2019

Bachelor Project

Factors effecting the production of sparkling wine in Denmark

Faktorer som påvirker produktionen af mousserende vin i Danmark

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ABSTRACT

The project's purpose statement focusses on the production of Danish sparkling wine and all the factors which are affecting the production. To shed light upon the topic, this project will describe how Danish grown grapes for sparkling wine can achieve a satisfying balance of its constituents, and how climate change will affect the suitability for winegrowing in Denmark.

The project is based partly on literature studies and partly on empirical data from wineries' harvest reports. The project starts with a brief description of all processes which are involved in the production of sparkling wine. Next up follows two analytical sections which focus on the varietal effect and the climatic effect. Topics such as Danish wine's competitiveness as well as the effect of limestone in the underground have been delimitated.

It's important to choose a variety that can ripen enough to reach a satisfying balance between sugar and acid. The variety needs to be mature enough to drop of its green and grassy aromas. However, the grapes need to be harvested before they develop too many varietal aromas, which potentially could mask the "champagne bouquet". Hybrid varieties could possibly fulfil these abilities but tend to develop too high an amount of volatile compounds in the fermenting. The variety, together with yeast strain and fermenting temperature control the development of volatile compounds. Regarding the development of volatile compounds, it's very important to consider the yeast strain and fermenting temperature, if hybrids should be used for sparkling wine.

The climate change seems to affect the suitability for winegrowing in Denmark positively. Several scientific reports suggest that the area for winegrowing in Europe will extend northward and eventually it will include Denmark. According to one of the newest reports, parts of Denmark could potentially grow *V. vinifera* within the period 2046–2070. Until that period, Danish producers of sparkling wine will probably be using hybrid varieties as their main crop.

PREFACE

This project is part of the final exam on the third and last semester on the PBA in Nature and environment on business academy Arhus. The project is written within the main topic "Microbiology". I strongly suggest that you pour yourself a glass of wine before reading this assignment, as it can become a bit "long-haired" at some points.

I want to thank Henry of Pelham for providing me their harvest reports from 2013 - 2019, and for giving me the opportunity to do my internship there. Likewise, I want to thank Foreningen Dansk vin, for the access to their harvest data.

This project is written in Canada, meaning that all supervision has been done via Mail correspondence. Because I want to study Oenology and Viticulture in Canada next year, this project is written in English to train my English skills

Supervised by

Jens Brøgger (JENB)

11/12 2019

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GLOSSARY

Because the topic of this project is a bit untraditional, I've chosen to write a list of technical wine terms, with an explanation to each of them. This page also includes the list of abbreviations used in this project.

Palate: Refers to the ability to recognize, taste and discover different characteristics in wine.

Lees: Dead yeast particles accumulates after fermentation as sediment.

Brix: Density scale for sucrose dissolved in grape juice. The Brix number is always shown in %.

Racking: Is the process where wine is removed from the lees. This can either happen through a valve placed over the lees sediment, or by sucking the wine from the top of the tank through a hose.

Inoculation: Refers to the step where yeast is added to the grape juice or to a base wine.

Bidule: A small plastic cylinder where the lees will accumulate when riddled.

Autolysate: Refers to the mixture of degraded cellular components.

Sur lie: France term for when wine is aged on the lees.

Terroir: Describe a particular region's climate, soils and the traditional winemaking practices.

Abbreviations

MLF: Malolactic fermentation

TA: Total acid

VA: volatile acid

FF: First fermentation

SF: Secondary fermentation

WI: Winkler index

HI: Huglin index

HyI: Hydrothermal index

DI: Dryness index

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Introduction

During the last 10 - 15 years winemaking in Denmark has developed from nearly nothing up to the around 100 commercial wineries that exist on Danish soil today. The journey for Danish winemaking has come to a point where it needs to identify itself with a more specific style of wine. Until now, everything from simple dry white wine to brandy and fortified wine have been tried out, to see what style our Danish grown grapes are best suited for. Due to the relatively cool climate, the varieties grown in Denmark are mostly hybrids and interspecific varieties (Olsen et al., 2011). But newly published scientific reports point towards a poleward expansion of European areas suitable for growing *V. vinifera* varieties, an expansion that might well include parts of Denmark (Dunn et al., 2019; Fraga et al., 2013; Irimia et al., 2018).

In 2000, the EU granted Denmark the status as an official wine country, which gave the Danish wine producers the opportunity to sell their wines on the national and international market. After the first 19 vintages as a real wine country, the Danish wine produces have begun to establish a reputation, especially within the category of sparkling wine. Multiple producers of Danish sparkling wine have sporadic proven that the quality can match some of the "high end" producers in champagne (Smith, 2017) (Liu et al., 2015).

The decisive factor which determinate the possibility of making the highest quality of sparkling wine is: The accessibility to grapes which hold just the right amount and balance of its constituents. The varieties must be ageworthy with a crisp and fresh acidity profile, often mineral-driven and a great ability to integrate yeasty characteristics like bread and creaminess. The varieties *Pinot Noir* and *Chardonnay* both contribute to the above-mentioned abilities and is therefore the most used variety for sparkling wine worldwide (Marian W. Baldy, 2009) (Jeandet & et al., 2011). The continuously warmer climate in Denmark is opening up for new agricultural opportunities which leads to this project's purpose statement:

How can grapes grown in Danish climate achieve satisfying balance of the constituents, which will later form the basis for the microbiological processes in high quality sparkling wine's fermenting stages?

- Which constituents are decisive when harvesting grapes for sparkling wine?
- Can high quality sparkling wine be made from *hybrids* instead of only *V. vinifera* grapes?
- What role will climate change play in the production of sparkling wine in Denmark?

This project's topics will be limited to the following factors: Comparison between the classical and hybrid grape's constituents, the climate change effect and the regional conditions for viticulture in Denmark. The high labor cost and the lack of the European Union subsidies result in an average price between 200kr and 300kr for a bottle of Danish produced wine (Alderman, 2019). The price issue and whether it's possible to compete on the existing global wine-market is delimitated together with the importance of limestone in the soil. Both topics are delimitated because they are missing the relevance in contrast to the project's main topic "microbiology".

The target group for this project will be new or established Danish wine growers who wish to produce sparkling wine (optionally with *V.vinifera* varieties) and/or widen their knowledge within the importance of the grapes constituents.

Paradigm and Methodology

Paradigm

A paradigm helps to determine, which methodological point of view a project should be based on. Therefore, it's important to define, which paradigm the project acknowledges to. The paradigm is chosen based on the investigator's basic assumptions and should guide the reader through the project.

This project uses the natural science's basic assumptions, which is based on experiments, measurements, observations, etc. Therefore, the ontological level of the report will be materialistic, which states that reality exists independent of our recognition of it. Because of that basis, the epistemological level aims to be objective.

The first section of the project, which deals with the various elements of making sparkling wine, follows, like the rest of this project, the natural science's basic assumption and an ontological materialistic level. The epistemological level in this section is mainly objective as the purpose of the section is primarily to determine the elements within the topic of sparkling wine, which in this project is considered to be an objective process.

The project's second and third section is based on measurements and the theory behind it which also attests to the natural science's basic assumption and thus an objective epistemological part.

Methodology

The methodological choices for this project consist partly of literature studies and partly of empirical data from wineries' harvest reports. This project will thereby predominantly be consisting of quantitative methods in the form of measurements, literature on scientific experiments as well as textbook theories. Thus, field-research and desk-research is used in this report.

To answer the purpose statement, this project is split into three sections, one introduction section and two analyzing sections. So, before the actual analysis begin, the report will focus on production of sparkling wine and the main microbiological processes that's involved in its creation. The aim of this first section is to discover where in the process the decisive factors occur. Based on that research, the requirements and the influence of the right climate and grape varieties can be analyzed. The description in the first section will give the reader a better understanding of the importance of the grape's constituents.

The second section focuses on the differences between the classic grape varieties for sparkling wine and the hybrid grapes, which are used in Denmark. This section's aim is to compare important factors between the two grape types, and thereby determinate the possibility of making high-quality sparkling wine only from hybrid varieties.

Third and last section focuses on the climate change and which consequences / opportunities they can result in. Based on scientific projection, this section will concentrate on which grape varieties that potentially could become possible to cultivate during the upcoming climate changes. Furthermore, this section will also describe regional climatic differences within Denmark's typography.

1 THE PROCESS OF MAKING SPARKLING WINE

1.1 INTRODUCTION TO SPARKLING WINE

Sparkling wine as we know it today has its origin back to the French Benedictine monks in the late 17th century, where the monk Dom Pierre Pe´rignon worked as a winemaker. Today the techniques and all the microbiological processes in sparkling wine are much better understood, and the development of different kinds of sparkling wine have been made (Pozo-Bayón et al., 2009). Like all other wines, sparkling wine is the product of fermentation, the difference from all the other wines is the amount of fermentation the wine goes through. Traditional sparkling wine needs to ferment two times before the wine is complete. The first fermentation is like the fermentation that happens in all other wines, where yeasts produce ethanol and the CO_2 which is released directly into the air through a vessel. Second fermentation is performed in an airtight container where the CO_2 from the fermentation is trapped. The result of this is a slowly carbonating of the wine, and the bubbles of sparkling wine are created (Garofalo et al., 2016; Martini et al., 1996).

Today sparkling wines are made with two different methods, the traditional method, also called the Champagne method, and the Charmat method. The traditional method is the way wines as Champagne and Cava are produced, while wines such as Prosecco and Spumante are made by the Charmat method (Pozo-Bayón et al., 2009). The big difference between the two methods is where they undergo their secondary fermentation. The traditional method always performes the secondary fermentation in the bottle, while the secondary fermentation in the Charmat method is performed in an airtight tank. The traditional method is definitely the most expensive way to make sparkling wine, but it gives the wine more complexity because it allows the wine to age on lees for years, and it makes finer bubbles that gives a more gentle mouthfeel (Garofalo et al., 2016) (Marian W. Baldy, 2009). In the next sections the traditional method will be used as an example.

1.2 THE VARIETIES

The traditional method or "*methode champenoise"* has its origin (as the name suggests) in the Champagne region in France. The method is therefore evolved to handle the most popular grape, which at that time was *Pinot Noir*. *Pinot Noir* was favored because of its reliability to ripen evenly from year to year despite the cool growing conditions. Even though the grape's skin is dark, the juice in the pulp is colorless. This means that with the right techniques, white sparkling wine can be made of *Pinot Noir,* these wines are called "Blanc de Noirs". If a sparkling wine is made only with green grape varieties (often only *Chardonnay)*, the wine is called "Blanc de Blanc" (Marian W. Baldy, 2009) (Jeandet & et al., 2011).

1.2.1 **V. vinifera**

Today the preferred grape varieties for sparkling wine worldwide are *Chardonnay* and *Pinot Noir*. These two varieties are often accompanied by a third, depending on where in the world the wines are made. In champagne the third variety will be *Pinot Meunier*, while the third variety in California will be *Pinot Blanc* (Marian W. Baldy, 2009). Each variety have their own special characteristics, which all contribute to the complex odor and flavor profile of a sparkling wine. *Chardonnay* gives acidity, elegance and aging potential, while Pinot Noir provides depth and body to the wine (Jackson R. S., 2008).

Pinot noir

Probably one of the world's most famous grape varieties, and the building block of Burgundy's treasury reds. The grape is very environmentally sensitive and appears to mutate easily. These mutations have given birth to e.g. *Pinot blanc, Pinot gris* and *Pinot Meunier*. The mutations can also be visible in the yield, where the lower-yielding clones seems to produce more flavorful wines. The more high-yielding clones are suited for sparkling wines or rosé. When *Pinot noir* is used in sparkling wine, it tends to generate a stable foamability in the wine. It is mostly sensitive to bunch rot, if the clusters become too compact (Jackson R. S., 2008).

Chardonnay

Chardonnay is the most widely grown white grape variety in France. It is vinified in countless styles all over the world, because of its pleasing fruit fragrance and its characteristic in the world's best sparkling wine. When grown in optimal conditions, the wine develops notes of various fruits, including melon, peach and apple. The vine itself and the berries are disposed to bunch rot and powdery mildew. Because of its good abilities to age, *Chardonnay* is often very important in vintage blends (Jackson R. S., 2008).

Hybrids

Even though *Chardonnay* and *Pinot Noir* is referred to as the king and queen varieties for traditional sparkling wine, other varieties have proven to possess good abilities as well. In regions even colder than the Champagne district where the *V. vinifera* varieties can't be cultivated, several new hybrids and interspecific grape varieties are used for sparkling wine (Marian W. Baldy, 2009).

Hybrid varieties are a crossing between two species e.g. *V. vinifera x V. labrusca*. The development of these new hybrid grape varieties started in France in the 1920s. During the last decades, varieties such as *Regent, Orion* and *Phoenix* have been bred by the European PIWI program. These grape varieties have high resistance to fungus attacks. The search for new resistant grape varieties has also continued in North America, where mainly Ontario, Minnesota and New York have been the frontrunners. With special interest in grapes for sparkling wine, *Cayuga White* from the breeding program in New York is probably the most promising (Jackson R. S., 2008).

1.2.2 **The Varietal effect**

In contrast to the following sections, where the varietal influence will be decremented, this section will roughly shed light upon the effect. According to (Caliari et al., 2014) grape varieties can have a solid effect on the production of sparkling wines. In a study (Caliari et al., 2014) made several single varieties sparkling wines with both *V. vinifera* varieties (*Chardonnay, Pinot Gris* and *Pinot Noir)* and five different hybrids varieties. Three out of the five hybrids had noteworthy higher volatile compounds than the classical grape varieties. The two last hybrids showed more similarity to the classical grape varieties but did still have a higher concentration of esters. The results indicate, that sparkling wine made from hybrids can provide differentiated characteristics mostly due to the volatile composition (Caliari et al., 2014).

1.3 HARVESTING

Harvesting of grapes for sparkling wine is a very delicate step in creation of the wine. The harvest is usually done by hand-picking into small boxes to avoid grape breakage. Only the healthy grapes are picked and is quickly transported to the press to prevent skin maceration and spontaneous fermentation in the boxes (Garofalo et al., 2016) (Jeandet & et al., 2011).

