, some winemakers choose to remove their influences completely. Winemakers can allow for natural fermentation to occur via the yeast found on the grapes to preserve the unique regional profiles. Conversely, they can remove the microbiota and inoculate with strains of commercially produced yeast with known metabolic processes to generate standardized taste profiles (Knight, Klaere, Fedrizzi and Goddard, 2015). Some winemakers may choose to simply add more of the present natural yeasts, amplifying the natural microbes' concentrations. The choice comes down to what is most important

- staying loyal to the region, or to the brand. For large companies that grow grapes across multiple regions, removing and replacing microbes ensures consumers will receive the same taste from any 2007 Cabernet Sauvignon they buy from that brand. More local wineries can choose to let the region influence the taste of the wine, providing a unique product. For many, winemaking is an art, and thus winemakers may want to remove the natural bacteria to create a certain aroma or taste profile for their wine. While there is no right choice, the growing knowledge of bacterial influences on wine taste may persuade winemakers to opt for more natural routes and embrace the regional characteristics to create a more unique and natural product.

SUMMARY

The impact of terroir on the regional properties of wine has long been well understood. The contribution of microbes to this affect, along with the interaction between factors of terroir, however, is a more recently considered field of study. Microbial populations have been found to play a significant role in winemaking; being shown to impact the health of the vine and quality of the harvest, to influencing chemical composition and subsequent organoleptic properties in the wine. Analysing metabolic pathways of microbes present in wine and correlating specific taste signatures allows for the artificial selection and prediction of taste profiles. The diversity in microbial taxa displayed on small and large geographic scales is indicative of the sensitivity of these populations to the local physical environment as well as climatic conditions. Such variation also speaks to the natural distinction regions demonstrate in each of their unique wines. Determining differences in taxa between global or regional vineyards provides evidence that microbes play a significant role in terroir, and although microscopic in size, they may result in the largest contribution to that full-bodied flavour.

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Mechanisms and Effects of Artificial Aging on Wine

Rachel Aubrey, Bea Co, Joseph D'Ercole and Sonya Grewal

The art of wine aging is an extensive, complex, and time-consuming task. Through the process of traditional oak barrel aging, winemakers have been able to perfect this craft for centuries. Although this method has been used for centuries, the desire to discover and develop additional artificial methods of aging has become increasingly popular. By doing so, winemakers are able to not only reduce the costs of production but also leave wine for sale on the market for longer periods of time. Novel artificial aging methods that hold more potential for the wine industry include micro-oxidation, ultrasound waves, high pressure, and even gamma irradiation. Although all are being tested, some are more efficient than others in creating higher quality wines. For instance, more research needs to be conducted on the potential of nanogold photocatalysis, gamma irradiation, and electric field as artificial methods.

INTRODUCTION

You're strolling down the wine aisle of your local LCBO when, suddenly, something catches your attention. You pick it up and find that it's both reasonably priced and looks very appealing. Then, from the corner of your eye, you see it. A label that says "Aged using gamma irradiation". All of a sudden, you find yourself very hesitant about whether you should purchase the bottle of wine and many questions start to arise. Is this safe? Is it going to taste like radiated wine? Why did they age my wine this way?

Recently, there has been new research on innovative methods that can accelerate the wine-aging process (Tao, García and Sun, 2014). The classic oak barrel wine-aging method may soon be a technique of the past. It is costly and time consuming, normally needing anywhere from three months to five years or even longer to age well (Tao, García and Sun, 2014). Thus, winemakers must consider this lengthy aging period before their product is ready for the market. With new innovative aging technologies, shorter aging periods may allow wine to be sold earlier and reduce storage costs for producers. Aside from speeding up the aging process, some methods can even improve the quality of taste (Tao, García and Sun, 2014). With further research, new modified wine-aging methods such as micro- oxygenation, ultrasonic waves, and high pressure have great potential in revolutionizing the modern winemaking industry.

ECONOMICS OF OAK BARREL AGING

The winemaking business is an expensive industry, especially when using traditional barrel aging methods. When you need to maintain the filling, topping, sulfuring, emptying, cleaning, and frequent sampling of the barrels, the expenses start to add up. The labour cost of this demanding process varies, although each barrel roughly needs one hour of maintenance annually. The cost can range from anywhere between $25 to $100 depending on the aging period and current wage (Stamp, 2015). Each barrel needs to be changed every five to six years, a replacement rate of 17% to 20% annually, which is a significant investment for any winery as barrels cost anywhere from $900 to $2000 (Butzke, 2010). Moreover, a major component of traditional aging is storage, as each barrel takes up roughly 2.2 square feet of floor space (Stamp, 2015). Heating and cooling expenses also need to be considered to maintain the optimal wine aging temperature (Jackson, 2008). Furthermore, wine is lost from absorption by the staves of new barrels, along with a 2% to 5% decrease in wine volume every year due to evaporation (Jackson, 2008). To compensate for this lost wine, additional volumes must be added to the barrel monthly, this wine is known as topping wine (Stamp, 2015). After a long waiting time and rigorous maintenance, the wine still needs to be bottled, labeled, marketed, distributed, and retailed to stores. The purchasing and planting of grapes, and heavy maintenance of a fully mature vineyard also needs to be considered. Taking all of this into account, the economics of using oak barrels in aging can be extremely challenging to keep up with, especially when wines could be made at less than $10 per bottle (Stamp, 2015).

FIGURE 1: Estimated percentages of cost associated with traditional oak barrel aging to produce one bottle of wine. Image created using statistics from Stamp (2015).

BACKGROUND CHEMISTRY

Before going into accelerated aging techniques, some chemistry should be covered. Aging may seem straightforward, but involves several chemical reactions, which produce many different products (Oliveira et al., 2011). More specifically, molecules in wine undergo oxidation that alters the wine's characteristics. The change in chemical composition can lead to a different flavour profile and thus a unique perceptual experience (Waterhouse and Laurie, 2006). This is accomplished by adding oxygen-containing functional groups as well as polymerization reactions, which involves combining large molecules (Oliveira et al., 2011). The reactants involved in wine aging can be broken down into two main categories: flavonoids and non-flavonoids (Oliveira et al., 2011). The flavonoids are a general class of particles that are derived from flavone (Figure 2). As suggested by the name, non-flavonoids do not relate to flavone, but include other molecules like tannins, which are very large and contribute to wine's bitterness.

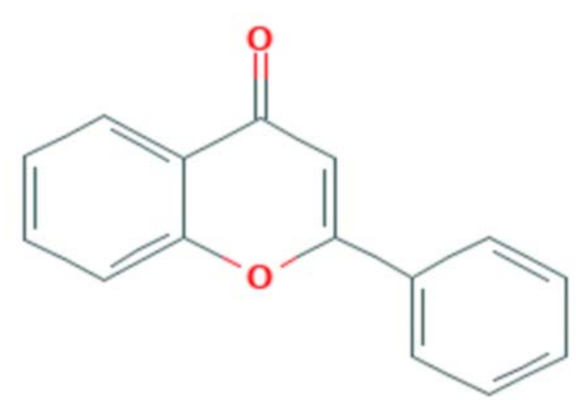


FIGURE 2: THE STRUCTURE OF FLAVONE, which undergoes oxidation and polymerization reactions (Waller et al., 2011).

Oxidation reactions in wine can be further broken down into enzymatic oxidation, which involves enzyme catalysis, and non-enzymatic oxidation (Oliveira et al., 2011). Enzymatic oxidation dominates early in wine production, though slows as proteins within wine denature. On the other hand, non-enzymatic oxidation occurs throughout wine production. As wine aging is concerned with oxidation, artificial aging means accelerating these reactions. Artificial aging increases oxidative stress by adding oxygen or by modifying other factors, like temperature or pressure. Overall these techniques stimulate oxidation reactions and subsequently stimulate aging.

As artificial aging methods cause chemical changes, they create a flavour different from traditional methods. Oftentimes, accelerated aging uses steel tanks as the vessel, rather than oak. In oak barrels, the wine maintains constant contact with the interior of the oak barrel, allowing for some molecules originating from wine to bind to the oak barrel and vice versa. Using steel tanks prevents this from happening, resulting in a different wine composition compared to wine aged in oak barrels.

