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Introduction

The Role of Fermentation

Temperature control in the winery involves manipulating temperature to slow down or accelerate winemaking processes or control chemical changes in the wine. Since wine is easily influenced by temperature, this technique is frequently employed for processes such as fermentation, cold settling, aging, and storage.

Temperature is a vital part of fermentation in winemaking. Fermentation occurs when yeast convert sugar to alcohol and carbon dioxide (Figure 1). Due to the exothermic nature of fermentation, temperature increases as sugars are metabolized. Heat production can be managed with the usage of external temperature control. This typically involves controlling tank or cellar temperature to keep the wine at a relatively lower temperature than it would reach naturally. Temperature manipulation changes the dynamics of the fermentation system and can be a beneficial source of control in winemaking.

Desirable fermentation temperatures vary for red and white wines. Red wine fermentation temperatures are optimally between 68-86°F (20-30°C), while white wine fermentation temperatures are recommended at or below 59°F (15°C) (Reynolds et al. 2001). Higher temperatures are favorable in red winemaking to enhance extraction of color, phenolics, and tannins from skins (Reynolds et al. 2001). The goal of white wine fermentation temperature control is to preserve compounds that contribute to aroma and flavor (Molina et al. 2007).

Experimenting with parameters of fermentation temperature can be beneficial, particularly when fermenting at lower temperatures for white, rosé, fruit, or aromatically delicate varieties. Lowering the temperature of the system causes fermentation to occur at a slower rate and contributes to several additional benefits. With modern technology and enhanced production methods, temperature control is attainable and manageable for wineries of any commercial size. The following paper will review the advantages of low temperature fermentations and how small (<10,000 cases) commercial wineries can implement this technique in their production.
Benefits of Temperature Control in the Winery

Primary Fermentation

Fermentation temperature affects many chemical and sensory properties of wine. Low temperature fermentation is advantageous because it preserves an array of aromas and flavors produced during primary fermentation (Torija et al. 2003). While wine aroma and flavor originates in the grape berry, *Saccharomyces cerevisiae* yeast cells give off various aromatic compounds through fermentation as secondary byproducts (Sweigers et al. 2005). The significant aromatics produced during fermentation are esters from fatty acids, organic esters, and higher alcohols (Gil et al. 1996). This class of aromatic compounds is influenced by fermentation temperature due to their low molecular weight, which makes them easily volatile (Sumby et al. 2010). In general, esters contribute fruity and floral aromas and flavors to wine. For example, ethyl hexonate is an ethyl ester that produces strawberry and green apple notes, and isoamyl acetate is an acetate ester that produces banana and pear aromas (Pambiachi, 2007).

The preservation of wine aroma and flavor due to lower fermentation temperatures has been well documented by research. Molina et al. (2007) found that higher concentrations of esters are developed at lower temperature fermentations due to a reduction of evaporative (volatile) loss, which increases stability of flavor and aroma compounds in wine. This study found that two aroma profiles were created in the same base wine when fermented at two different temperatures: 15°C versus 28°C. These findings exemplify that temperature creates differences in flavor and aroma.

Temperature control has also been shown to prevent the development of off-flavors, specifically volatile sulfur-containing compounds like hydrogen sulfide. Higher (above 30°C/86°F) fermentation temperatures increase the rate of fermentation, which may enhance production of undesirable byproducts produced by the yeast (Reynolds et al. 2001). The most common off-flavors associated with high temperature and rapid fermentation are sulfur-derived compounds including hydrogen sulfide, mercaptans (thiols) and disulphides (Gladish 1999). These compounds have been associated with aromas or flavors reminiscent of rotten eggs, cooked cabbage, skunk, and landfill, amongst other descriptors. While some of these off-aromas may be remediated with copper additions, use of clean lees, or other product additions, these techniques can be challenging to achieve a clean wine and time consuming on cellar personnel. Furthermore, additional flavor stripping of desirable aromatics may occur (Pickering et al. 2005).

Cooler fermentations have been shown to improve the clarity of wine (Comfort 2012). Clarity is typically achieved through racking, cold settling, cold stabilization, and fining, but low temperature fermentation may be an alternative option for enhanced clarity. At lower temperatures, yeast cells are less likely to give off colloids, thus improving clearness (Jackson 2014). Colloids derive from yeast and pectin, which form polysaccharides and aggregates after a physiochemical change (i.e. temperature), diminishing clarity (Drioli et al. 2010). Therefore, the use of lower temperature fermentation may minimize potential for cloudy or hazy wines by the end of primary fermentation.

Lowering fermentation temperature can also better control microbial growth and minimize potential spoilage (Jackson 2014). For example, at higher fermentation temperatures (above 21°C), some bacteria can produce undesirable amounts of diacetyl, creating a buttery flavor that may be unwanted (Bartowsky 2009). Also, spoilage yeasts such as *Pichia membranifaciens*, *Pichia anomala*, and *Candida* species can develop in the absence of proper temperatures, contaminating wine surfaces and producing unwanted acetic acid or ethyl acetate volatiles (Loureiro and Malfeito-Ferreira 2003). The growth of spoilage organisms is dependent on various factors, such as oxygen exposure. But, the use of temperature control can be an effective hurdle in minimizing their presence. This can potentially reduce the need for higher doses of sulfur dioxide through production. As consumer perception encourages limited sulfur dioxide use (Pretorius and Bauer 2002), such practices can be advantageous to wineries’ brands.