It is no coincidence that the Champagne region is the world's second northernmost significant grape district, only passed by the Mossel district in Germany. In these cool conditions the grapes ripen very slowly which results in relatively high proportion of total acid and malic acid, while the pH, sugar content and varietal character are lower than normal. If normal still-wine were made from such grapes, the wine would be low in alcohol, very tart and lack most form of fruity character. Yet, these grapes still hold the ideal composition for Champagne, because sparkling wines need tartness to balance the very sweet dosage, and the low alcohol level will be raised in the secondary fermentation. The lack of varietal aromas and flavors is useful as well, because they could potentially mask the wines most important aromas, which are the ones that comes from long aging on the lees after the secondary fermentation (Marian W. Baldy, 2009).

Even though grapes for sparkling wine often are grown in cool climate regions, the grapes are always harvested early, when the right balance between TA (Total acid) and brix have been achieved (See Table 1). The cool climate allows the grapes to mature and drop of the green and grassy character before the acidity level gets too low. In warmer regions the grapes will be too immature when the right balance between TA and Brix exist inside the grapes. Meaning that, as long as the grapes reach satisfying level of brix and acid, colder weather will only increase the chance of reaching maturity (Marian W. Baldy, 2009) (Jackson R. S., 2008).

Table 1 Average grape composition (Marian W. Baldy, 2009)

	Chardonnay	*Pinot Noir*
TA (Total Acid) g/L	8,5 - 15,0	9,0 - 17,0
Brix %	17,8 - 21,4	17,0 - 20,0
pH	2,85 - 3,3	2,9 - 3,3

1.3.1 **Pressing**

After harvest, the next step in the process of sparkling wine is the pressing, which also plays a crucial part in ensuring of the quality. The grapes are usually pressed without any crushing to avoid macerations, oxidations and the development of flat aromas. The pressing for sparkling wine is normally split into different fractions, which gradually increase the pressure in the press (Scott Laboratoties, 2018)(Garofalo et al., 2016). The fractions are traditionally split up as followed:

- *Cuvée*: The first gentle pressing. It is high in acidity and sugar content, with little potential for oxidation.
- *Taille*: Second pressing with higher pressure. It is lower in acidity and contains more minerals and higher pH.
- *Rebêche*/Hard Pressing: this is the final pressing. Runs with high pressure which result in more tannins and phenolics.

(Scott Laboratoties, 2018) (Jeandet & et al., 2011)

Approximately 80 % of pressed juice is *Cuvée,* the last 20 % is *Taille* and *Rebêche*. At the end, it is only the *cuvée* that will be used for sparkling wine. *Taille* and *Rebêche* is often used for distillation or vinified apart from the cuvée and may be used for blending (Jeandet & et al., 2011).

1.3.2 **Additions**

Right after the juice have been extracted, SO_2 is added as it's transferred to a refrigerated stainless-steel tank for chilling. Typically, the amount of SO_2 range from 30 - 80 mg/l, depending on quality of the fruit and the pressing fraction. Bentonite clay is often added to the juice as a clarifying agent (Jeandet & et al., 2011). Whenever Calcium- or Sodium Bentonite minerals are dissolved in water, their ions become negatively charged. In contrast, the particles that float around in the wine, and causing it to look cloudy are positively charged. Particles with same electric charge will cause them to repel each other and therefore keep floating around in the juice (Ferreira et al., 2001).

Because the bentonite ions are negatively charged, they will bond with a positively charged cation and causing both particles to sink down to the bottom of the tank forming a layer of sediment. The juice can later be racked out, leaving most of the sediment in the tank. The juice will then appear much clearer (Ferreira et al., 2001).

Bentonite is one the only clarifying agents which can be added to the juice pre-fermentation. The negatively charged bentonite ions will eventually settle on the bottom unable to bond with the positively charged cation in the top of the tank. But as the juice starts fermenting, CO_2 bubbles will form, bringing the negatively bentonite ions to the surface. On the way, bentonite collects positively charged particles and cause them to fall back down to the bottom (Wine Makers Academy, 2013). Before the yeast is added, the juice will be chilled down to approximately 10 ºC and left to cold settle for 24 - 28 hours (Marian W. Baldy, 2009).

1.4 FIRST FERMENTATION

One thing to consider before harvest begins, is which yeast to use. Saccharomyces cerevisiae is the standard yeast species for wine making, and the most common used for the base wine of sparkling wine. The S. cerevisiae have a countless number of different strains, all of them with different character and ability (Jeandet & et al., 2011). Strains like, DV 10, IOC and Levuline CHP are popular for champagne wine. These yeast strains are selected based on their resistance to SO_2, high enzymatic activities, tolerance to high alcohol levels, low production of H_2S and their ability to kill other yeast strains. Non-Saccharomyces/ indigenous yeast species have previously been considered as spoilage yeasts, because they can develop some very distinct flavors and off-flavors in the wine. However, winemakers around the world have begun to use specific strains as response to consumers demands. Non-Saccharomyces yeast have lower alcohol tolerance, whish mean that S. cerevisiae always will be the yeast ending the fermentation (Garofalo et al., 2016).

1.4.1 **Starter Culture**

When the juice is clarified, the alcoholic fermentation can be started. First step is to acclimatize the yeast, so that it can survive the high sugar contents and low pH in the hostile environment that the juice represents(Garofalo et al., 2016). The yeast is first rehydrated in water (37 °C) often mixed with yeast nutrients. After approximately 15 minutes acclimatizing, the hydrated yeast will be introduced to a small amount of juice. Doing the next couple of hours, the yeast culture will gradually be introduced to more and more juice. when the yeast culture is within 5 °C of the tank temperature, the culture can be added (Henry of Pelham, 2014).

As soon as the yeast culture is added to the juice the fermentation will start. Fermentation usually occurs in relatively warm temperatures, at 15–18 ºC. A lower fermentation temperature will give the wine a grassier odor, where the high fermenting temperature will lead to a lack of varietal character, because warmer fermentation allows the volatile aroma components to escape. The fermentation is completed within 7-10 days, and the wine is then racked out and filtered to avoid any off flavors that could come from yeast or other solids. Next step is to cold stabilize the wine to avoid the precipitation of potassium bitartrate (also known as wine crystals or wine diamonds) in the final wine (Marian W. Baldy, 2009).

1.4.2 Cold stabilization

During fermentation, tartrate compounds bind with different compounds in the lees, precipitated tannins and pigments (Hubble, 2017). The concentration of potassium bitartrate in the juice is almost saturation, and because potassium bitartrate is more soluble in water than in alcohol the wine becomes supersaturated, which inevitable will lead to precipitation. Furthermore, the solubility of potassium bitartrate is reduced a lot at lower temperatures. Therefore, the most common method to tartrate stabilize a wine, is by chilling it to such a low temperature (-5 °C) that it allows as many potassium bitartrate compounds to precipitate as possible. The reduction of potassium bitartrate in the wine will secure that the wine reach stability ones the temperature rises again. Secondly, the wines acidity level will be lower and pH higher (Margalit, 2012) (Butzke, 2010). The right temperature can be calculated with following formula:

$$\text{Cold stabilization temperature } (-°C) = \frac{\%\, Alcohol}{2}$$

1.4.3 Malolactic fermentation

If desired, Malolactic fermentation (MLF) can take place after the first fermentation or simultaneously (co-fermentation). It's important that the MLF is completed before the wine starts its secondary fermentation. The use of MLF is common practice in champagne and other cool climate regions, as it causes the pH level to rise and has a reductive effect on the time required for maturation. The lower acidity level also improves the wine's biological stability, and modifies its sensorial qualities (Garofalo et al., 2016). Producers who want their wine to undergo MLF, inoculate their wine with a particular strain of *Oenococcus oeni* to ensure a rapid onset. If other species of lactic acid bacteria start the MLF it can result in off-flavors in the wine (Jackson R. S., 2008).

O oeni is a lactic acid bacterium, with the ability to the decarboxylate malic acid into lactic acid (MLF). The transformation from malic acid into lactic acid is happening in the cell's cytosol, where the malolactic enzyme "malate decarboxylase" reduces NAD+ to NADH and thereby releases energy to the transformation. The malolactic enzyme removes a carboxyl group from the malic acid compound and bind a H+ ion which then form a lactic acid compound. The lactic acid diffuses from the cell, and the result is a fall in concentration of H+ ions in the cell, which lead to an electrochemical gradient (Cañón et al., 2017). Because the concentration of H+ is bigger outside the cell, it's possible for the ATPase to convert ADP to ATP by enclose new H+ into the cell (See

Figure 1). The result of this ATP synthase is of course a drop in concentrate of H+ ions in the wine, which leads to an increase of the wine's pH (Bartowsky, 2005) (Fugelsang & Edwards, 2007).

When using *O oeni* for MLF the winemaker should be aware of factors that could limit the process. Low pH values, high concentrations of SO2 or other inhibitors, lack of nutrients and high ethanol levels are factors to consider when using MLF (Mira de Orduña, 2010). The process proceeds best at 18 °C or higher (Jackson R. S., 2008).

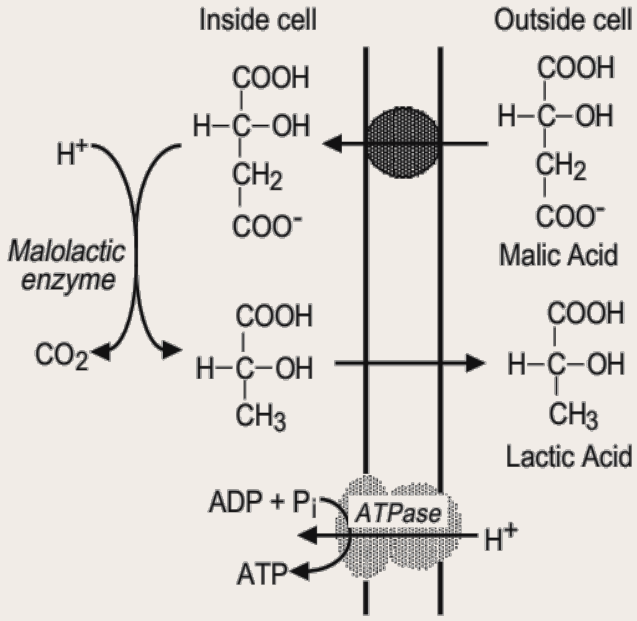


Figure 1: Decarboxylation of malic acid into lactic acid though ATP Energy generation by Oenococcus oeni (Fugelsang & Edwards, 2007)

1.4.4 **Base Wine**

The final base wine should typically have light pale color and a low aromatic character. It usually holds a moderate alcohol concentration (10 – 11%), low levels of volatile acidity and residual sugar and a TA between 12–18 g/L. At this point the base wines are not balanced and will be unpleasant to drink, but they will be balanced after the Secondary fermentation (Garofalo et al., 2016; Torresi et al., 2011).

1.4.5 **Blending the Cuvée**

After stabilization and maturation, the base wines are ready for the cuvée blending. The second use of the term "Cuvée" refers to the blending of different base wines (Jackson R. S., 2008). The Cuvée is made from base wines which can differ in grape varieties, vineyard origin, press cut and harvest date. To minimize variation from year to year, the cuvée can also be blended with reserve wine from earlier vintages. The result of a blend from different vintages ensure stable quality and characteristics and is categorized as a non-vintage (NV) sparkling wine (Marian W. Baldy, 2009). The reserve wines are often kept for two to three years at 12 - 13 °C in an airtight tank protected from oxygen. Reserve wines can somewhere be kept for longer time (e.g. ten years) (Jeandet & et al., 2011).

Mixing the cuvée is based solely on sensory evaluation and is repeated until satisfaction. The winemaker who makes the blends needs to envision how the wine will be after the secondary fermentation plus two to four years of aging on lees. Experience matters a lot in this step and the process of blending can take from five to seven weeks (Marian W. Baldy, 2009). When mixing wines from different vintages a disruption in the tartrate equilibrium may occur. So, the NV cuvée will often need to be cold-stabilized ones again and filtered afterwards (Jackson R. S., 2008).

1.5 SECONDARY FERMENTATION

1.5.1 Yeast

The strain for the starter culture to the secondary fermentation (SF) needs several additional abilities compared to the yeast used in the first fermentation (See Figure 2). The Cuvée and later the final wine represents an even more hostile environment for yeast growth than the previous fermentation. The conditions in the Cuvée is usually characterized by high concentration of acidity, ethanol and SO_2. Furthermore, the yeast strain should be able to survive critical factors such as low temperatures and a growing amount of CO_2/pressure up to 6 atm (Garofalo et al., 2016).

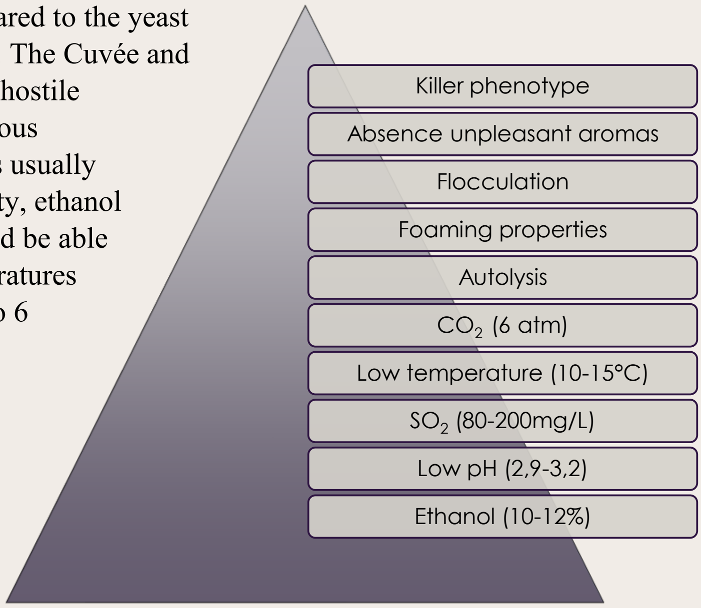


Figure 2: Yeast abilities required for the secondary fermentation (Garofalo et al., 2016).

Beside all the harsh factors the yeast must deal with, it also needs the abilities to undergo autolysis. A yeast strain with high autolytic capacity has proven to increase the quality and have positive influence on the organoleptic and foaming properties of sparkling wine. A further biological character of interest is the yeast's flocculation capacity. The yeast's abilities to flocculate is an important criterion, because high flocculation skills enable the removal of sediment in the final wine. Before the yeast can be added to the Cuvée, it should be acclimatized in a starter culture similar to the one for the base wine. This step is also known as "prise de mousse", and it's essential for the fermentation to proceed successfully (Garofalo et al., 2016).