MICRO-OXYGENATION

During the early 1990s in France, Patrick Ducournau conceptualized micro-oxygenation (Blaauw, 2009). It is now among one of the most commonly employed methods to age wine in a controlled manner, and in 2007, 83% of large wineries in America had employed micro-oxygenation (Blaauw, 2009). Micro-oxygenation entails the periodic addition of small amounts of oxygen, while removing carbon dioxide (Figure 3). This technique is advantageous compared to barrel aging, since it can reduce the aging duration, lower costs, and allow for a great deal of control (Blaauw, 2009; Tao et al., 2007). Generally, using micro-oxygenation in wine development leads to a softer and more rounded taste, making wine more easily consumed and ready at an earlier time (Rieger, 2000; Blaauw, 2009). This is accomplished by modifying tannins, which are flavonoid derivatives with a bitter taste. Overall, micro-oxygenation functions to remove the bitterness associated with wines and reduce the aging duration. Micro-oxygenation not only improves overall taste, but also adds colour intensity, as polymerization reactions can create coloured pigments (Blaauw, 2009).

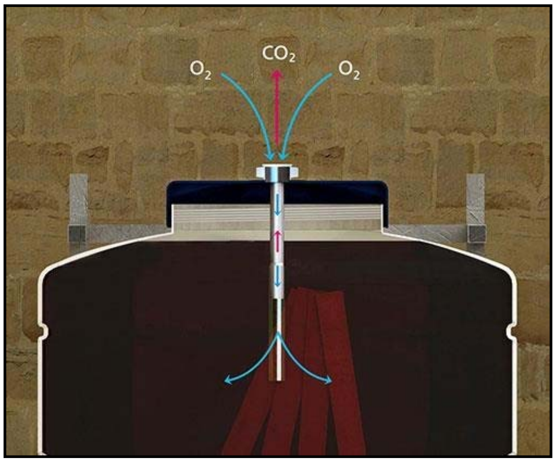
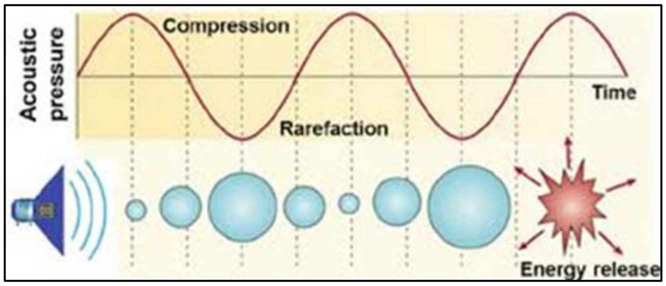


FIGURE 3: MICRO-OXYGENATION involves removing carbon dioxide, CO_2, while adding O_2 (RedOaker, 2009).

Despite its benefits, micro-oxygenation is not without potential harmful effects on wine. These negative effects generally happen when too much oxygen is added and can lead to excessive polymerization (Blaauw, 2009). This causes wine to become drier, have reduced freshness, and lose colour. Though the loss of colour may seem counterintuitive as micro-oxygenation causes polymerization, too much oxygen can actually force large molecules to solidify. One of the most concerning risks is having microbes grow within wine. While aging, wine is usually kept in an environment with low oxygen content. Adding oxygen shifts changes the environment and can promote growth of bacteria, most notably acetic acid bacteria and *Brettanomyces*, which can render a wine undrinkable (Blaauw, 2009; du Toit et al., 2006a). Micro-oxygenation could help the wine industry lower costs and increase product quality, though it requires a great deal of care when considering the possible risks.

ULTRASONIC WAVES

When thinking of ultrasounds one first thinks of their use in the medical field for applications such as imaging. Yet imagine a world where ultrasonic waves are sent through wine creating intense pressures and temperatures and a delicious wine as the final product. In 1937, ultrasound was used as an alternative to natural aging in both fermented and distilled alcoholic beverages (Francisco Garcia, Zhang and Feng, 2016). In the wine industry, ultrasonic waves can be used to stimulate reactions which resemble traditional wine aging, although at an increased rate. More specifically, natural aging is stimulated through a process known as acoustic cavitation caused by the presence of ultrasonic waves in liquids (Zhang and Wang, 2017). In general, acoustic cavitation defines the process of the growth and collapse of microbubbles found within the wine (Ashokkumar, 2011). This process causes an increase in the rate of the chemical reactions that occur naturally. The bubbles expand and contract to a point in which the bubble is no longer at a stable size and releases energy while bursting, generating very high temperatures and pressures (Figure 4) (Nagarajan et al., 2006). Experiments have determined that the temperature within a cavitation bubble may reach between 750K to 6000K, although this is simply an estimation varying among papers (Ashokkumar, 2011; Young, 1999; Misik, Miyoshi and Riesz, 1995). By localizing these conditions, one can induce certain chemical reactions thus accelerating the rate of wine aging reactions. In addition, the conditions create highly reactive radicals that are involved in the aging reactions of wine. Through this process, numerous chemical properties of the wine are altered, including antioxidant properties (free radicals), pH, and the overall colour of the wine (Zhang and Wang, 2017; Fu et al., 2018).



As seen with micro-oxygneation ultrasonic waves

FIGURE 4: ACOUSTIC CAVITATION diagram illustrating the process in relation to the acoustic pressure from the ultrasonic waves. When pressure increases the bubble compresses, when pressure decreases rarefaction of the bubble occurs, eventually the fluctuating pressure causes the bubble to explode, releasing immense energy. (Goncalves, Silva and Cavaco-Paulo, 2015).

can have negative effects on the quality of wine. In order to avoid negative qualities, an optimal ultrasonic frequency must be used. Through tasting by panelists, it was discovered that an optimal ultrasound frequency range is between 20 to 100 kHz, as too high of ultrasound frequency is not optimal for the wine aging reactions while too low will not create the desired effects (Tao, García and Sun, 2014). A noted change from naturally aged wine is the ability of ultrasound treated wines to last longer after reaching their peak taste and aromas characterised by the presence of soft tannins. By extending this peak taste period, ultrasound is able to extend the shelf life of the wine (Tao, García and Sun, 2014).

Ultrasonic waves can also be used in the extraction of biological compounds from surfaces, although future investigation would need to be done for it to be used within the wine industry. In terms of wine aging, ultrasonic waves do not have to be used alone, they can be used in order to extract oak-related compounds into the wine from oak chips added to a steel tank. This process simulates the release of compounds from the oak barrels in natural aging (Ashokkumar, 2011).

Ultrasound waves have the possibility to extend the shelf life of the wine itself, as well as enhance the overall quality of the wine when used at the correct frequency. Winemakers not only will eventually save money from avoiding the traditional oak barrel method altogether, but also are able to create better products and have them on the market for longer periods of time.

ULTRA-HIGH PRESSURE (UHP)

UHP treatment has become a very common method in the food and beverage processing industry for the sterilization and preservation of foods. You're probably wondering how this technique is used to increase the shelf life of certain foods or is able to age wine in such a short period of time. As the name implies, the product undergoes compression as it is placed under high pressure, decreasing its volume in the process, as seen in Figure 5 (Chen et al., 2012). Certain microorganisms and enzymes are inactivated eliminating any pathogens in the food or drink. Additionally, this change in pressure alters the three-dimensional structure of proteins and other macromolecules through the process of denaturation (Chen et al., 2012). UHP treatment therefore affects cell morphology and the functional properties and texture of the final product.

Due to its great value and success in the food processing industry, UHP treatment has recently been applied to the wine industry. There are several advantages to using this technique over the traditional methods for vinification. For example, the aging period of wine is significantly shorter when employing this treatment and the cost is relatively inexpensive in comparison to barrel aging (Tao, García, & Sun, 2014).

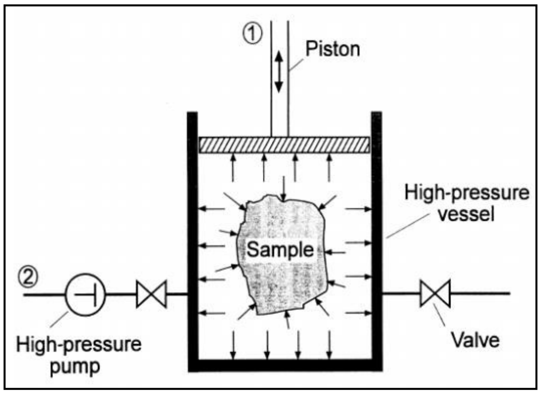


FIGURE 5: Treatment with UHP involves keeping the wine in a pressurized vessel. An example of this is using pistons to compress samples in a sealed container.

Now you might find yourself questioning whether this procedure affects the overall quality of wine. It's a fair assumption to believe that treating a beverage with such intense pressure would without a doubt negatively alter the taste and flavour of the wine. This, however, is not necessarily true. In fact, this technique has actually been found to enhance wine quality. In a recent study, it was found that as pressure levels increased, the chroma value, a measure of the wine's saturation, also increased (Sun et al., 2015). This resulted in an overall improvement in wine colour. Additionally, the hue value, another quality defining colour, began to decrease as the treatment pressure continued to increase (Sun et al., 2015). Low hue values are associated with shades of red, whereas high hue values pertain to shades of violet. Higher levels of pressure may inflict damage to the structure of anthocyanins, a flavanoid known to contribute to pigmentation in wines, resulting in changes in the hue value (Sun et al., 2015). Another notable observation is that there was a slight decrease in alcoholic content in the wine following UHP treatment at increasing pressures and durations (Sun et al., 2015). It was hypothesized that this treatment promoted the association of water and ethanol molecules, two major components of wine, in esterification reactions resulting in this decrease. Overall, UHP treatments were found to improve the appearance and taste of wines in this study. Based on the results, the researchers suggested that the energy from this technique could enhance the molecular activation energy and promote esterification, oxidative, and polymerization reactions, therefore improving wine colour, aroma, and quality (Sun et al., 2015).

There are no UHP-treated wines currently on the market (Sun et al., 2015). More research needs to be conducted in order to understand how the composition of wine is affected by this accelerated aging technique. In addition, we need to see whether this procedure has any unforeseen impacts on human health before distributing UHP-treated wines to the public.

DISCUSSION

Winemaking is a complex process and involves a lot of different factors. Since the wine market is competitive, winemakers strive to reduce costs (Figure 6). A significant cost associated with wine production is wine aging, thus accelerated aging techniques have found recent popularity. Although the more plausible novel artificial methods include micro-oxidation, ultrasonic waves, and even high pressure, research is also being done on more abstract methods such as nanogold photocatalysis, gamma irradiation, and electric fields as artificial methods (Tao, García and Sun, 2014). In order for these methods to become more probable, more research needs to be conducted on their chemical impacts to the wine and any potential harmful side effects. In addition, wine makers need to consider how the public would react to drinking wines that have been treated with these unique techniques, rather than traditional barrel aging. Consumers also might question the safety of these procedures and the potential side effects.

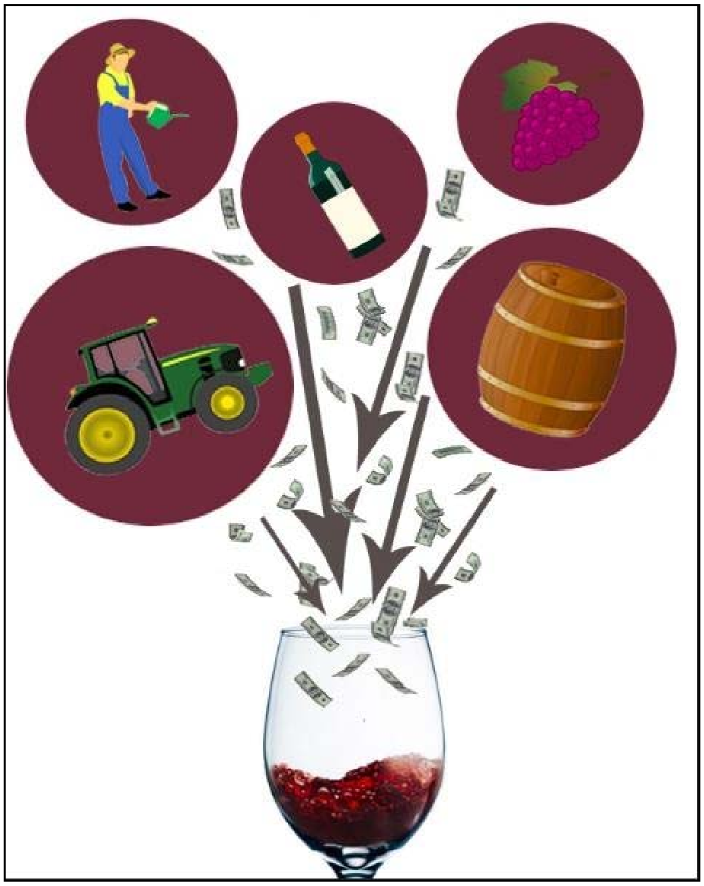


FIGURE 6: In order to produce one glass of wine numerous aspects must be considered in the cost (Stamp, 2015). The costs involving aging can be greatly reduced through the process of artificial aging mechanisms.

Effective marketing strategies are critical in order to appeal artificially aged wines to the average consumer, such as yourself. The typical customer's perception of artificially aged wine can make it more difficult to increase sales as the products are viewed to be both controversial and foreign. Even when the wine is tested safe by toxicity tests, consumers may still be skeptical of any potentially harmful effects (Tao, García and Sun, 2014). Others are also concerned about the lack of natural oak flavours from the barrel affecting the quality of taste (Crump et al., 2014). The innovative technologies may reduce the expenses of production, however, there needs to be more investigation in marketing techniques and consumer interest to determine the cost and benefit of these new aging techniques.

Transitioning out from oak barrel aging will also be a difficult choice for many winemakers as they have acquired decades of knowledge from their own familiar aging techniques (Tao, García and Sun, 2014). Most likely, a combination of old and new techniques will be more common to implement in wineries today (Tao, García and Sun, 2014). Once implemented, the overall cost of the wine will decrease. These combinations of traditional and new techniques propagate the shift towards newer innovations helping us attain shorter aging periods and thus reduce the production costs.

SUMMARY

Although, all of these new technologies have great promise to the modern winemaking industry, further research is necessary for progress to be made. These methods are only in their experimental stages and as research advances, these technologies have the potential to become an industry standard. Thorough cost-benefit analyses must be conducted in order to determine if winemakers are able to reduce costs while still being able to produce wine of the equivalent or better quality. It will be interesting to see how the practices of micro-oxygenation, ultrasonic waves, and high pressure will unfold in the future of the winemaking industry, but for now, the standard of oak barrel aging is still most commonly practiced. Currently, these practices are rarely seen on the market, but if you ever see a gamma-irradiated wine in your future LCBO visit, will you be the one to take it off the shelf? Will you think it's safe or are you too scared to take a risk?