1.5.2 Tirage

The "prise de mousse" will then be a part of the "Triage", which is a concentrated solution of 50-65% sucrose, yeast nutrients, adjuvant (usually bentonite, to help removal of yeast cells) and the "prise de mousse". When the Cuvée is filled into a bottle a small amount of the tirage is added simultaneously. The amount should be dosed very carefully, and each bottle should receive what's equivalent to 18g sucrose. If the Cuvée contains residual fermentable sugar, the amount must be subtracted (Jackson R. S., 2008). After the Cuvée and triage is bottled a small bidule is inserted into the bottle's neck followed by a crown cap. The bidule helps prevent leakage, contact with metal cap and works as conveyed when the lees needs to be removed (Torresi et al., 2011).

During the SF the 18g of sucrose will be converted to ethanol and CO_2. The wine's alcohol content will generally rise 1 % and the pressure inside the bottle will increase up to 6 atm, because of the trapped CO_2 (See Figure 3). The Bottles are then stacked horizontally in a special aging room at low temperature (12–15 °C). The horizontally position will increase the efficient contact surface between wine and yeast (Jackson R. S., 2008) (Garofalo et al., 2016).

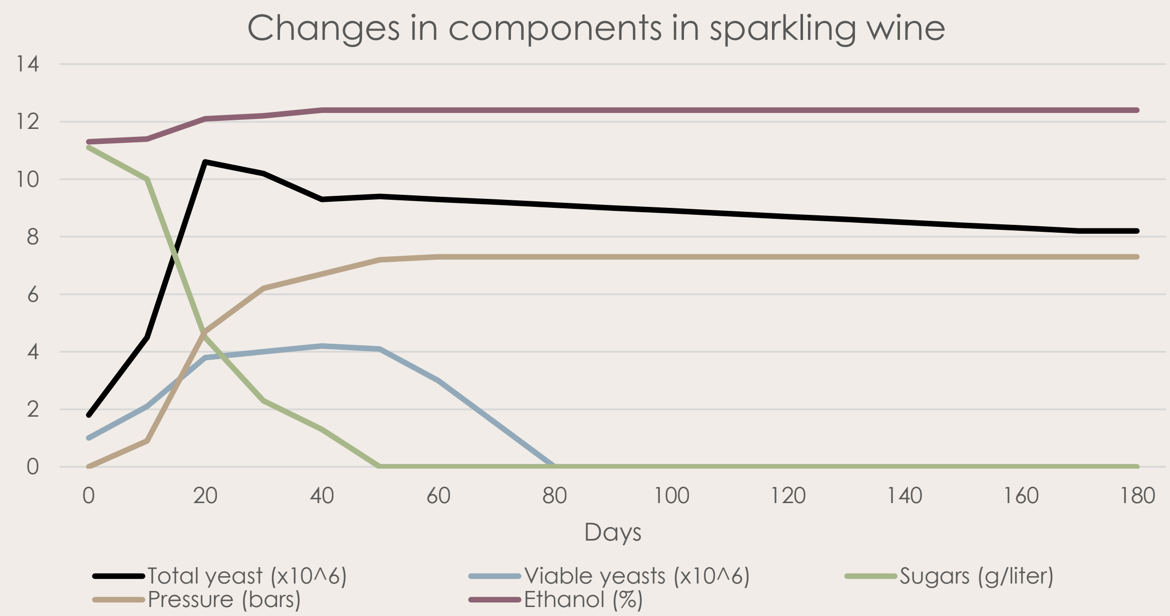


Figure 3: Changes inside the bottle during sparkling wine secondary fermentation (Jackson R. S., 2008)

1.5.3 **Aging**

Although many biochemical factors are involved in composition of sparkling wines, it undoubtedly seems like the SF and the aging of the wines on lees are the key factors in sparkling wine's quality (Pozo-Bayón et al., 2009). During the SF the wine is stabilized, CO2 is formed and the ageing with the yeasts begins (sur lie). The length of the SF depends mainly on temperature and yeast strain. If the wine is fermented at 12–15 °C it will occur in no less than 0.5–1.5 month. At the end of SF, the prolonged ageing where the wine is in contact with lees begins (Torresi et al., 2011). During this period, the wine starts maturing and undergoes autolysis which consequently will enrich the wine by the components of the autolysate. It should be noted that the quality and quantity of the yeast autolysate is influenced by many factors such as: temperature, ethanol content, pH, population and the duration of yeast contact (Dharmadhikari, 1995).

1.5.4 **Autolyse**

The term autolysis literally means 'self-destruction' and was used for the first time in 1875 by Salkowsky. The term can be defined as the hydrolysis of biopolymers done by hydrolytic enzymes that rupture a yeast cell's cytoplasm and cell wall releasing all the intracellular compounds into the wine. The autolysis process begins very slowly when sucrose and other nutrients in the wine are consumed. Without anything to feed on, the yeast cells start using their own internal energy reserves, and eventually the cells will get exhausted and begin degeneration, which will start the autolysis process (See Figure 4) (Torresi et al., 2011). The autolysis process can be divided into two parts:

1. Degradation and solubilization of the cell's organelles, which mainly includes proteinaceous substances. This phase is also knowns as proteolysis.
2. Degradation of the cell wall, which is the structure responsible for yeast cell's shape.

(Dharmadhikari, 1995)

Proteolysis - Yeast cells contains a lot of protein degrading enzymes, which normally are located in a vacuole. But upon cell death, the structure inside the cell become disorganized and the enzymes meet their surroundings. The proteolytic enzymes can now hydrolyze peptide bonds and create protein breakdown products such as amino acids and peptides (Dharmadhikari, 1995).

Degradation of cell wall - the cell wall envelops the cells protoplast and maintain the cell's specific shape. The cell wall constitutes to 15 to 20% of the cell's weight and the wall itself consists of 80 to 90% polysaccharides plus a small amount of proteins and lipids. Glucans and mannans are the two main polysaccharides in the cell wall. Glucan helps to retain the cell's shape, while the mannans are linked to proteins (mannoproteins) and are important for the structural components of the cell wall. The enzymes protease and glucanase are responsible for the degradation of the cell wall constituents and cause it to become porous. Eventually the cell wall collapses, and a mixture of peptides, amino acids, fatty acids, glucans and mannoproteins is released into the wine (Dharmadhikari, 1995) (Vichi et al., 2010).

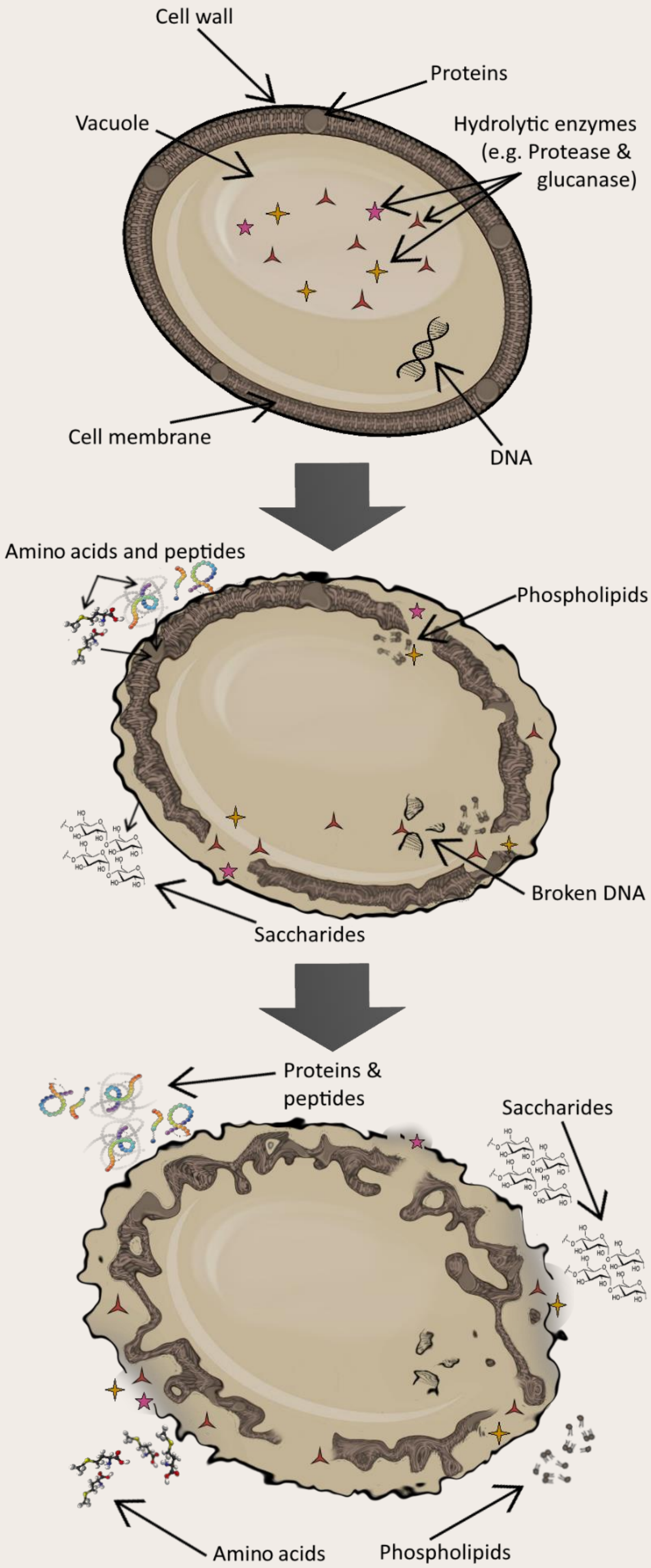


Figure 4 Morphological of a yeast cell during autolysis (Own creation) inspired by (Wang et al., 2018).

The autolysis is a slow process and can last anywhere from a few months up to several years, depending on factors such as nutrient availability, temperature and yeast strain. However, it is possible to speed up the process by adding exogenous beta-glucanases to the wine (Torresi et al., 2011). The key constituents that are released during autolysis includes polysaccharides, fatty acids, nitrogenous compounds, nucleic acid components, aroma compounds and various vitamins. All these components play an important role for the quality and aromas of sparkling wine.

Polysaccharides especially the mannoproteins are known to increase the fineness and persistence of bubbles in sparkling wine and improves the wine's stability against protein haze. The fatty acid compounds origin from lipids in the cell's plasma membrane and cell wall. During autolysis, the lipids degraded to fatty acids consisting of 8 to 16 carbon atoms. When these fatty acids are released, they can be involved in the creation of aldehydes, esters and other volatile compounds, which have a big influence on the wines flavor. Nitrogenous compounds such as proteins, peptides and amino acids have shown a positive correlation on the wine's "body sensation", they enhance the foam stability and can absorb volatile compounds retaining wine aromas. Moreover, amino acids precursors of aroma compounds. In conclusion, the compounds from the autolysate improve the wines sensory quality and increase its richness and roundness (Garofalo et al., 2016; Torresi et al., 2011; Vichi et al., 2010) (Dharmadhikari, 1995).

1.5.5 **Riddling**

Riddling, also known as *"remuage"* is the step where yeast lees flocculate and convey into the bottle's neck. Historically, this manual process was a very time consuming and expensive step in the production of sparkling wine. The process of manual riddling takes about 3-8 weeks, where the bottles are placed in A-shaped racks called a pupitres (See Figure 5). At first, the bottles are placed about 30º from a vertical angle. During the time of riddling, the bottles are gradually turned more upright to an angle about 10–15º from vertical. Each day, the bottles are hand-rotated one eighth of a total rotation. The riddling is complete when all the yeast lees is composed in the bottle's neck. The longer the yeast is in contact with the wine, the more homogenous and compact the sediment is (Jackson R. S., 2008) (Torresi et al., 2011).

Most places, manual riddling has been replaced by machines, because they can work continually, moving the bottles twice a day and thereby reduce the ridding time (See Figure 5). An automatic riddling machine can reduce the time of riddling to about 10 days and requires much less space. Hand riddling is still used in small wineries and in order to determine how a machine should be programed for a specific wine (Marian W. Baldy, 2009).

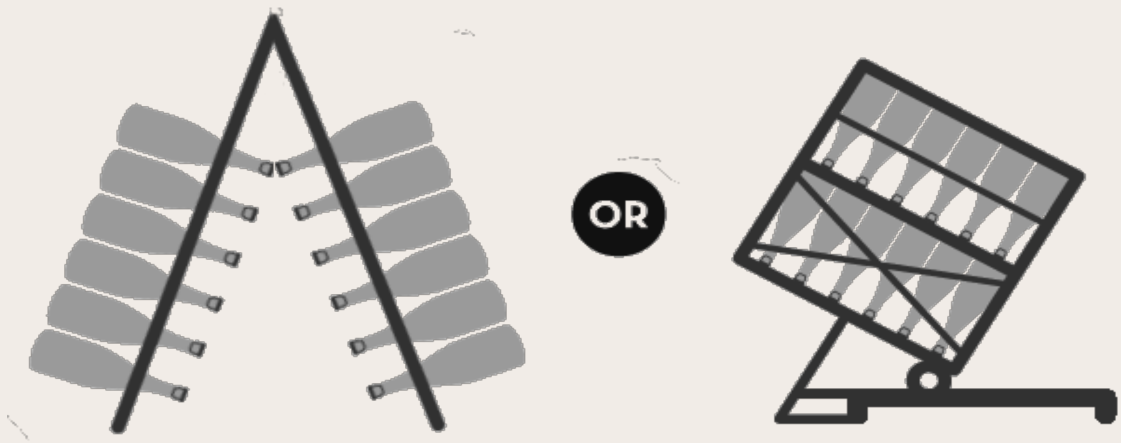


Figure 5: Illustrations of the two main riddling methods. Pupitre (traditional methods) to the left, automatic method to the right (Scott Laboratoties, 2018).

1.5.6 Dégorgement

Dégorgement is the final step of the elimination of the yeast lees from the bottle. When all the lees are collected on the bidule, the bottles are carefully placed upside down, and then the neck is submerged into a -20 °C liquid of $CaCl^2$ or glycol solution. The bottle's neck is kept in the liquid for approximately 15 minutes until the lees is captured in a solid icecap. The bottles are then placed neck-up, the crown cap is removed and the pressure within bottle eject the icecap, leaving the bottle with only pure wine (Torresi et al., 2011).