MORE TO EXPLORE

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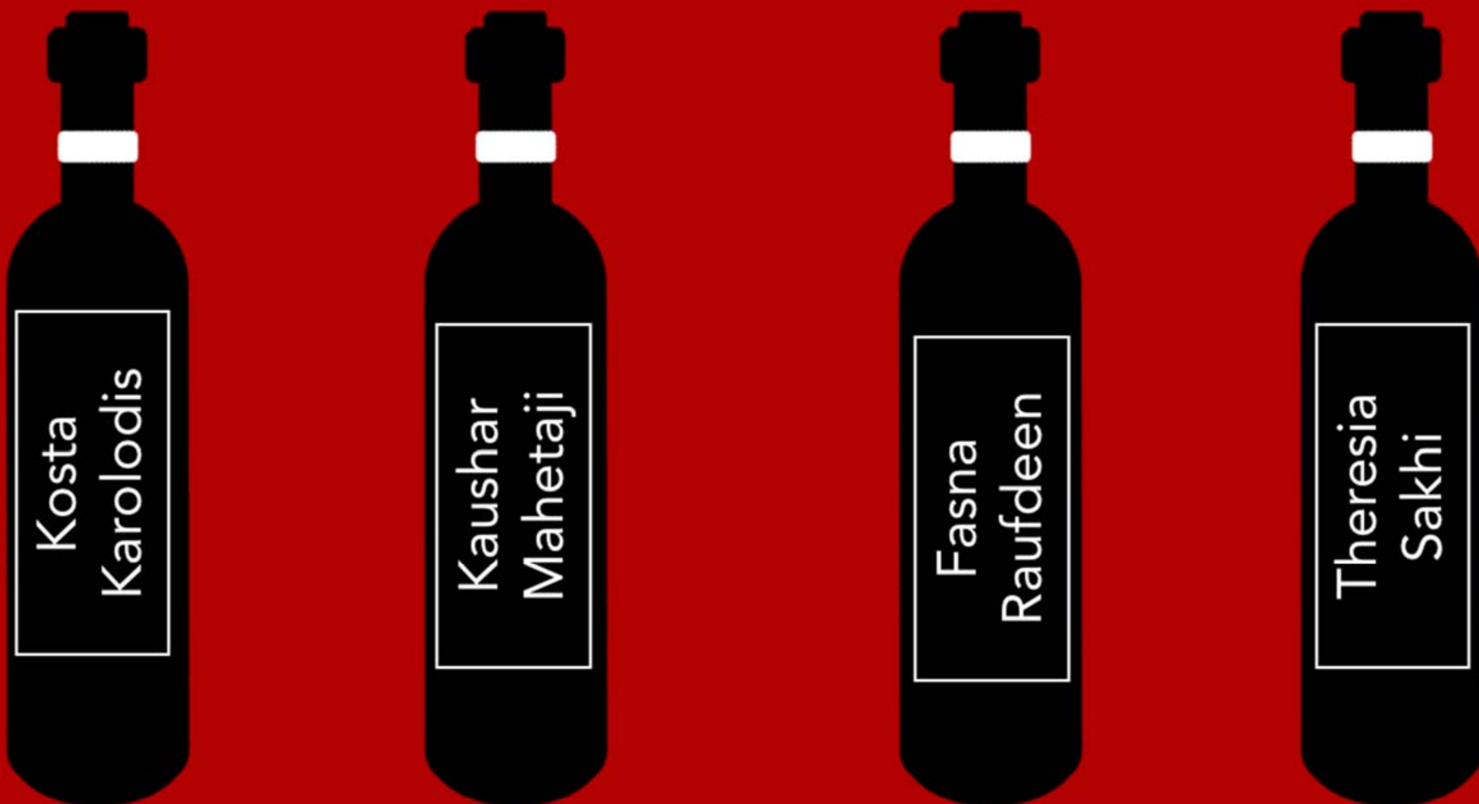
GREAT EXPECTATIONS
THE MILLENNIAL AND THE WINE LABEL



Just how far will the marketing industry reach to transform their liquid into paper? From tapping into underlying snobbery marked by a desire to feel experienced, to clothing bottles in chic burgundies, the marketing industry does not refrain from playing psychological mind games.

How do the marketing strategies used for wine labels affect millennials on a psychological and neurological level? To answer this, you will witness the creation of an "ideal" label. Each element of the label is catered to a millennial demographic - a subsection of consumers that believe that the wine industry naturally fosters "grape" expectations.

INTRODUCTION

Are you an individual who relishes moments marked by freedom, power, and control? Do you appreciate wine that provides a sense of intellect, creativity, or adventure at the dinner table? While these questions may intrigue the reader, it is the entrepreneur who seeks to understand the responses provided by the consumer. These responses are vital to understanding the appeal of wine labels on bottles including the Australian Yellow Tail Shiraz and Apothic Red.

The Australian Yellow Tail Shiraz is indiscreet in boasting its roots. A broad, simplistic bottle with a mosaic-coloured kangaroo below humble black print on a bright yellow label, houses a dark plum-berry-licorice mélange. A direct contrast, Apothic Red, a similar blend of berry and spice, stows its contents in a bottle with a scarlet-red storybook "A." The locality for this wine is more discreet with "California" printed in an inconspicuous grey. These pasted labels, shown in Figure 1, may be marketing gimmicks. Yet, for the average consumer, the contents of a bottle are first understood through the label.

FIGURE 1: A. Yellow Tail Shiraz label – a kangaroo cover housing a full-bodied smooth wine produced from the Syrah grape and B. Apothic Red label - a red, black, and white wrapper for a blend of ripe fruit and vanilla (LCBO, 2018).

A cross-country Australian study asked 426 average wine consumers to indicate important contributors for wine selection. Researchers concluded that wine drinkers feel that front labels are not the most significant factor when purchasing a wine (Mueller et al., 2010b). Conversely, other studies have suggested that label design is vital in consumer decision-making, reporting that consumer response to labels is subconscious and unlikely to be actively recognized by the individual (Mueller, Remaud and Chabin, 2011).

The purpose of wine labels is not unlike a novel spine or book cover, forcing a hand in a musty old bookstore with shelves of unfamiliar reads. Unfamiliarity when identifying wines is common in the industry, as available wines are continually cycled. Wines may also be discontinued due to an inability to meet sales targets. The LCBO will remove bottles from their shelves if they fail to meet product quality, packaging, and labeling standards, in addition to maintaining production supply quotas. These changes are especially impactful for millennials who are less likely to have established taste preferences when compared to consumers included in the Traditionalists, Baby Boomers, and Generation X demographics (Williams and Page, 2011).

Generation Y or millennials, born during or after the 1980s, drink a wide range of alcoholic beverages including wine (Pyöriä et al., 2017). Different elements of labels are attractive to varying segments of a market. For this demographic, lower pricing, brand name, social success, and pleasure are prioritized above health. Millennials also tend to choose drinks priced $20.00 or under rather than fine wines or drinks produced in Old Wine country. With 76% of wine consumption accounted for by millennials in Ontario, the marketing industry has shifted its focus to target these consumers (Wright, 2016).

Millennials are less knowledgeable about the wine industry and are consequently more vulnerable to

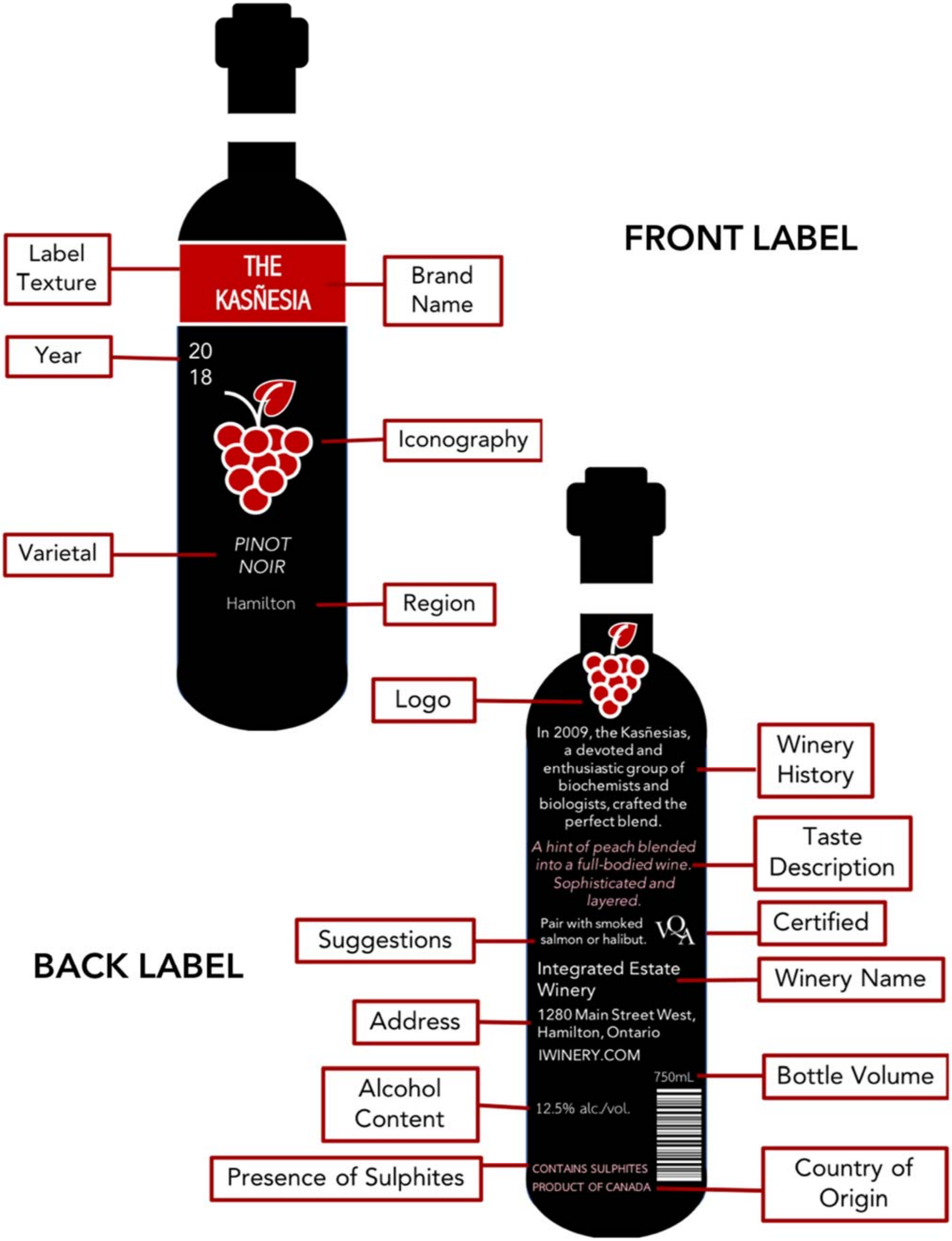


FIGURE 2: Key elements of a front and back label displayed through a hypothetical wine bottle.

marketing tactics when selecting wines (Atkin and Thach, 2012). Fortunately, front labels instigate consumer interest, while back labels are used to convey necessary information (Yuan et al., 2011). Front labels tend to focus on: texture, language and terminology, iconography, and colour. Back labels consider: locality, sensory descriptors, winery history, and suggestions from the winemaker. These components of a label can be visualized in Figure 2.

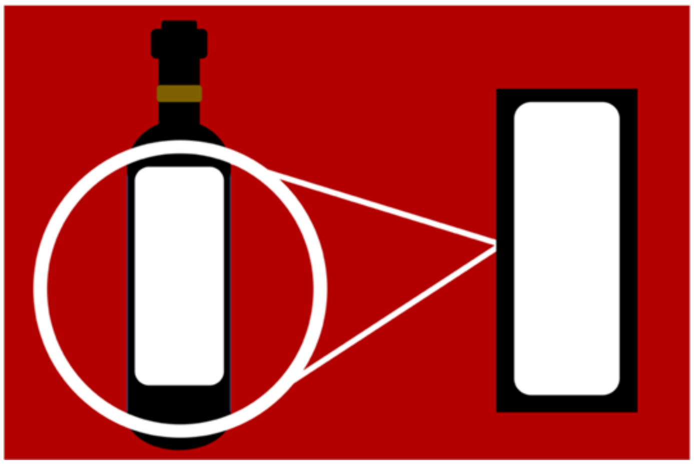


FIGURE 3: A blank label on which a front and back label will be crafted.

Label design requires careful consideration, which will be explored by constructing additions to Figure 3.

THE FRONT LABEL

Texture and Embossment

Unlike experienced wine drinkers of the Baby Boomers and Generation X demographic, millennials are easily influenced by peer group dynamics. They often aim to select wines that meet a societal definition of sophistication (Teagle, Mueller and Lockshin, 2010). By examining label texture and embossment, millennials are able to assess and attribute quality to a wine based on initial perception (Williams, 2018).

By targeting perceived value, the marketing industry can focus on finding the perfect balance between embellished and classy using strategic packaging.

Recent literature suggests that individuals will touch finely-textured surfaces, and more specifically, millennials will glide their fingers across wine labels for physical inspection (Williams, 2018). This is due to the Duplex Theory of Tactile Texture Perception, which explains the coupling of spatial and temporal (time-based) cues suggesting the presence of dual perception mechanisms (Hollins and Risner, 2000).

Fine-grained textures, as indicated in Figure 4, are manufactured with linen labels, glossy imagery, and handcrafted paper. These fine-grained textures are perceived through temporal cues induced by vibrational signals when skin slides against abrasive material activating mechanoreceptors (Fagiani and Barbieri, 2016). This often increases the perceived value of the respective wine (Williams, 2018). Uniform plastic material creates the opposite effect, as indistinguishable grain size appears inexpensive. Since coarse-grained materials rely on spatial cues that consider shape and distribution visually, these materials are also less likely to be physically touched.

FIGURE 4: A glossy fine-grained sheet of hand-crafted paper is used to encourage the consumer to pick up the bottle for examination.

Similarly, since intricate details are interpreted as expensive and laborious, metallic foil and embossed ornamentation also attract consumers. To maximize positive perception, marketing strategists must strike the ideal balance between overcompensation through decoration and a plain stark white label.

Any foiling on a label is associated with an expensive wine (Williams, 2018). Figure 4 avoids unnecessary embellishment, as millennials are unlikely to purchase an expensive bottle. However, full gold coverage of a bottle produces feelings of deception and dishonesty, as participants presume trickery was used to sell a low-end product (Koslow, 2000).

Language and Terminology

The language used on wine labels is essential to attracting millennial consumers (Barth and Elliot, 2012). In essence, wine terminology involves illustrative terms that clearly describe either the taste or the process with which the wines were produced.

Terminology can be divided into three categories: origin, bottle conditions, and wine types. As per the different origins, a common term used for Italian wines is “DOCG” or “Denominazione di Origine Controllata e Garantita,” referring to the highest quality wines from Italy (Corrado and Odorici, 2009). Although consumers are not always aware of acronyms, curiosity gages the interest of millennials. The term “Vieilles vignes” or “old vines,” refers to high-quality grapes, which are grown in low yields ranging from 30 to 120 years old (Nedilko, 2006). A common term used for dessert and fortified wines is “Ruby Port,” which is an inexpensive wine made from mixing multiple vintages. This wine has also been aged for a short-time period prior to bottling. The terms used to describe dessert wines have already been established and are well-known amongst millennial consumers, as they have the one thing millennials are looking for: sugar (Fowler et al., 2010).

When describing bottle conditions, the terms used are separated into label conditions, as well as cork and capsule conditions. For instance, “WISL” and “WASL” denote “Wine Stained Label” and “Water Stained Label” respectively. When describing capsule types, acronyms such as “WXC” and “NC” correspond to “Wrinkled Capsule” and “Nicked Capsule” (Nedilko, 2006). This type of terminology is used in particular to indicate whether a wine is a rare wine, investment-grade fine wine, or standard table wine. While millennials may find understanding rarity interesting, they are more likely to be drawn to the brand name, where true marketing innovation lies.

FIGURE 5: Our hypothetical wine has been named “Devil’s Advocate.” “Devil’s Advocate” is a phrase used to indicate an individual who supports a point of view that they do not necessarily align with. By playing devil’s advocate, arguments are discussed further and a conversation is made more interesting.

When formulating brand name for wines, authenticity is a critical factor, as it reinforces status. Brand name can potentially ward off any competitors sharing a market. For millennials, a creative and user-friendly brand name attracts more consumers, and can be remembered quite easily. The focus of the brand name however, should be on the history of the winery, or an aspect that brings value to unique characteristics (Beverland, 2005). An example of a popular wine brand is “Barefoot Wine,” where the founder of this company initially crushed grapes with his bare feet in his garage (Veseth, 2013). Figure 5 uses this logic, using the phrase "Devil's Advocate" to indicate a novel and unconventional wine.

Iconography

Icons and symbols influence the decisions made by consumers when selecting a product or brand (Johnson and Bruwer, 2007). Within the wine industry, retailers are continuously searching for innovative ways to successfully communicate information to their consumers. Iconography is an effective method used to engage consumers within industry categories with high competition and low product familiarity.

The use of signs and symbols is believed to be effective in intuitively communicating "ease and simplicity" to the consumer (Caldewey and House, 2004). The study of communication via signs and symbols is commonly known as semiotics, and has been used as the basis for formulating inexpensive to average-priced wines (Johnson and Bruwer, 2007). On the contrary, fine wines have been found to lack essential elements of iconography. Instead, they focus on colour, texture, and embellishments.
A study conducted at Portland State University in 2007 found that animals, animated logos, portraits, and specifically colourful icons, decrease the perceived value of wine bottles (Johnson and Bruwer, 2007). However, natural icons such as flowers, vines, and trees are shown to communicate positivity and growth, rendering them highly respected symbols to consumers. The use of a natural icon can be observed in Figure 6. Put simply, bottles with large abstract or floral designs are considered highly valuable.