Common practice is then to add a dosage solution, also called *"liqueur d'expédition"*. The dosage can be a mixture of wine, sugar, brandy, SO2, citric acid or copper sulphate. The specific formula is depending on the winemaker's aspiration for the wine. The composition of the dosage solution has big influence on the wine's characteristics, structure and aroma profile. A few wines receive no dosage solution, these wines are often labeled *"brut nature"* (Garofalo et al., 2016) (Jeandet & et al., 2011). It is the amount of sugar, which determinate the sweetness level of the wine. The wine is categorizes as followed:

- Brut: 0–15 g/l
- extra-dry: 12–20 g/l
- sec: 17–35 g/l
- demi-sec: 33–50
- doux: >50 g/

  (Torresi et al., 2011)

During the Dégorgement process, the wines will lose approximately 0.5 to 0.8 bar of the CO2 pressure. Finally, the bottles are ready to receive a cork and a wire hood to keep the cork restrained. The bottles are now stored for further 1-9 months, giving the dosage some time to marry with the wine. This last aging period enrich the wine with additional complexity in the bouquet. After the last aging period, the wines are ready to be labelled and receive the characteristic foil cap. The labelling also marks the end of the wine's biological journey (Marian W. Baldy, 2009) (Jeandet & et al., 2011).

1.6 SUBSET

During all the processes of making sparkling wine, several steps along the way seems to have a special importance to the final product. These steps count: right balance in the grape's constitutions (Harvest time), pressing pressure, yeast strain and temperature for the FF, cold stabilization, malolactic fermentation, blending the cuvée, right yeast strain for SF, autolyse and dégorgement. None of these steps (except "right balance in the grape's constitutions") have something to do with the climate.

The biggest issue for making high quality sparkling wine in Denmark is thereby the climate. The process from grape to wine can be done almost anywhere. The issue comes down to whether it's possible to continuously harvest suitable grapes for sparkling wine in Denmark. The question can be broken further down into two sub-questions:

1. Currently only hybrid varieties can be continuously cultivated successfully in Denmark. However, research point toward big varietal differential when it comes to hybrids. Is it possible to make high quality sparkling wines of the hybrids which can be cultivated in Denmark? And which hybrid grape varieties are best suited?
2. Will it be, and approximately when will it be, possible to grow more classic varieties for sparkling wine in Denmark?

The next two sections in this project will try to answer the two questions above, together with the remaining questions in the purpose statement.

2 The varietal effect

To determine whether *V. vinifera* varieties (*Chardonnay* and *Pinot Noir)* are better choices for making sparkling wine than hybrids is very difficult. There is no doubt that the sparkling wines made from *Chardonnay* and *Pinot Noir* generally speaking are better, because the methods and yeast strain are evolved for these varieties (Garofalo et al., 2016).

To answer the first question about which hybrid varieties that can be used for sparkling wine, this report will present data about previous harvests in Denmark. The previous harvests will be compared to basic numbers for sparkling wine and numbers from a Canadian producer of high-quality sparkling wine. A rule of thumb says that the grapes are ready to be harvested when they hold about 17-18 brix and around 11g Ta g/l (Buhler, 2019) (Silverthorne, 2019).

2.1 Sugar / Acid balance

Most Danish winegrowers are members of the Danish winegrower association. Every year the association produce a harvest report made from all the member's harvests. Unfortunately, the harvest reports from Danish winegrower association do not tell which wine the harvested grapes are intended for. However, the reports are still very useful. As previously mentioned, grapes for sparkling wine will always be the first grapes to be harvested. This means, that none of the grapes in the report are harvested earlier because of another intention for the grapes. The grapes which are harvested too early are because of bad weather or diseases.

On the other hand, all the grapes with too high level of brix or too low level of acid, will probably have been good for sparkling wine, if they were harvested earlier. Because of the cool climate, Danish grapes will almost always reach maturity before getting too high brix or too low acid (Liu et al., 2018) (Marian W. Baldy, 2009). On the two following charts, the average numbers in brix and total acid of different hybrid grapes at the point of harvest are shown (See **Fejl! Henvisningskilde ikke fundet.** and Appendix 2). Both charts are marked with a target line (about 17-18 brix and around 11g TA g/l). The purple and green colors illustrate whether the grapes potentially could have been harvested for sparkling wine. When a line for a specific variety is present in the green area, it means that they probably could have been harvested earlier whit the right Brix and TA balance. When a line for a specific variety is present in the purple area, it means that the grapes didn't reach satisfying levels of brix or TA.

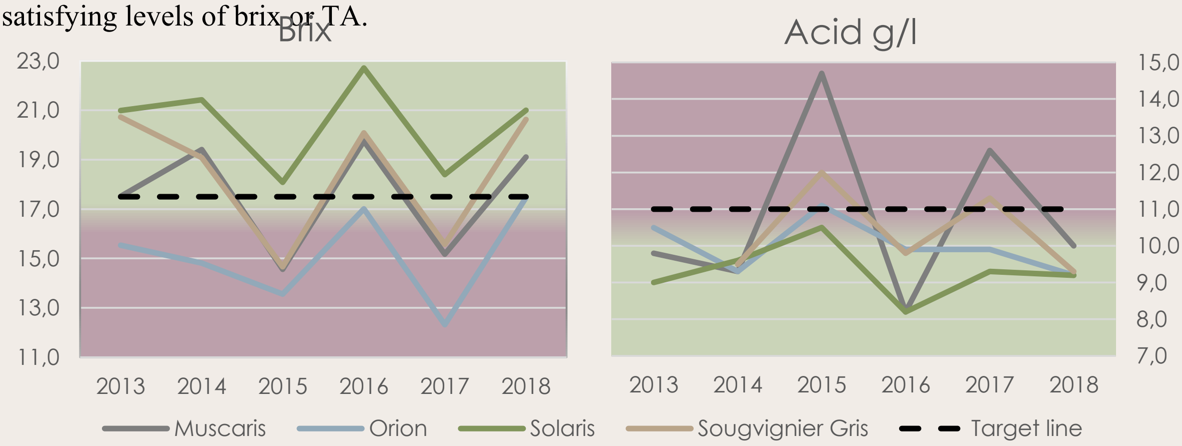


Figure 6: Charts showing the average contents of brix and TA g/l for four different hybrid varieties harvested different places in Denmark from 2013 up to 2018 (Holt, 2018).

The only one of the four hybrid varieties that managed to stay out of the purple area is *Solaris*. Wine made from *Solaris* is often characterized by a fruity and floral nose and palate. These aromatics notes could potentially mask the “champagne bouquet” (the odor that comes from aging on lees). The importance of harvesting before the varietal character become to dominate is definitely something to consider when making sparkling wine whit *Solaris* (Marian W. Baldy, 2009) (Liu et al., 2015). Despite the aromatic profile of Solaris, the potential for sparkling wine when grown in Denmark seems to be there. *Orion* and *Sougvignier Gris* is generally known to have a more anonymous profile than *Solaris*, but their ability to ripen constantly seems to be less absent in the current Danish climate (Foreningen Dansk Vin, 2019).

To support the analysis of the Danish grown hybrid varieties. The same analysis has been performed with the classic grape varieties *Chardonnay* and *Pinot Noir* harvested for sparkling wine (See Figure 7 and Appendix 3). The two classic grape varieties are grown by a Canadian producer of high-quality sparkling wine (Graham, 2019).

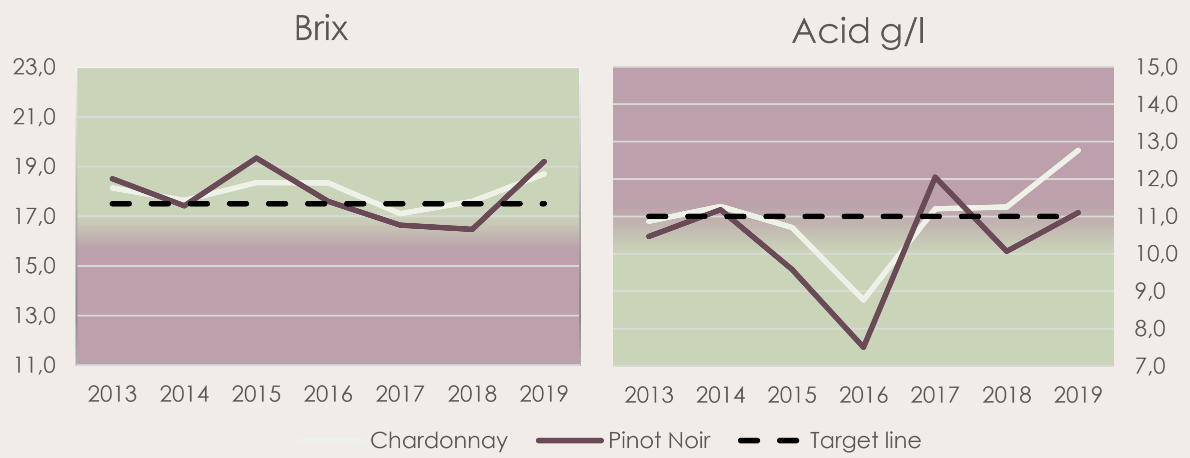


Figure 7: Charts showing the average contents of brix and TA g/l for two classic varieties harvested in Ontario Canada from 2013 up to 2019 (Henry of Pelham, 2019).

As it appears on the charts in Figure 7, both *Chardonnay* and *Pinot Noir* are continually closer to the target lines without reaching too deep into the purple area. It’s also clear that the grapes are harvested much closer to the brix target line than to the TA target line. The last three years Henry of Pelham has used a formula to decide when to harvest. This formula focuses more on the right balance between brix and TA, rather than reaching for a specific number. This new tool could also explain why some of the grapes at Henry of Pelham have been harvested with more than 11g acid pr. l during the last three vintages. It should be mentioned that the formula is not meant to stand alone. The winemakers at Henry of Pelham do still account for appropriate levels of both brix and TA (Buhler, 2019) (Silverthorne, 2019). The formula is shown below.

$$\frac{Brix\ x\ 10}{TA} = between\ 13 - 15$$

As the formula suggests, the result of this calculation should aim inside the ratio from 13 - 15. In the chart below, the result of both the classic grape varieties and the hybrid varieties are calculated (See Figure 8).

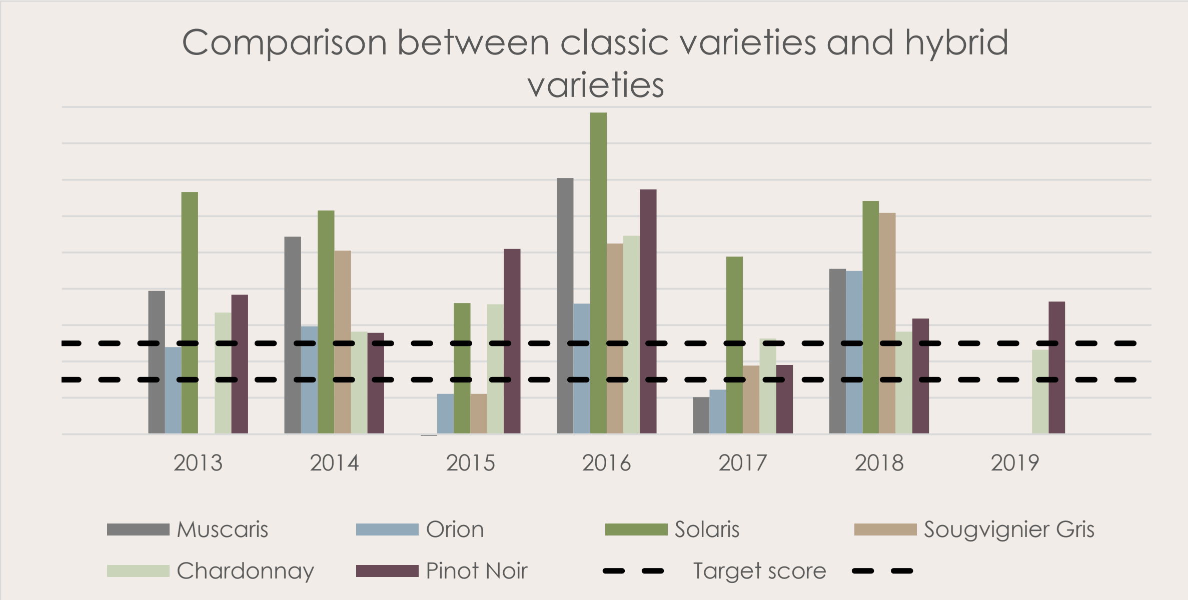


Figure 8: The chart showing the results from the formula calculated on all six varieties from 2013 - 2019. The target gap is marked with dotted black lines (Holt, 2018) (Henry of Pelham, 2019) (Buhler, 2019) (Silverthorne, 2019).

The chart in Figure 8 shows that the *Chardonnay* and *Pinot Noir* grapes from 2017 to 2019 was continuously close to the target gap. All other results tend to reach the target gap randomly. Although, it seems like the hybrid varieties are closer to the target gap in the vintages with low levels of brix (2015 and 2017). However, because the formula is not meant to stand alone the hybrid grapes from 2015 and 2017 did not reach a satisfying level of brix. As it appears in Figure 7, left chart, the brix levels in *Chardonnay* and *Pinot Noir* grapes are pretty constants around 17 - 18 throughout the years. When grapes reach 17 - 18 brix they are starting to mature and drop of their green and grassy flavor profile (Marian W. Baldy, 2009).

2.2 PH LEVELS

The last interesting comparison between the classic varieties and the hybrids is their level of pH when harvested. Low pH level normally means high TA, but the ratio between pH and TA is not always the same. E.g. two grapes with the same weight can differ in pH even though they have the same amount of TA g/l. The pH level also depends on which type of acid there is present in the grape and what concentration they are present in. TA in grapes is mainly made up of malic acid and tartaric acid. In regions with a warm climate, grapevine will metabolize their malic acid quicker than in cooler regions. That is why grapes from cooler regions have higher levels of malic acid. The tartaric acid does not decline markedly during the ripening. Grapes with a high concentration of malic acid compared to the TA have the lowest pH levels. This is because malic acid is a stronger acid than tartaric acid. Sugar, on the other hand, is closer related to photosynthesis in the leaves and the transportation to the berries (Haynes, 2010) (Haggerty, 2013) (Jackson R. S., 2008) (Marian W. Baldy, 2009) (Margalit, 2012).

The two charts in Figure 9 show the average pH and TA for four of the Danish grown grape varieties and the two Canadian grown varieties (See Figure 9).