The use of iconography in the wine industry can also be supported by psychological theories that cater to particular consumer groups. For instance, Gestalt psychology is a theory proposed in the early 20th century, which claims that the innate

FIGURE 6: A simple grape bunch comprised of circles, a single leaf, and bent stem, represents prosperity, growth, and fertility. For the millennial, a grape bunch embodies consistency between drink and label appearance, in addition to implying quality. Two tear-dropped shapes beside the bunches exhibit the pouring of wine.

behaviour of human beings is to observe details within a larger visual context (Wagemans et al., 2012). When applied to labels, this theory implies that individual elements can be interpreted as a whole to convey a single narrative. Since wine labelling is all about storytelling alongside the art of seduction, icons play a significant role. Using the Gestalt Theory of Perception, wine retailers understand that at the end of the day, it is about the big picture.

Colour Psychology

The use of colour in wine labels also has an impact on a consumer's initial impression of a product. Colour can help a wine stand out, differentiate itself from its competitors, and evoke positive feelings about the product in consumers. Conversely, colour can also lead consumers to associate negative attributes to a wine, such as poor quality.

In psychology, the study of human response to color is often referred to as colour psychology. While the evidence linking specific colours to certain human responses is inconclusive (Singh, 2006), a number of colour theories in the field of psychology have emerged over the years. Among these theories is the colour-in-context theory, which proposes that the "meaning" derived from a colour is dependent on the physical and psychological context in which it is presented (Elliot, 2015). Rather than there existing an innate, specific emotional or physical response to every colour, people impose different meanings onto colours depending on the situation. For example, green may be viewed positively in the context of a traffic light signalling "GO," but could also carry a negative connotation in the context of food, as seeing green mold on a rotting sandwich is not very appetizing. But what does this mean in the context of wine labels and marketing?

Studies into wine customer preference have shown that when it comes to wine, customers tend to prefer warmer colour pallets, such as burgundies, reds, and neutrals, associating those with more expensive and desirable wines (Boudreaux and Palmer, 2007). In this context, dark and rich colours evoke positive feelings in customers, as these colours are traditionally associated with red wines due to their colour. Additionally, as colour saturation increases, potency is perceived to increase correspondingly (de Mello and Pires Gonçalves, 2008). As a result, darker, richer colours may indicate that a wine is more potent, and therefore stronger and of higher quality.

FIGURE 7: Strong red with colour code R: 192 G: 0 B: 0, once rare and expensive, has been associated with passion and primal instinct, in addition to super-human heroism, magic, blood, love, and fire.

While darker labels may be popular with wine consumers as a whole, recent trends in label colours have shown that millennials respond better to bright non-traditional colours. In the hypothetical label pictured in Figure 7, a vivid red is used for the brand name as well as iconography to tailor to a millennial audience. This label also incorporates classic elements, such as the background, which is retained for general appeal.

In a study conducted at the University of Guelph, when asked to design a wine label, participants aged 19 to 22 were found to create labels using bright colours such as reds, oranges, and greens, rather than the conventional burgundies (Barth and Elliot, 2012). Although this is a narrow age interval, it suggests that the emerging demographic of wine consumers has a unique perspective when it comes to the design and look of wine labels. Millennials reject the traditional and predictable designs in favour of more innovative label colours that are exciting and adventurous.

A millennial customer is looking for a fun, likely inexpensive wine, and wines with traditionally coloured labels – which are associated with sophistication, high quality, and price – do not fit this description. Since millennials are the new emerging market in wine sales, it is important for winemakers to consider the psychology behind the colours used in their labels and aim to create designs appealing to the millennial consumer.

THE BACK LABEL

Locality

When examining a wine label, one of the first aspects a customer may encounter is the wine's country of origin. Simply the presence of a country of origin on a bottle of wine can influence how a customer feels about the wine's quality and value. Although wine is consumed and produced around the world, Old Wine Countries (countries where winemaking originated) such as France and Italy have historically had a reputation for producing sophisticated and high-quality wines. Consequently, it would be reasonable to assume that wine drinkers around the world would prefer these imported products from Old Wine Countries over more locally sourced options. However, studies conducted globally have shown that this is not the case. Despite being from "New Wine Countries," when surveyed, both male and female US consumers preferred US made wines (Garcia, Atkin and Nowak, 2007), while customers in Australia and New Zealand also preferred their locally made wines over foreign alternatives (Atkin, Garcia and Lockshin, 2006). Clearly, wine drinkers around the globe have a preference towards wines produced in their own countries, but what is responsible for this bias?

A possible explanation is the mere-exposure effect, or familiarity principle. This psychological phenomenon asserts that people develop preferences for things that they are more familiar with, or which they have been exposed to previously (Zajonc, 2001). A customer will buy a locally made product, or a product made in their own country, because they already have positive associations with the country in which they live, and in turn, this makes locally made products seem safe and reliable by association.

This phenomenon is especially present in millennials. Studies into millennial consumer habits have shown that millennials prefer to shop local, and exhibit regional pride, as well as carry positive associations to their local communities (Cummins, 2015).

In Ontario, Canada, local support is often given to wineries in the Niagara region, such as the award-winning Rosewood Estates Winery located in Niagara-on-the-Lake. This is a small family-owned winery and meadery that spans over 40 acres of land. To gain perspective on the significance of labels in marketing, and considerations made during label creation, an interview was conducted with operations manager, William Roman.

The impact of these local wineries in the Niagara Peninsula, makes it an important element for the back label shown in Figure 12. Locals support this winemaking region home to a range of wineries from local specialty producers to major international winning winemakers.

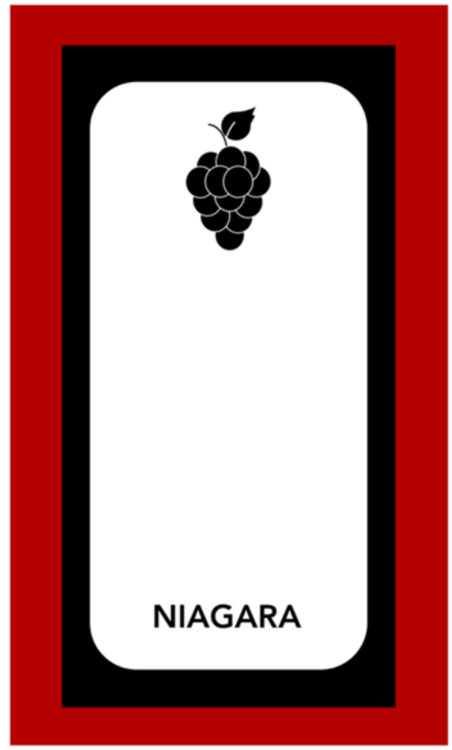


FIGURE 12: Rolling hills and lush scenery describe the Niagara Peninsula in Ontario, Canada. Including "Niagara" on the label appeals to locals.

While recent studies on marketing demographics do not refer to wine purchasing directly, the general takeaway is the same; due to the sense of familiarity they feel to their communities, millennial customers have an affinity for products that are produced in their country or community. As a result, this sense of fondness towards locally made products might explain why millennials, and other age-based demographics, generally prefer to buy local wines. While these local wines may not have the associated sophistication of wines made in Old Wine Countries, they do evoke a sense of community, authenticity, and familiarity that millennial consumers seek.

APPLICATION

An Interview with an Operations Manager of a Local Winery in the Niagara Peninsula

William Roman (Rosewood Estates Winery, 2018)

Is there a specific bottle of wine that your company uses to target millennials?

None of our wines are specifically generated or made to target millennials. Some of the wines you could argue are more suited towards their desired likeness, but in all honesty, this isn't the case for us.

When it comes to labels, what are some specific aspects that you incorporate?

We shoot for a very classic looking traditional label juxtaposed with edgy names. Riesling AF for example (Figure 8).

AF = arrested ferment, a winemaking technique to make wine 'off-dry' (which means there's a bit of residual sugar or sweetness found on the palate), but it also means "As F***." It works on both levels, is cheeky, and plays to many different generations. One of the first people outside of Rosewood that I mentioned this new wine name to was a middle aged man who laughed, and said how his daughters would love the name because everything to them was "AF." He was familiar with the term because of his daughters.

FIGURE 8: "AF" wine label – an elegant, traditional, and classy label with a contrasting name, which would appeal to millennials (Roman, 2018).

How do you formulate your labels in order to allow consumers to personally relate to them?

We try to give a name or sense of identity to every wine - something that consumers (of all demographics) can relate or associate to, and something that is relevant to the wine itself. This shares a story of transparency and authenticity, which to us is very important. Night Moves Gamay (Figure 9) was named because we sorted through the grapes for two weeks straight throughout the night (24 hours of sorting for two weeks using two different crews rotating each twelve-hour period), hence Night Moves - because we made moves at night to make that wine.

I've also attached the Nebulous label here (Figure 10), because it was an instant hit at the farm - this is because of the style of production being a zero-add wine (meaning nothing was ever added into the wine). The label here was designed because of the beautiful pink cloudy and hazy colour - hence the pink cloud and name = "Nebulous." Again, it's about the name having a direct association to the wine to bring it full circle to tell a story.

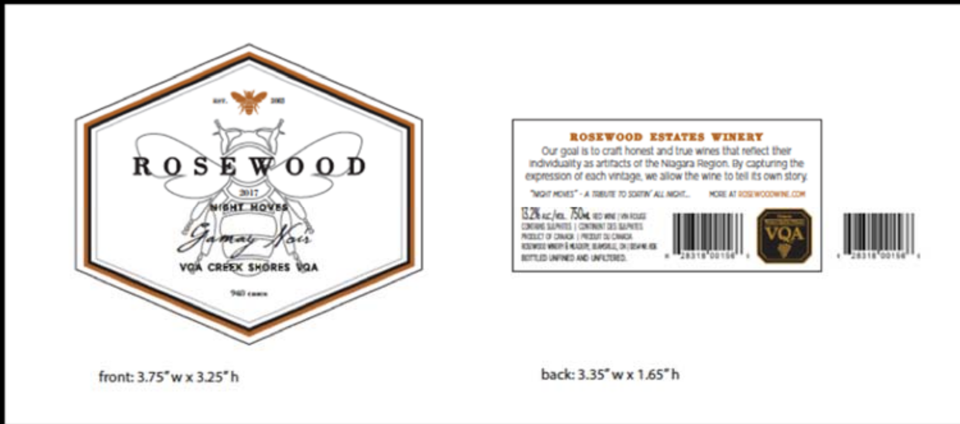


FIGURE 9: "Night Gamay" – a literal interpretation of the winemaking process that took place (Roman, 2018).

FIGURE 10: "Nebulous" – a name that aligns with the associated image – iconography (Roman, 2018).

When storytelling through wine labels, what sorts of emotions do you aim to evoke in your consumers?

The emotion we try to evoke is really about the name and wine style. Take Nebulous (Figure 10) and Lock, Stock & Barrel (LSB) in Figure 11 for example. Nebulous is light and bubbly (it's a natural sparkling wine known as a pet-nat), and has a label that communicates this with large white space and a modern feel. It is warm and whimsical; I think the suspended watercolour cloud does a good job of evoking these emotions and showing the consumer that this product is fun at $25 a bottle. LSB is a more serious wine – heavily aged in oak and heavily extracted. It is a big wine that packs a punch. It's big all around, and is richer and darker in nature. The label communicates this in my opinion. It's meant to be a serious wine.

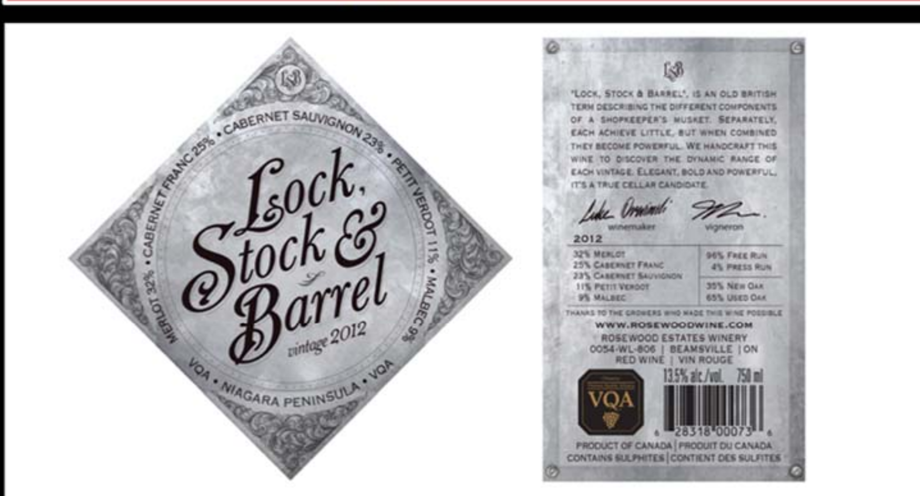


FIGURE 11: " Lock, Stock & Barrel" – a heavy silver coloured label with curved font (Roman, 2018).

Taste Descriptions

Taste descriptions in the wine industry allow consumers to qualitatively relate flavours from personal experiences to assess the overall quality of a particular wine. Numerous studies have indicated that taste descriptions are amongst the most valued component on the back label of wine bottles (Danner et al., 2017). However, a limited number of studies have been conducted to investigate the interplay of intrinsic consumer psychology and information presented on back labels.

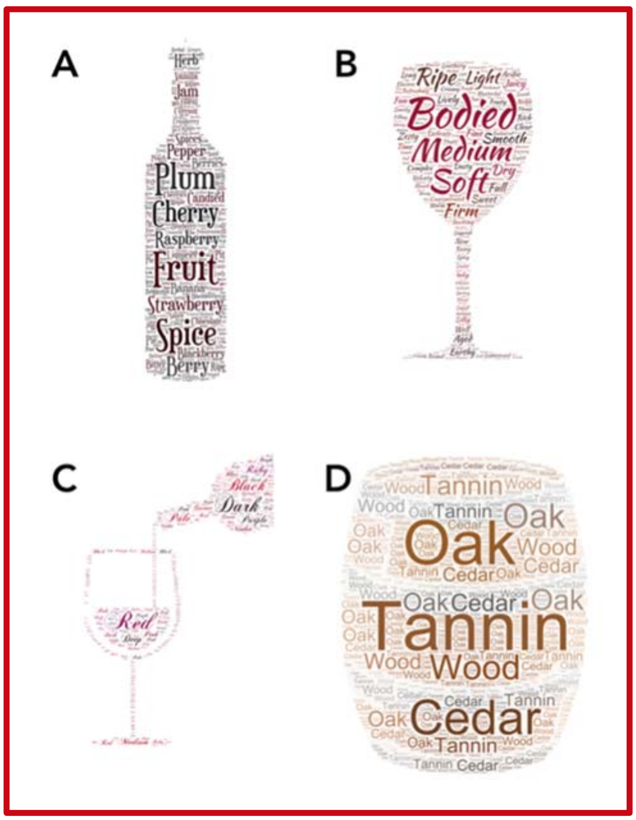


FIGURE 13: Word clouds highlighting terms used in taste descriptions that are A) source-based B) evaluative C) colour-based D) process-oriented. Size of terms indicates frequency. Images were created using 55 of the most common red wines from the LCBO priced between $5.00 - $20.00 (LCBO, 2018).

Taste descriptions include terminology, which can be divided into four categories. Source-based terms describe the origin of the flavours, while evaluative words dictate the quality or agreeability of the wine. Colour-based terms are also included alongside process-oriented terminology, which focuses on the barrels and techniques employed. Figure 13 displays the popularity of specific terms in taste descriptions.

A recent study of Australian white wines demonstrated that wine descriptions containing objective sensory information significantly increased preference for the wine bottle and willingness to pay for high priced wine by 21% and 37% (Danner et al., 2017). In other words, descriptive terms such as passionate, relaxed, envious, and warm-hearted trigger sensory receptors and are able to elicit more positive and intense emotions. Specifically, it was found that including vivid examples to describe sensory characteristics of the wines increased the participants' willingness to purchase the bottle by at least 1 point on the 9 point hedonic scale (Danner et al., 2017).

Source-based descriptors, such as the three found below, also contribute to this willingness, as they explain the contents of the bottle (LCBO, 2018). Figure 14 aims to include a blend of evaluative and source-based descriptors to create a label that caters to the senses.

"Medium ruby in colour; aromas of sweet black cherry, strawberry, and candied fruit; off-dry with the same flavours as detected on the nose."