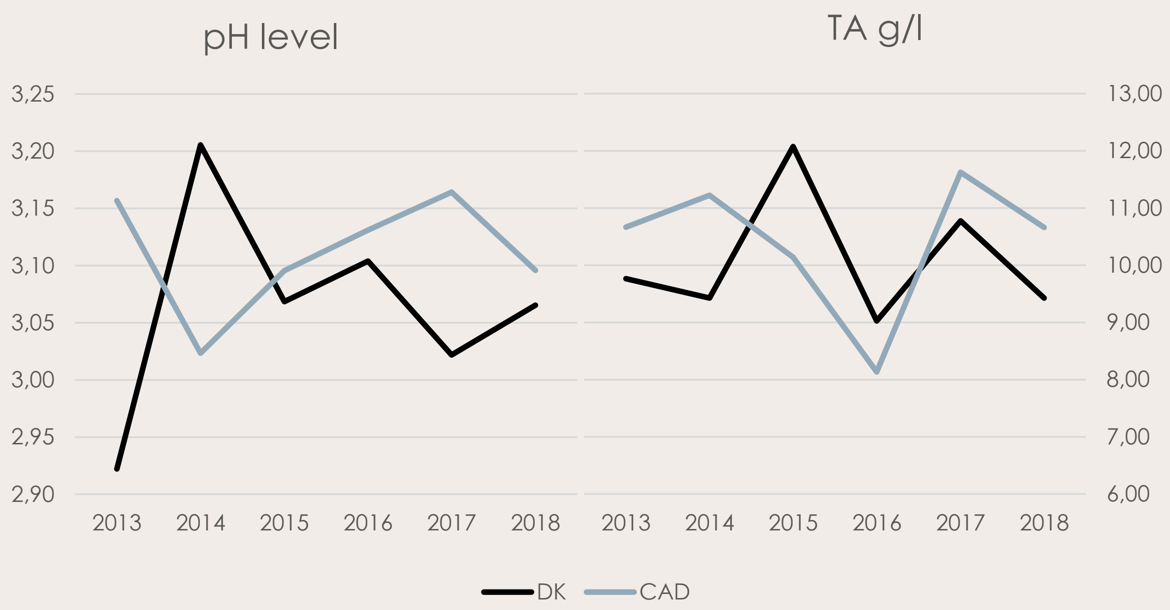


Figure 9: Comparison of pH level and TA g/l between Danish hybrids and the classic varieties grown in Canada (Holt, 2018) (Henry of Pelham, 2019).

On the left chart it appears that the Danish grown grapes have lower pH than the Canadian grapes in five out of the six years. The right chart show that the Danish grapes only have the highest acidity in two out of six years. This point towards a higher concentration of malic acid in the Danish grapes most of the years. This assumption can be supported by Sven Moesgaard, one of the leading producers of sparkling wine in Denmark. He had his wine approved by the European Union based on a number of special characteristics, one them being a particularly high content of malic acid (Troelsø, 2012) (Fødevarestyrelsen, 2018).

2.3 FLAVOR COMPOUNDS

When considering grape variety's suitability to a specific climate, it's not only the sugar/acid balance that needs to be considered. In general, there are several important flavor compounds which should be found in sparkling wine (See Table 2) (Kemp, 2019). Unfortunately, very few/none scientific articles have been made investigating the components in sparkling wines made from hybrids.

Instead of measurements on finished fermented sparkling wine, this report will present measurements of these components in base wines made from *Chardonnay* and *Pinot Noir.* As representatives for the hybrid varieties, *Solaris* and *Marquette* will be used for comparison. Both wines made from hybrid varieties are still wine, which is done fermenting. Meaning, their purpose was not to be used for sparkling wine. However, these two wines have been chosen in lack of better representatives. *Solaris* is a white grape, which can be used for sparkling wine, while *Marquette* is mainly used for red wines. The comparison will therefore mainly be focused on *Solaris*. *Marquette* is part of the comparison simply to give a wider image of hybrid's compounds. *Solaris* is an interesting choice because of its performance in the previous section (about sugar / acid balance).

Furthermore, *Solaris* is chosen, because it thrives in the Danish climate and it's the most widely grown white grape variety in Denmark (Liu et al., 2015).

Table 2: List over important flavor compounds in sparkling wines (Kemp, 2019) (Liu et al., 2015).

	Odor descriptions	
Compounds	Esters	Alcohols
• Ethyl butanoate	Apple	
• Ethyl hexanoate	Apple peel, fruit	
• Ethyl octanoate	Fruit, fat	
• Ethyl decanoate	Grape	
• Ethyl Lactate	Fruit	
• Ethyl succinate	Wine, fruit	
• Propanol		Alcohol, pungent
• Hexanol		Resin, flower, green
• Dodecanol		Leaf
• 2,3 Butanediol		Fruit, onion
• 2-Phenyl ethanol		Honey, spice, rose, lilac

The following results are from three different scientific articles (See Table 3). Unfortunately, not all compounds were measured in the article regarding *Chardonnay* and *Pinot Noir*. These compounds are therefore not a part of the comparison table (See Table 3 and Figure 10). The compounds in *Chardonnay* and *Pinot Noir* will be used as guidelines in the comparison. The three scientific articles used in the following table and chart all showed standard deviations (S). The results from (Liu et al., 2015) and (Slegers et al., 2015) have clearly higher standard deviations than the results from (Herrero et al., 2016). The different is most likely due to a wider sampling in (Liu et al., 2015) and (Slegers et al., 2015) articles. In the article made by (Liu et al., 2015) the samplings were taken from wineries all over Denmark, and despite the small size, the climate can differ a lot from one location to another.

Table 3: Comparison between vinifera and hybrid varieties of important compounds in base wine for sparkling wines (numbers in µg/l). [1]: (Herrero et al., 2016) [2]:(Liu et al., 2015) [3];(Slegers et al., 2015) S: Standard deviation

Compounds	Chardonnay[1]	s	Pinot Noir[1]	s	Solaris[2]	s	Marquette[3]	s
Ethyl butanoate	326	37	342	41	1028	340	327	300
Ethyl hexanoate	1032	155	1067	207	1220	790	803	319
Ethyl octanoate	1378	200	1462	268	1436	730	2383	519
Ethyl decanoate	401	75	410	415	1636	330	445	323
Ethyl lactate	313	58	385	60	1358	1700	58	21
Ethyl succinate	992	302	924	271	1689	200		
Hexanol	872	118	1051	161	1369	570	1795	140

The table and chart show clear differences in four out of the six ethyl compounds and a minor difference in the hexanol concentration (See Table 3 and Figure 10). The concentration of ethyl hexanoate and octanoate in the *Solaris* wine were very similar to the concentration in the base wine from *Chardonnay* and *Pinot Noir*. The remaining four ethyl compounds seems to be too far away from the guidelines.

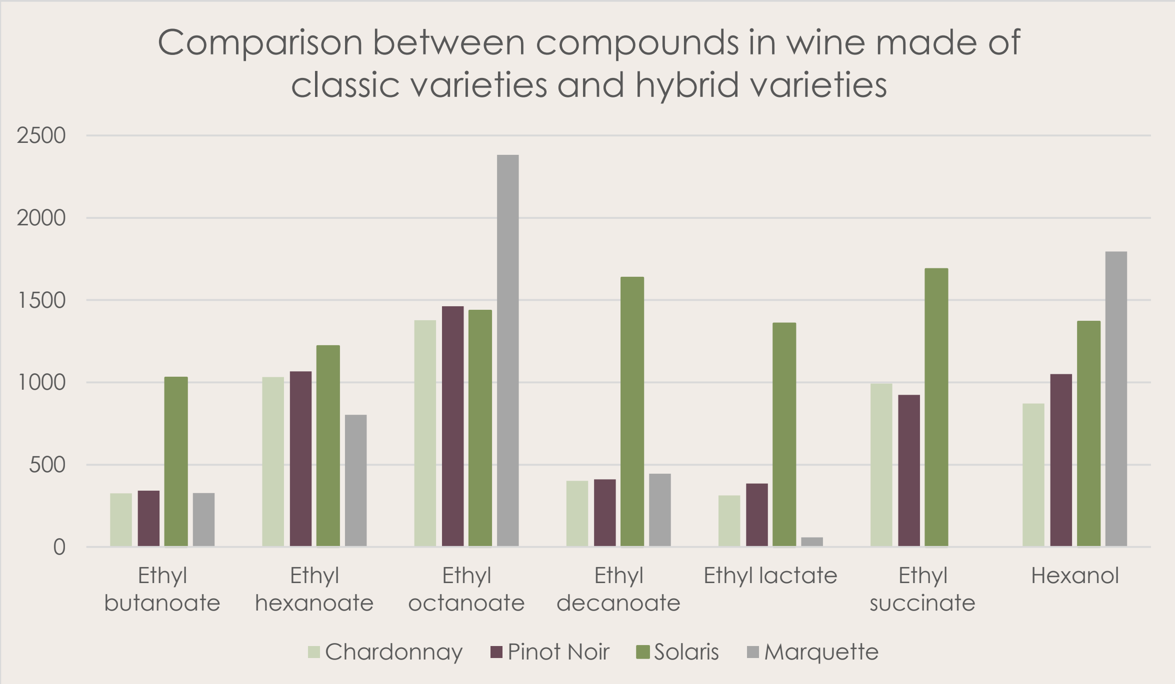


Figure 10: Graphic illustration of the four wine's compounds

2.3.1 **Ethyl butanoate**

Ethyl butanoate is a shorter-chain fatty acid which often contributes to a fruity character, especially in young wines. In sparkling wine, the aim is to minimize the fruity character. Therefore, it's very important to minimize the concentration of ethyl butanoate if *Solaris* base wine is used to make sparkling wine. Ethyl butanoate is produced during alcoholic fermentation. The production is affected by the choice of yeast strain and is favored by a cool fermentation temperature as well (Jackson R. , 2012) (Herrero et al., 2016).

2.3.2 **Ethyl decanoate**

Unlike Ethyl butanoate, production of ethyl decanoate is favored by higher fermentation temperatures (15–20 °C). However, the effect of yeast strain is the same as other esters like ethyl butanoate (Jackson R. S., 2008). Ethyl decanoate is also known to have a negative effect on the wines quality (Lukić et al., 2008).

2.3.3 **Ethyl lactate**

The concentration of ethyl lactate is notably higher in the *Solaris* wine than in the *Chardonnay* and *Pinot Noir* wines. The reason for this difference is simple. Because the *Solaris* grape is grown in a cooler climate it naturally has a higher concentration of malic acid when harvested. The TA is likely to be the same, but the ratio between malic acid and tartaric acid is different. The result of this difference is a much larger amount of converted malic acid into lactic acid in the *Solaris* wine. But, because of ethyl lactate's relative weak odor, the concentration does not seem to be aromatically significant. However, ethyl lactate is still among the important compounds, because it is the result of the malolactic fermentation (Jackson R. S., 2008) (Ruocco et al., 2019).

2.3.4 **Ethyl succinate**

The ethyl succinate ester is often mentioned in terms of wine quality. The formation of ethyl succinate is increased as ethanol concentration starts to rise. Higher temperatures, as well as lower pH levels, will favor the formation of these esters (Ruocco et al., 2019) (Rice, 2018).

2.3.5 **Hexanol**

Higher alcohols like hexanol is another class which can form volatile compounds. These compounds are typically formed by yeast via the catabolic pathway from their related amino acids or via the anabolic pathway from the glucose. Because of hexanol's vegetable and herbaceous odor, it often has a negative effect on the wines quality (Ruocco et al., 2019). Research have shown that the yeast strain only has little effect, while the pH level and the fermentation temperature have no significant influence on the production of hexanol. The factors which does affect the production of hexanol are varieties, vintages and the terroir (Ranikine & Pocock, 1969). Among these three factors, grape variety is the most interesting consideration in terms of sparkling wine production in Denmark.

3 THE CLIMATIC EFFECT

During the last 50 years the world's wine-producing countries have gone through major climatic changes. However, several scientific climate prognoses suggest that the next 50 years will result in even bigger climatic changes (Dunn et al., 2019) (Fraga et al., 2013). Traditionally, wine growing has been possible between approximately 30-50 degrees of latitude north and south. Temperature wise this area will be between 10 - 20 ºC annual isotherms (See Figure 11) (Marian W. Baldy, 2009). The tendency points in the direction of a poleward expansion, as well as a decline in the current wine regions. Today, serious wine producers can be found as far north as 60 degrees of north latitude in the Oslo Fjord. Near the 30 degrees latitude, the warmer climate is pushing the grapevine beyond their optimum growing conditions (Dunn et al., 2019; Olsen et al., 2011).

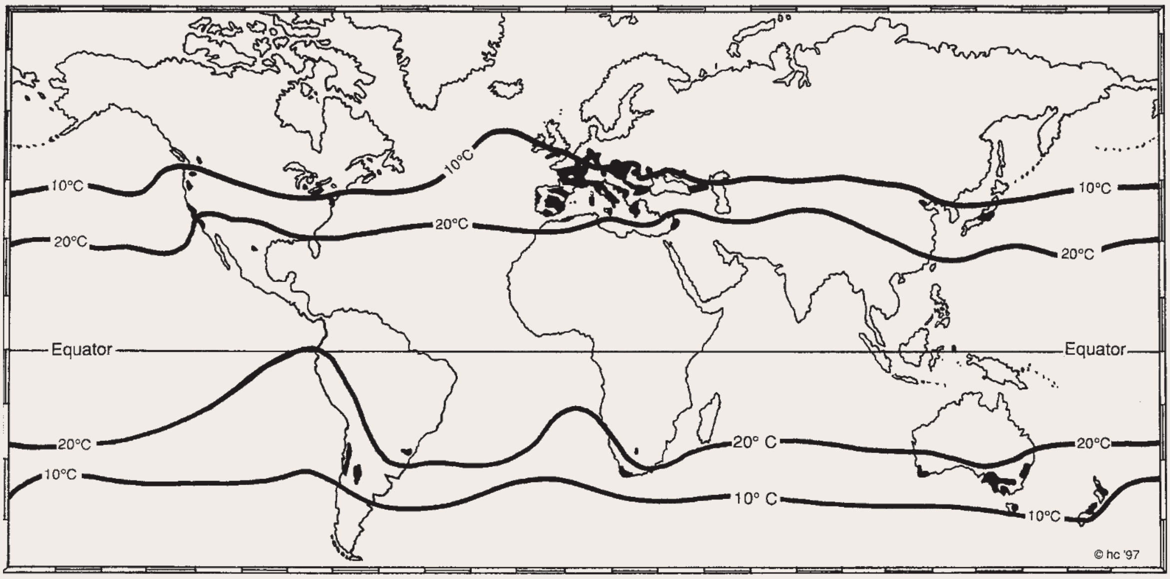


Figure 11: The two belts of the world where it's traditionally possible to grow grapes (Jackson R. S., 2008).