~Bodacious Smooth Red

"Dark ruby in colour, the nose shows aromas of dark berry, toasted vanilla and oak spices. It is medium-bodied, fruity and toasty."

~Misterio Malbec

Big, bold and black fruit with delicious fleshy ripeness wrapped in toasty oak. Polished tannins. Black pepper with a hint of eucalyptus on the finish.

~ The Lackey Shiraz

A study conducted in 2013 found taste descriptions to be the most important component of the back label for millennials when choosing wine, rated at 4.81 on a 7 point Likert scale (Pagliarini, Laureati and Gaeta, 2013). These descriptions included phrases that evoke emotional responses such as "crispic acidic finish" or "passionfruit aromas" (Yuan et al., 2011). Sensory descriptions such as these are used by marketers, who must continuously think of innovative ways to appeal to a millennial's senses.

FIGURE 14: Creating a taste description that aligns with the design of the label, and appeals to the senses.

Winery History

The "story" or historical significance of the wine informs the consumer of the region it was made in, the tastes and flavours found in the wine, and how it was made. Millennial consumers subconsciously use this feature to evaluate the quality of the wine. In particular, a 2009 study conducted in Beijing found that university students are mostly influenced by the brand name and the origin of the wine (including history and winemaking process) when it comes to making purchases (Sun et al., 2009). This demonstrates that the back label itself does hold a fair amount of significance for millennial consumers, whether that may be the history or the country of origin of the wine.

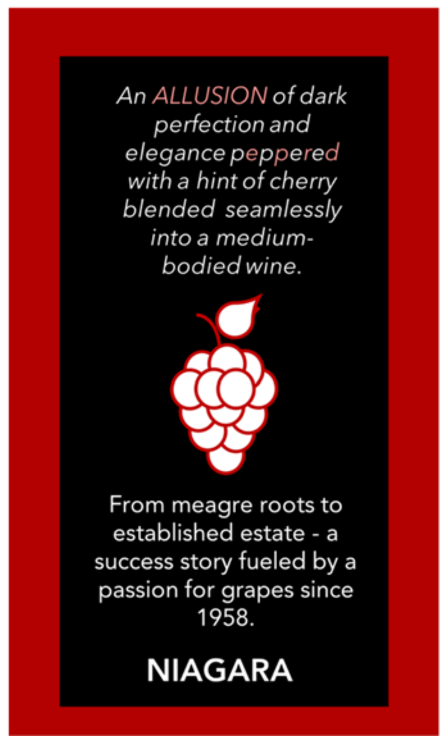


FIGURE 15: Although short, the winery history included here provides a date, and hints at a story of endurance, hardship, and support for an underdog.

The historical significance of the wine also evokes emotional responses, which affect attention span. As a result, long term memory retention increases, which improves the ability to retrieve information from the bottle at a later date (Tyng et al., 2017).

However, there are studies that show that the elderly pay more attention to region and origin to determine wine quality in comparison to millennials (Mueller et al., 2010a). There is no definite consensus on the standing of the historical significance or "story" of the wine on the back label, seen in Figure 15.

Suggestions by the Maker

For 331 average Australian wine consumers, ingredient information was the least significant component of a back label, while food-pairing suggestions by the winemaker were deemed the most important (Mueller et al., 2010a). For millennials who are just beginning to infiltrate the wine market, insecurity towards wine knowledge is common. These individuals are more prone to suggestibility, causing them to conform to an expert opinion and strive to follow a risk-perception strategy that minimizes "bad" purchases (Atkin and Thach, 2012).

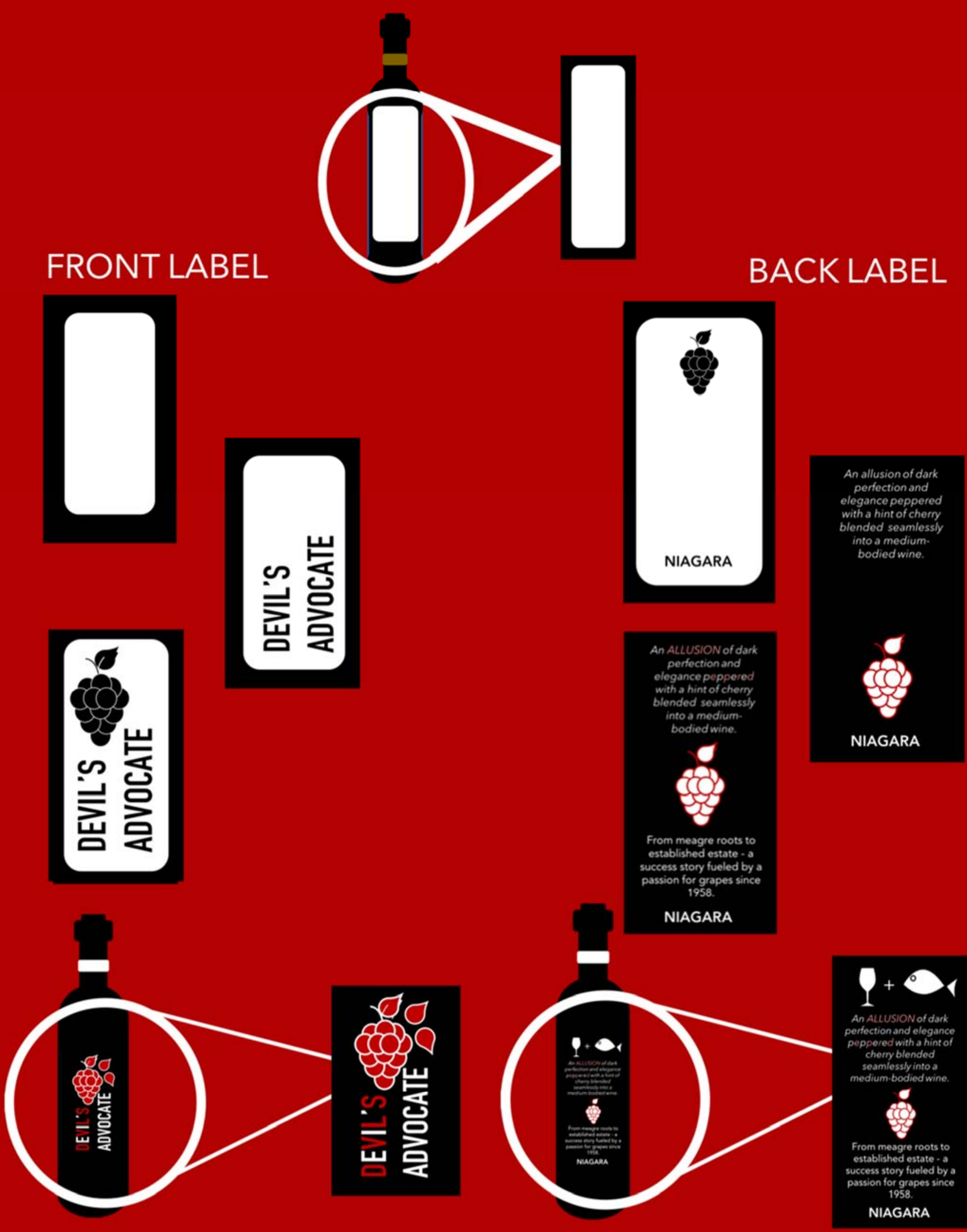
FIGURE 16: A pairing has been included suggesting that this wine works well with fish.

Food-pairing suggestions, displayed in Figure 16, form expectations for the consumer, which sways their evaluation of a given product (Michael, Garry and Kirsch, 2012). Behaviour changes to produce an expected outcome, as implied through the Response Expectancy Theory (Kirsch, 1985). By agreeing with expert opinion, individuals reduce personal agency and choice (Lush et al., 2017). Supporting a subconscious reduction in personal choice, studies show that millennials devote attention to awards – also a form of expertise.

SUMMARY

With each element, we have grown closer to constructing a complete label. Although our hypothetical label does not include all plausible components of a label, it considers those that are believed to influence millennials. Studies and current research serve as limiting factors to understanding the psychological and neurological ties aligned with marketing to millennials in the wine industry. Using the knowledge available, the figure below displays completed front and back labels for a bottle of "Devil's Advocate." A perfect concoction for today's millennial.

PIECING THE LABEL TOGETHER



MORE TO EXPLORE

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