The poleward movement of the existing wine regions can be perceived either as challenges or opportunities. The northern European regions could be where they will benefit from these opportunities, as it is expected to increase the suitability for viticulture here. Among these new wine regions southern British Isles, the Netherlands, Denmark, northern Germany and Poland are mentioned (Fraga et al., 2013; Irimia et al., 2018). In a scenario where the greenhouse gas emissions continue to rise in the next decades, and then stabilize at the end of this century, the temperature is projected to rise 1,1 ºC in Northern Europe by 2035, and 2 ºC by 2065 (Nesbitt et al., 2016).

3.1 INFLUENCE ON VINES AND GRAPES

When growing grapevines, the biggest factor is the terroir in which the vines are grown. Terroir is known to give the grapes a special characteristic derived from the soil, climate and farming practices. Of these three factors, climate has the biggest influence on terroir. Even though grapevines can grow in a wide spectrum of climate, each variety have their own optimum growing conditions. Each variety has a well-defined thermal requirement to complete its vegetative cycle and to survive water and heat stress. For instance, the grape varieties *Merlot* and *Grenache* are both grown in the Mediterranean region, where great climate change are expected to occur. *Merlot* have high demands of water to thrive, while *Grenache* is much better at adapting to water scarcity. The growers of *Merlot* in the Mediterranean region will be challenged and may need to plant other varieties such as *Grenache.* The growers of *Grenache* will face even more dryer condition, leaving them whit very few alternatives (Dunn et al., 2019; Santillán et al., 2019).

Even if the vines manage to adapt their vegetative cycle to the climate changes, other challenges may occur. Widespread observations in the European grape region show that harvest dates have advanced in the last 10–30 years. Observations from Baden, Germany demonstrate that the average dates for the beginning of grape maturation of *Pinot Noir* had advanced by 3 weeks from 1976 to 2006. In Alsace, the mean annual temperature has been increased with 1,8 ºC from 1972 to 2002. In 2002 the harvest day was two weeks earlier than 1972, and there were 33 more days with a mean temperature above 10 ºC (Mira de Orduña, 2010).

The issue with these advanced harvest dates also shows its effect on the grape's constituents. While the tartaric acid is relatively stable regarding temperature shift, the concentration of malic acid is tightly connected to the temperature during maturing. A decrease in malic acid also means a higher pH level, which will lead to an increased risk of microbial contamination. Low pH level in fresh grape juice is essential for the microbiological stability (Mira de Orduña, 2010). Furthermore, the earlier metabolism of malic acid in Chardonnay and Pinot Noir grapes from champagne, will result in less mature grapes because they will need to harvest earlier.

3.2 THE EFFECT ON DANISH VITICULTURE

Different tools to categorize climate zones for viticulture have been invented during the last 50 years. The two most used indexes for evaluating suitability for viticulture is the Winkler index (WI) and Huglin index (HI). The WI was invented in 1944 and is calculated by using the daily minimum and maximum temperatures during the grape-growing season. (one degree-day equals the average daily temperature minus 10 °C) (See Table 4) (Cardell et al., 2019).

Table 4: Definition of the four indexes which will be used later in this section (Cardell et al., 2019; Fraga et al., 2013).

	Definition	*Units*	*Suitable threshold*
Winkler index	$\sum \frac{Tmax + Tmin}{2} - 10°C$	ºC	
Huglin index	$\sum_{April}^{Sept} \frac{(T-10) + Tmax - 10)}{2} d$	ºC	> 900
Hydrothermal index	$\sum_{April}^{Sept} (T \ x \ P)$	°C mm	<7,500
Dryness index	$\sum_{April}^{Sept} (Wo + P - Tv - ES)$	mm	>–100

T: Mean temperature (ºC), Tmax: Maximum temperature (ºC). Tmin: minimum temperature (ºC), D: Length of day coefficient, Wo: Soil water reserve (mm), Tv: Potential transpiration in the vineyard (mm) Es: Direct evaporation from the soil (mm)

HI considers the daily mean and maximum temperatures in the growing season (April to September). In contrast to WI, the HI weights the daily maximum temperature more and adjusts it to the potential sugar content in the grapes. Furthermore, the HI also considers the increasing length of the daylight towards higher latitudes (See Table 4) (Cardell et al., 2019).

WI is solely based on a thermal impact while HI also considers daylight. For a wider image of the conditions that effect suitability for viticulture, more factors needs to be considered. A Hydrothermal index (HyI) which considers the precipitation compared to the mean temperature, is necessary to evaluate the risk of pests and diseases. The last factor which effects the vines suitability is a Dryness index (DI). The DI considers the precipitation (mm), soil water reserve (mm), potential transpiration in the vineyard and direct evaporation from the soil. The DI does not seem to affect the Danish viticulture suitability, but it is included in an overall assessment of new wine regions (Fraga et al., 2013).

In the following sections, the WI will be used as a guideline to show whether it is worth researching the other indexes. If it is so, the other indexes will be able to indicate a more precise projection for whether the future Danish climate will be suitable for viticulture.

3.2.1 **Winkler index**

In November 2018 (Cardell et al., 2019) completed a larger research regarding "Future effects of climate change on the suitability of wine". The research focused on the European wine regions and how the climate change will affect them. One of the projections was made based on thermal related forecasts, which is then illustrated on a map of Europe divided into categories from the WI (See Figure 12). Some of the map is trimmed away, because it had no relevance for this report.

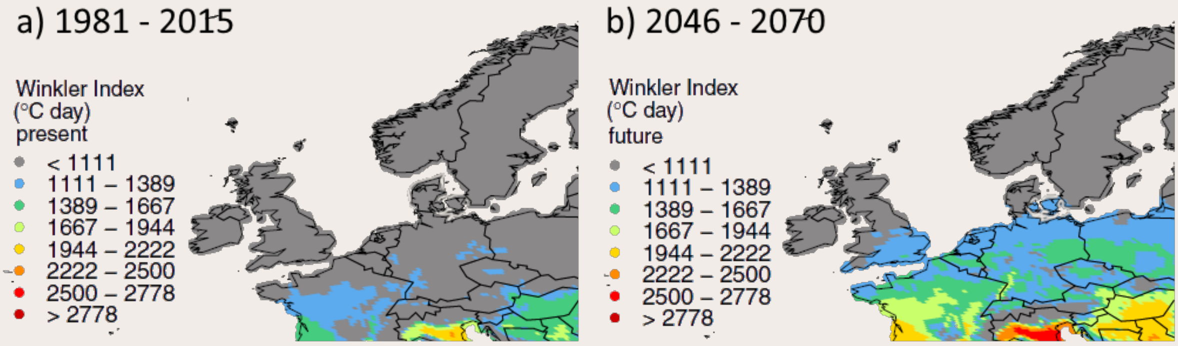


Figure 12: Present WI (a). Future WI (b) (Cardell et al., 2019).

The WI projection indicates a northward expansion, as well as an increase over southern and western Europe. Regions like La Rioja, Piemonte and Bordeaux all seem to move one step up in WI categories (See Table 5) (Cardell et al., 2019). This shift in categories will probably lead to a replacement in cultivated grape varieties for those regions affected by the temperature. A replacement of grape varieties is not only expensive because of the physical replanting. The wineries will also need to understand how to process these new grapes in order to make a wine, where the varietal character matches the profile from the local terroir (Mira de Orduña, 2010). The projection also shows potential for new wine areas that seems to meet the requirements for region 1b in the future. Among these areas are Belgium, Netherlands, north Germany, Poland, south Britain and parts of Denmark (Cardell et al., 2019).

Table 5: Winkler Region Growing Degree-Day Limits and Wine Style Suitability (Jones, 2015).

Regions/ categories	*Degree-Days (C° Units)*	*Suitability*
Region 1a	850-1111	Only very early ripening varieties achieve high quality, mostly hybrid varieties and some *V. vinifera*.
Region 1b	1111-1389	Only early ripening varieties achieve high quality, some hybrid grape varieties but mostly *V. vinifera*.
Region 2	1389-1667	Early and mid-season table wine varieties will produce good quality wines.
Region 3	1667-1944	Favorable for high production of standard to good quality table wines.
Region 4	1944-2222	Favorable for high production, but acceptable table wine quality at best.
Region 5	2222-2700	Typically, only suitable for extremely high production, fair quality table wine or table grape varieties destined for early season consumption are grown.

The WI index's projections were positive regarding a possible winegrowing future for the Danish climate. The next three indexes (Huglin Index, Dryness Index and Hydrothermal index) will be composited to one final projection which accounts for the most important climatic factors in wine growing, and thereby give a more comprehensive projection. These indexes will be made from 15 different climate models, and they will be formed by 11,506 grids, each of them 25 km^2. For a wine region to be marked a s suitable on the composited map for wine growing, it will need to fulfil the following criteria (Fraga et al., 2013):

1. HI: ≥ 900 °C
2. DI: ≥ −100 mm
3. HyI: ≤ 7,500 °Cmm

3.2.2 **Huglin Index**

The threshold definition for the HI is believed to be 900 °C, instead of the traditionally threshold which is 1200 °C. This lower threshold is considered to include northern European regions with a marginal suitability for viticulture. The low threshold can be justified when compared to similar studies in western United States and Australia, where a WI above 850 °C was found to be already suitable for viticulture. A WI at 850 °C is very close to be equal to 900 °C on the HI (Fraga et al., 2013).

Like the WI from (Cardell et al., 2019), the HI from (Fraga et al., 2013) shows a northward expansion of the region suitable for viticulture in Europe (See Figure 13). Areas such as central and western Europe seem to increase strongly on the HI, while regions in the southern Europe is expected to become too hot for winegrowing. The extension to the north is projected to arise within the latitude belt 50-55°N (Fraga et al., 2013). Northern Germany and southern England, which today is considered very cool regions for winegrowing (HI ≤ 1500), are expected to be suitable for varieties such as *Chardonnay* and *Pinot noir* in the future period (2041–2070) (Cardell et al., 2019).

3.2.3 **Hydrothermic Index and Dryness Index (mm)**

Hyl and DI are two sides of the same coin. The projected change in the HyI includes an enhancement of the humidity levels over the eastern and central parts of Europe (See Figure 13). This change in HyI can mainly be explained by the joint effect of moister and warmer conditions in the future. A further, unnecessary humidity can trigger pests and diseases such as gray mold and downy mildew (Fraga et al., 2013).

On the other hand, the projected changes in the DI during growing season can result in harmful water stress and a reduction in vines productivity. The change in the DI for the future period seems to affect the southern half of Europe the most, especially areas such as southern Iberia, Turkey and Greece. So, while high humidity may represent threats or challenges for wine growers in eastern and central Europe, dryness and warmer weather result in harder condition for growers in the southern Europe (Fraga et al., 2013).

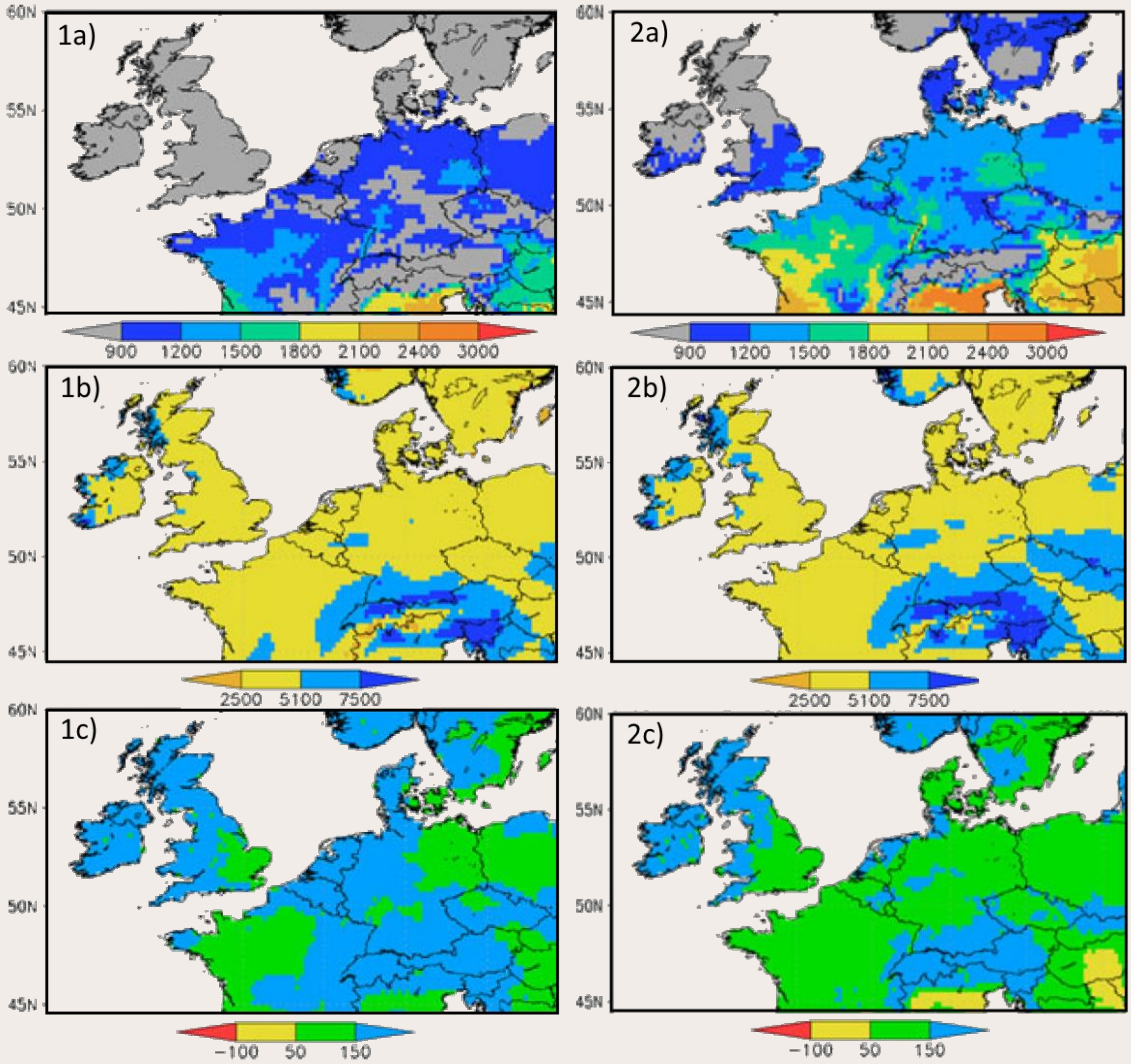


Figure 13: Present climatic conditions (1a: HI, 1b: HyI, 1c: DI). Future (2041–2070) projected climatic conditions (2a: HI, 2b: HyI, 2c: DI) (Fraga et al., 2013)).

3.2.4 **Composite Index**

The CompI is, as mentioned previously, an attempt to combine the most relevant atmospheric requirements for wine growing in a single index. This index is categorized from 0 - 0.99, that is the probability for years with optimal growing condition for viticulture. The CompI have been applicated in recent periods (1980–2009) over traditional European wine regions. Most of the world's famous wine regions are located in Europe, mainly in southern Europe, and they did all excess 0.5 (50 % of optimal years). The result of this test, was enough proof that the CompI was able to indicate whether a region will be suitable for wine growing and how continuously an optimum year will occur (Fraga et al., 2013).

The 15 different climate models have been combined to form three possible scenarios for the future of European viticulture (2041–2070). The three scenarios include a median model (2a), a more severe model (2b) and a less severe model (2c) (See Figure 14).

All three models reveal a decrease in the areas suitable for winegrowing in the southern Europe, especially due to the changes in the DI over these areas. Contrariwise, the large areas in western and central Europe are projected to increase their suitability for viticulture, mainly because of favorable thermal change. Looking further up north, there are solid indications that new regions will become suitable for viticulture soon. Places such as the Netherlands, southern British Isles, Denmark, Poland and northern Germany all seems to benefit from these climate changes (See Figure 14). The projections reveal a significant change in the number of suitable grid boxes north of 50°N latitude for 2041–2070, although the numbers gradually decrease towards 60°N latitude. There do not seem to be a remarkable change in suitable grid boxes within the latitude belt of 41–50°N, while the decrease in suitable grid boxes south of 41°N can be explained by dryness and lack of precipitation.

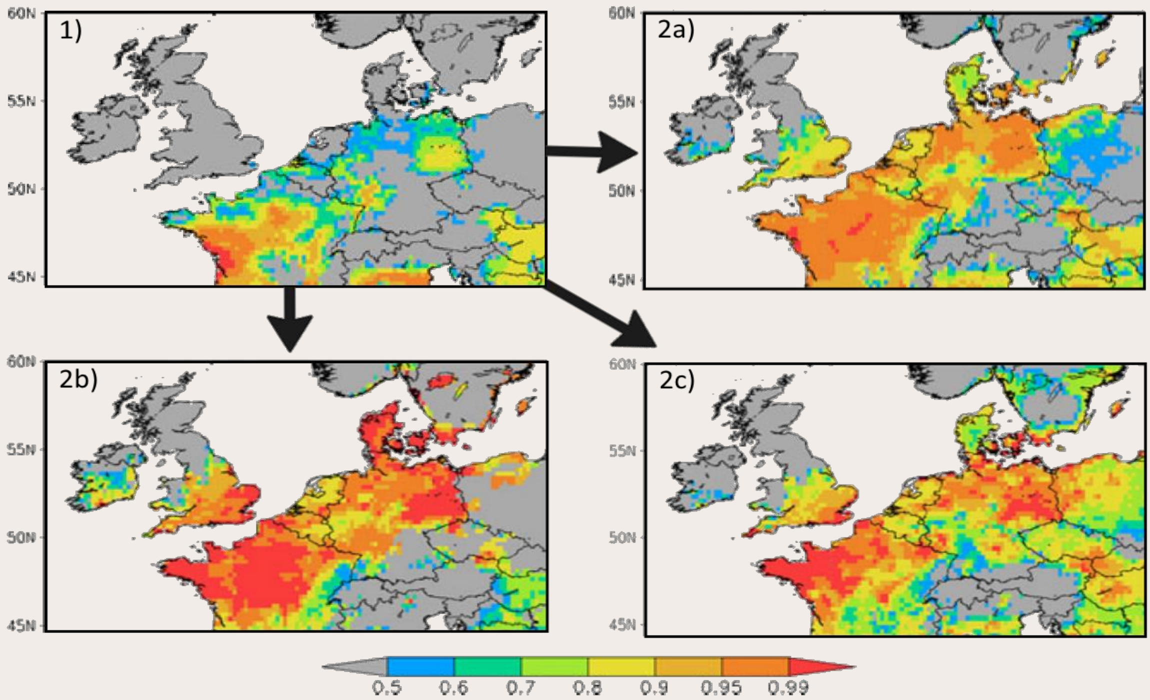


Figure 14: Present CompI (1). Future (2041–2070) CompI projection (2a:median model, 2b: a more severe model and 2c: a less severe model) (Fraga et al., 2013)

The conclusion of (Fraga et al., 2013) article definitely point towards a more suitable climate for viticulture in Denmark. Still, the projections don't seem to reveal an unambiguously probability that classic grape varieties like *Chardonnay* and *Pinot Noir* can be grown in Denmark, at least not within the next few decades. In a study completed at Aarhus university, they investigated how the climatic conditions for the *Chardonnay* grape will develop in Europe from 2020 - 2040. Their research was also based on the HI and showed that the climatic conditions for *Chardonnay* will move northward, but the right conditions will not reach Denmark before 2040 (Olesen & Kristensen, 2012). *Chardonnay* and *Pinot Noir* both have a thermal requirement of 1700 °C on the HI (Kemp, 2019).

Looking further out in the future, several "optimistic" projection suggests that early ripening *V. vinifera* varieties can be cultivated with continuously success in Denmark. E.g. (Cardell et al., 2019) suggest that parts of Denmark (mainly the eastern part) will reach between 1500 - 1800 °C on the HI within the period 2046–2070. While the article from (Fraga et al., 2013) suggests that most suitable regions in Denmark (2041–2070) seems to reach between 1200 - 1500 °C on the HI.

The effect of perception and high humidity is not that emphasized in the research made by (Fraga et al., 2013), at least not in Denmark. Other studies point towards a high pressure from pests and diseases if the temperature rises as expected. (Schernewski, 2011) has investigated the future opportunities for wine growing near the Baltic coast. He also concludes that the thermal growing condition for some early ripening *V. vinifera* varieties exists, but he questions their sensitivity to fungal diseases.

3.3 REGIONAL DIFFERENCES IN DENMARK

Although Denmark is a relatively small country, the regional climate still tends to vary on essential factors for winegrowing. The annual precipitation varies from approximately 580 mm (the area between Zealand and Fyn) to 820 mm in southwest Jutland. The annual amount of sunshine hours range from 1400 (central Jutland) to 1600 (eastern part of Denmark) (Olsen et al., 2011).

Constraining factors such as the amount and intensity of precipitation, length of growing season, soil drainage, risk of frost and amount of sunshine all affect the chances of growing vines successfully. If just one of these factors are absent, the harvest can be affected badly because that factor will be the limiting factor. The consequence of these marginal growing condition means that the placement of a vineyard in Denmark needs to be considered very carefully (Olsen et al., 2011). In the following section, the constraining factors will be described together with climatic data and measurement to map the most suitable places for winegrowing in Denmark.

3.3.1 **Frost damage**

The vines are particularly exposed to frost damage in the few days after bud break, which normally will occur in the medio/ultimo April. Secondly, if vines are exposed to frost at the end of the season, the vines will shut down and the grapes will stop maturing. During the growing season, the varieties have different tolerance to frost, from -1°C to -3°C. The chances of temperatures below 0 °C in the late spring and early autumn are quite common and must be considered when choosing a location (Marian W. Baldy, 2009).

When considering places with low risk of frost, local topography must be evaluated. The proximity of large amounts of water will have positive thermal effect compared to frost. Places near the sea or a lake will benefit from the thermal stability that the water provides. Likewise, an open landscape that prevent accumulating of cold air pockets is also preferred. In contrast, valleys or lowland areas where the cold air can't escape is in risk of frost damage, and generally cooler temperatures during the growing season will occur such places. Location on a hillside will also prevent the risk of frost, as cold air can drain downwards (Jackson R. S., 2008). Data from DMI confirm that the locations near the coast statistically experience fewer days with frost (Gensbøl & Gundersen, 1998).

3.3.2 Temperature

This factor is probably one of the most researched areas in winegrowing. Generally, the vines start their bud break (beginning of the growing season) when the temperature reaches 10 °C. Each variety have their own specific minimum temperature. When this minimum temperature is reached, phenological responses start inside the vines and become gradually more and more rapid up to an optimum temperature (Jackson R. S., 2008). As described in the section above, it is the frost that determinate the end of the growing season. The regional temperature thereby controls the length of the growing season for viticulture.

Since the maturation of the grapes often poses a problem in Denmark, this factor must be among the most important ones. The WI is, as previously mentioned, one of the most used tools to measure suitability for viticulture compered to temperature. Data to complete these researches is delivered by DMI and calculated by (Olsen et al., 2011). Data from eight years was used to form a map over Denmark, consisting of 10 km^2 grid boxes (See Figure 15). The data used in this map is from 1999 to 2006 showing three categories of growing degree days. The categories range from low suitability (690-760 degree days), medium suitability (760-830 degree days) and high suitability (830+) (Olsen et al., 2011).

3.3.3 Solar radiation

Temperature is often believed to have a much larger impact than solar radiation. But sun exposure is almost as crucial for the vines to thrive and for the grapes to mature. Denmark has a small advantage, in form of the extended day length in midsummer. Growing on south facing slopes will also increases both solar exposure and heating of the vineyard (See Figure 16). It's especially in high latitude regions that the south facing slope can make a difference. In the spring and autumn, the sun sets relatively low over Denmark, which create a wider angle when the solar radiation hits a flat surface. When solar radiation hits a south facing

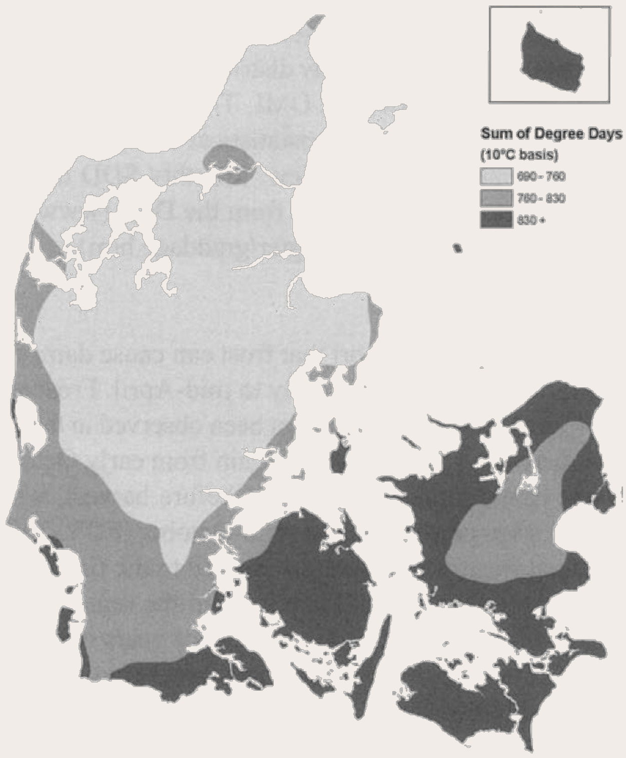
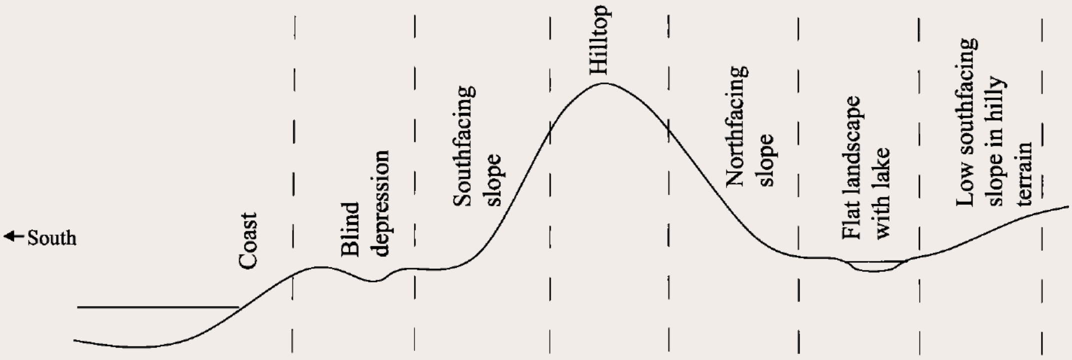


Figure 15: Regional amount of degree days divided into three categories, for the period of 1999-2006 in the growing season (Olsen et al., 2011) .

slope, the angle would be smaller and the concentration of light greater. If the vineyard is near the coast or a larger lake, the reflection from the sunlight into the water can create an even greater solar radiation, which greatly affect the ripening of the grapes.



Suitability	Low	Low	Good	Low	Low	Medium	Medium
Argument	Salt deposition and wind	Frostprone due to bad circulation	Abundant sunshine	Wind	To little sunshine	Good thermal effect from lake in fall	Shadow from hilltop opposite lake

Figure 16 Landscape advantages/disadvantages (Olsen et al., 2011).

For viticulture, the total amount of sunshine hours should be at least 1100 hours annually. For stable high quality, 1300 hours of sunshine per year are required, and the best quality is achieved at 1700-2000 hours of sunshine annually (Schernewski, 2011). The average number of sunshine hours in Denmark during the period 1981-2010 was 1,574 hours, and in the period from 2006-2015 the average was 1,722 sunshine hours. Average annual hours of sunshine also vary from year to year and from place to place. The central part of Jutland has the lowest number of sunshine hours (around 1600), while the Kattegat region and Bornholm have the highest (Around 2000) (Cappelen, 2019).

3.3.4 **Precipitation**

The annual precipitation in Denmark is relatively high when considering winegrowing. The high amount of rainwater also means that troubles with dryness rarely occur. However, the problem with rain occurs when it is during the harvest period (September to October). It is so, because in this period the grapes and vines are vulnerable to pest and diseases (Gensbøl & Gundersen, 1998).

The average annual precipitation varies greatly from year to year and from place to place. The average annual rainfall in Denmark during the period 1981-2010 was 746 mm. Normally, it rains most in Central Jutland and least in the Kattegat region. The annual rainfall nationally in Denmark has increased about 100 mm since the 1870s (Rubek, 2018).

An ideal annual precipitation for viticulture is approx. 450-500 mm annually, with the condition that it is evenly distributed. It is especially during the growing season from June to August that the vine plant needs a lot of water, whereas during the harvest season it should preferably be drier. A period of heavy rainfall during the summer and fall will result in an increased risk of fungal diseases (Jackson R. S., 2008). The use of hybrid varieties in Denmark is the primary reason why the large amount of annual precipitation rarely causes overwhelming problems (Gensbøl & Gundersen, 1998).

3.3.5 Soil drain

The vine is generally very tolerant to different types of soils. In fact, it can grow in almost all kinds of soil: sandy, clay, calcareous, rocky, poor and / or fertile soil. The biggest problems occur if the soil is waterlogged, which means that places such as marshes and generally low-lying areas are unsuitable for viticulture. Fertile soils produce more vigorous growth, and if the vineyard manager can handle the vigorous growth, it will result in greater yields. However, strong growth can also result in too much shading, which will subsequently result in less yield. Poor soil gives less growth and thus less yield. This also means that there will be less shade in the vineyard, which increases the quality of the wine. The greater sun exposure of the grapes is probably the reason why some of the world's most prestigious wines come from areas with poor growing conditions (Jackson R. S., 2008).

Since Danish viticulture is still young, there is no evidence of which soil types are most suitable for certain grape varieties. However, a very heavy clay soil is very likely to cause problems due to poor air exchange and poor drainage (Gensbøl & Gundersen, 1998). In a heavy clay soil, the roots will be located in the surface and they will therefore be exposed to both frost and drought. However, that does not mean that a clay soil is necessarily poor soil (Jackson R. S., 2008).

DISCUSSION

The first section in this project "The process of making sparkling wine" is based primarily on scientific articles supported by textbooks. The topic is well described by many sources, and the processes do not differ radically from one source to another. For sections where the sources have disagreed (e.g. the timing of cold stabilization), factors such as validity (scientific articles, textbooks) and recentness of the source, have been considered.

Second section analyses the difference between *V. vinifera* and hybrid varieties for Sparkling wine. There seems to be a disagreement about the influence of the varietal's effect on the final sparkling wines. Most of the sources focus on the differences made with specific yeast strains, while only few sources described the varietal differences. Achieving the right balance between sugar and acid doesn't seems to be the issue, while the tendency of more volatile compounds in the hybrid wines seems more obvious. The amount of volatile compounds in the wine can often be affected by yeast strain and fermenting temperature. But whether it's possible to adjust the amount of specific flavor compounds enough by using the right yeast strains and fermenting temperature is difficult to answer. There seems to be a conflict between warm and cold fermentation in order to control ethyl butanoate and ethyl decanoate. The amount of both esters seems to be too high in the *Solaris* wine. Butanoate is favoured by cold fermentation while decanoate is favoured by high fermentation. Common practice is to ferment warm, so the problem with ethyl decanoate needs to be considered when choosing the yeast strain. An earlier harvest could also prevent this varietal character, if the sugar/acid balance is still in place.

The harvest reports from "The Danish winegrower association" lacks credibility because of irregular sampling from each variety and each vintage. The big variation in the weather also contributes to the uneven charts regarding the Danish harvest reports. The harvest reports from Henry of Pelham are more validated as they are made professionally and completed with the same technique every year. The comparison between the volatile compounds in the *Chardonnay* and *Pinot Noir* base wines and the *Solaris* wine is composed by two different Scientific articles (Herrero et al., 2016) and (Liu et al., 2015). Meaning that different techniques and instruments have increased the potential for biases.

Third section about the climatic effect is dominated by two scientific articles (Fraga et al., 2013) and (Cardell et al., 2019). Many reports have been made about how climate change will affect grape growing in Europe, all of them using different techniques and indexes. (Fraga et al., 2013) and (Cardell et al., 2019) are chosen because they represent the majority of the techniques and indexes. (Fraga et al., 2013) is a relative old article, but is very detailed and extensive, while (Cardell et al., 2019) is new and represent the lasted research within the subject. All indexes in both articles are made up by 25 km^2 grids, which allows for big variation inside the individual grids. None of the scientific articles focuses on the solar radiation projections, and only vary little is mention about it in the articles. Because the uncertainty of the climate change projections, and the big regional climatic variation in Denmark, a conclusion of specific grape varieties for the Danish climate at a certain time seems very complex.

All indexes in this project are zoomed in on the northern and western part of Europe, meaning that the southern and eastern part is trimmed away. Especially in Figure 14 this zoomed index can be misleading, because the level of severity doesn't seem to match the indexes. The reason why the 2b (a more severe model) does not look more severe than 2a and 2c, is because the severe part of that index is in the southern Europe.

In general, all sources used to state essential elements in this project have a high degree of validity. The majority of these sources are scientific articles (peer reviewed) supported by textbooks. One of the textbooks which is used a lot in this project is (Jackson R. S., 2008). The book is used at universities for Oenology and Viticulture, and Ronald S. Jackson is also the co-author of many other university textbooks. Therefore, the continuously use of (Jackson R. S., 2008) seems valid. In the section regarding pH level and acidity, (Haynes, 2010) stated that malic acid was stronger than tartaric acid. This statement seems to be contradicted by (Margalit, 2012) who states the opposite. Both sources are from textbooks with high validity. This project refers to (Haynes, 2010) because his statement matches the theory behind the collected data in this project. One of the sources for Hexanol is very old (Ranikine & Pocock, 1969), so the validity and whether the knowledge is outdated can be discussed. In less essential elements of the project, articles from magazines and websites have been used.

The method used in this project is partly based on literature study and partly on collection of data from wineries. The idea with the introduction section about Sparkling wine in general, appears to have had its justification in this project. The section explains the basic steps in the production, which gives the reader a better opportunity to understand the following sections. Second section compared *V.vinifera* varieties with hybrids, and it worked to some extent. The comparison does illustrate important differences between the two grape types but still includes too many biases. The measurement should have been performed on wine which have completed all their fermentations. Furthermore, all grapes in the comparisons should have been intended for sparkling wines. In the comparison of volatile compounds between *Chardonnay, Pinot Noir* and *Solaris* (Table 3 and Figure 10) the *Solaris* wine had a big disadvantage because the yeast strain and fermenting temperature was not intended for a base wine to sparkling wine. That disadvantage will probably have caused the differences to be more radical than if the *Solaris* wine was intended for Sparkling base wine. Third section about the climatic effect and the climate change, would have benefitted from sources with greater focus on the Danish climate. When a research is performed on an area as big as Europe, the specific result regarding Denmark will be minimal and less accurate.

Regarding the different results this project has discovered, there seems to be notably differences between the classic grape varieties *Chardonnay* and *Pinot Noir,* and the hybrids varieties which is used in Denmark. These differences can be minimized, with the right yeast strain and fermenting temperature. The fact that some studies (Cardell et al., 2019) point towards a possibility for growing *Chardonnay* and *Pinot Noir* within the time frame 2046 - 2070, is quite interesting and at the same time a bit scary. With the regional climatic differences in Denmark in mind, these projections seem surprisingly promising for Danish viticulture.

CONCLUSION

The biggest factors regarding the production of sparkling wine in Denmark are the right choice of grape varieties, yeast strain and fermenting temperature. At the moment, only hybrid varieties can reach a continuously satisfying balance between sugar and acid while still reaching maturity. The biggest issue with these hybrids are their tendency to form volatile compounds. It will most likely be necessary to blend different hybrid varieties and vintages to form a NV cuvée which continuously reach a high-quality standard. The yeast strains for the first and secondary fermentation need to be chosen with care, and the Danish producers need to follow the development of new yeast strains which potentially could increase the quality of their products. In general, first fermentation should be fermented warm, while secondary fermentation should be fermented slightly cooler at 12- 15 °C.

The balance between sugar and acid is crucial for the final harmony in the sparkling wine when it's done fermenting and aging. Grapes for sparkling wine need high acidity to counter the sweet dosage which is added during the production. The more specific constituents in grapes are hard to account for, because the characteristics of grapes often first show post fermenting, when the juice have been transformed into wine. Each grape variety have a special characteristic, which later plays a main role in the forming of volatile compounds during the fermentations. The two other players in the forming of volatile compounds is the yeast strain and the fermenting temperature.

It is possible to make sparkling wine from hybrid varieties. However, the quality of these wines is harder to account for because of their often-high proportion of volatile compounds. The hybrid variety *Solaris* shows good ability to ripen and seems to thrive in the Danish climatic conditions. Furthermore, it seems to reach satisfying levels of sugar and acid continuously throughout the years. However, its aromatic profile expresses itself during fermentation when high levels of volatile compounds are developed. Varieties such as *Orion* and *Sougvignier Gris* have a less aromatic profile and may be better suited for sparkling wine. Making a blend (cuvée) with the three varieties will also be possible. Vintages with bad weather can be compensate when making a NV cuvée, because reserve wine from other years can be used to reach a satisfying result. Still, to succeed production of high-quality sparkling wine in Denmark, more research needs to be conducted about which hybrid varieties produce the right concentration of compounds during the fermentation. The same focus needs to be put on the selection of yeast strains for both the first and secondary fermentation compared to which varieties are used.

There is no doubt that the climate change will improve the contention for viticulture in Denmark and thereby the production of sparkling wine. All sources used in this project (regarding the climate change effect on viticulture in Europe) point towards an expansion of the area suitable for viticulture north of 50°N including Denmark. Whit the expectation that the research and development with new clones/varieties continues, the use of *V. vinifera* varieties in Denmark seems possible within the projection period (2046–2070). Until that period, Danish producers of sparkling wine will probably be using hybrid varieties as their main crops.

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APPENDIX

1. SUPERVISING - LOG BOOK

Mail correspondence

Fra: Niklas Christensen <niklas_christensen@outlook.dk>
Sendt: 23. oktober 2019 23:14
Til: Jens Brøgger (lektor – jenb@eaaa.dk) <jenb@eaaa.dk>
Emne: Problemformulering

Jeg sidder i øjeblikket i Canada og bøvler lidt med min problemformulering til bacheloropgaven. Jeg er indtil videre kommet op med følgende udkast til en problemformulering:

(How) can grapes grown in Danish climate achieve satisfying balance of the constituents, which will later form the basis for the microbiological processes in high quality sparkling wine's fermenting stages?

- Which constituents are decisive when harvesting grapes for sparkling wine?
- Can high quality sparkling wine be made from *hybrids* instead of only *V. vinifera* grapes?
- What role will climate change play in production of spakling wine in Denmark?

Jeg har derfor følgende spørgsmål:

Jeg er i tvivl om hvorvidt mit hovedspørgsmål og det midterste af min underspørgsmål skal være åbne eller lukkede spørgsmål. Hvad er tænker du om det?

Tænker du ellers at problemformuleringen har nok mikrobiologisk indhold?

Kræver bacheloropgaven at man inddrager andre fag som sekunderer emner?

Fra: Brøgger (lektor – jenb@eaaa.dk) <jenb@eaaa.dk>
Sendt: 29. oktober 2019 09:35
Til: Niklas Christensen <niklas_christensen@outlook.dk> Jens
Emne: Problemformulering

Jeg synes at din problemformulering er fin, og den giver god mulighed for at få en masse mikrobiologi med ind i opgaven. Som udgangspunkt tænker jeg åbne spørgsmål i din PF.

Det er ikke et krav at du inddrager andre fag/emner i din opgave.

Fra: Niklas Christensen <niklas_christensen@outlook.dk>
Sendt: 13. november 2019 01:18
Til: Jens Brøgger (lektor – jenb@eaaa.dk) <jenb@eaaa.dk>
Emne: Vejledning Canada

Jeg er så småt kommet godt i gang med opgaven, og føler lige at jeg har brug for at vende et par ting med dig. Bare lige for at høre om jeg er på rette spor.

Jeg har starter med et introduktionsafsnit om selve produktionen af mousserende vin. Her kommer jeg bl.a. også ind på nogen af de mere mikrobiologiske processer, samt hvilke dele af produktion der kan skabe problemer i Danmark.

Efter det første afsnit har jeg tilføjet en delkonklusion som giver anledning til to nye spørgsmål. Betyder det at jeg bør lave min problemformulering om, eller kan jeg blot gøre opmærksom på de nye problemstillinger og efterfølgende besvare dem i de efter følgende afsnit?

I det næste afsnit forsøger jeg primært at undersøge forskellene mellem danske druer og klassiske druer som er høstet til mousserende vin. Dataene om de klassiske drue har jeg fra mit praktiksted og dataene om de danske druer er fra høstrapporter udgivet af "Foreningen Danske Vinavler". Jeg sammen ligner nogle af de parametre som jeg fandt ud af var de vigtigste i første afsnit.

I sidste afsnit undersøger jeg hvordan klima forandringerne kommer til at påvirke mulighederne for vinproduktion i Danmark. undersøgelserne kommer til at bygge pål videnskabelige artikler om samme emne.

Hvordan lyder den opbygning? tænker du at der er noget jeg mangler noget eller bør uddybe noget?

Jeg har også haft lidt problemer med at finde ud af hvilke syrer der på virker pH niveauet mest. Jeg har to forskellige kilder som siger hver deres ting. begge kilder synes at være valide nok. Jeg har brugt den som giver mest mening i forhold til teorien og de data jeg har. Den anden kilde gør jeg opmærksom på i diskussionen.

Det drejer sig om æblesyre og vinsyre.

Og så lige en sidste ting. Jeg skriver jo opgaven på engelsk, men bruger stadig den danske version af "skriv med omtanke". Vil det være bedre hvis jeg brugte den engelske udgave? og i så fald, er det en du kan sende til mig?

Fra: Brøgger (lektor – jenb@eaaa.dk) <jenb@eaaa.dk>
Sendt: 15. november 2019 04:57
Til: Niklas Christensen <niklas_christensen@outlook.dk> Jens
Emne: Problemformulering

Jeg har vedhæftet den engelske udgave af skriv med omtanke, det vigtigste er naturligvis de engelske overskrifter, ellers er de skriftlige formalia identiske i den danske og engelske udgave.

Umiddelbart synes jeg at din opbygning lyder god. Jeg synes ikke du behøver at ændre din PF, den skal fungere som udgangspunkt, og det vil være fint at diskutere den bagefter.

I forhold til syrer og PH-værdi, synes jeg det giver god mening at gøre som du skriver

2. Harvest report from FDV

See extra material (Harvest report FDV)

3. Harvest report from Henry of Pelham

See extra material (Harvest report Henry of Pelham)