White wines, especially aromatic varieties (e.g. Reisling, Gewürztraminer, Traminer, Vidal Blanc), rosés, and fruit wines benefit from the effects of lower temperature fermentations (below 15°C or 59°F) to help retain their delicate aroma and flavor described previously. Red wines traditionally require higher temperature fermentation (~28°C, 82.4 °F) to achieve color and tannin extraction from the skins (Molina et al. 2007). Color extraction is particularly important for varieties with unique anthocyanin profiles (e.g. Pinot Noir) or minimal tannin concentrations (e.g. Concord, Chambourcin, Noiret, Chancellor) that struggle to develop color (Reynolds et al. 2001). However, the use of temperature control for red wine making is beneficial to ensure the temperature does not get too hot (>30°C, 86°F), which can lead to rapid fermentation, a stuck fermentation, or off-flavor development. Fermentation temperature has also been shown to influence red wine flavor (Sacchi et al. 2005). Maintaining fermentation temperatures close to 15-20°C (59-68°F) is ideal for fruity, light red wines (Reynolds et al. 2001). If fermentation temperatures reach 30°C (86°F), aromas and flavors associated with earthy descriptors become more dominant in the finished wine (Reynolds et al. 2001).

Malolactic Fermentation

Temperature has implications on malolactic fermentation (ML) in wine production. ML is a secondary fermentation where malic acid is converted to lactic acid by lactic acid bacteria (Lui 2002). Since this process requires a temperature range of 16-25°C, storage temperature of tanks and barrels are pertinent. Increasing cellar temperature for varieties in barrels going through ML may be required. However, winemakers can preserve other wines in the cellar by maintaining temperature independently in each tank.
Temperature can be manipulated for other purposes in ML, as well. For example, temperature is sometimes lowered for increased stability or for inhibiting ML (Davis et al. 1985). Additionally, some evidence shows that temperature may have an effect on the quantity of byproducts from ML bacteria, such as diacetyl production (Martineau et al. 1995). Diacetyl imparts a buttery flavor, which can be desirable in some wines (i.e. Chardonnay) but can be undesirable in other varieties or lead to spoilage (Bartowsky and Henschke 2004). At about 21°C (69.8°F), this byproduct accumulates to noticeable amounts (NPCS Board of Consultants & Engineers 2011).

**Other Production Opportunities for Temperature Control**

**Concerns with Stuck Fermentation**

One of the greatest concerns in low temperature fermentations is the risk of an increased lag phase and a decreased growth rate of yeast (Blateryon and Sablayrolles 2000). This is sometimes referred to as a "sluggish" or "stuck" fermentation. In these situations, yeast are minimally consuming sugar to convert it to ethanol (Bisson 1999). However, sluggish and stuck fermentations differ from slow fermentations. In stuck or sluggish fermentations, the rate of sugar consumption decreases dramatically toward the end of primary fermentation, while slow fermentations have a decreased sugar consumption rate throughout the entire duration of primary fermentation (Blateryon and Sablayrolles 2000). Stuck and sluggish fermentations do not directly result from the low temperature, but rather from other yeast stressors including, but not limited to: nitrogen deficiency, lack of oxygen, excessive clarification, microbial spoilage growth, pH, and fatty acid development (Van de Water 2000). However, the use of temperature control should be regularly monitored as cooler temperature can inflict some of these properties on the wine during fermentation.

When a stuck or sluggish fermentation occurs, winemakers are encouraged to test the wine to determine the cause and develop options for treatment. Delle Units are one way to evaluate a sluggish wine. With this method, it is first necessary to test alcohol and reducing sugar separately. Delle Units can be calculated using the equation [(4.5 x % alcohol) + % reducing sugar]. If the Delle Unit is at or above 65, restarting the fermentation is possible but will be difficult (Van de Water 2000). At or above 80, the chances of restarting fermentation are slim to none (Delfini 2001). When fermentation cannot be restarted, several measures can be taken to get the fermentation out of its sluggish state, such as introducing oxygen or re-inoculating with a hardy yeast strain (Sablayrolles et al. 1996).

Testing for Lactobacilli is another way to provide insight on a sluggish wine. A presumptive confirmation of Lactobacilli can be made using a phase contrast microscope to look for rod-shaped bacteria (Figure 2). Some species of Lactobacilli can produce acetic acid, and growth can occur during a time when S. cerevisae growth is stuck and wine is generally unprotected by sulfur dioxide (Edwards et al. 1999). The presence and growth of Lactobacilli can make restarting fermentation challenging. If no Lactobacilli or other spoilage bacteria are present, it is possible to take measures and get the fermentation progressing by slightly increasing wine temperature to more optimal ranges for yeast growth. If temperature increase alone does not restart the fermentation, re-inoculation of a hardy wine yeast is typically recommended (Van de Water 2000). Winemakers may need to ensure that all other conditions, including oxygen content, are optimal for their selected yeast to finish the fermentation to dryness. Many suppliers offer stuck or sluggish fermentation protocols to restart a fermentation.

![Figure 2. Image of Lactobacilli (surrounded by round yeast cells) in juice (Image provided by: Enartis Vinquiry, Wine Microbiology CD)](Image 318 x 399 to 570 x 588)

**Implementing Temperature Control**

One way to implement temperature control is through the use of controlled cellar temperature. A traditional cellar is about 55°F (15°C), but 50-60°F are acceptable cellar temperatures (Butzke 2010). Insulation of the facility can greatly assist with maintaining temperatures and minimizing energy costs, especially if the cellar is cooled by natural means (Smyth 2011). However, ambient temperature does not provide optimal control over internal tank temperatures. While red wine fermentations can generally suffice in cellar temperatures alone, white wines are best kept in tanks with more adequate temperature control (Butzke 2010).

Refrigeration systems are a more accurate way to control tank temperatures. In these systems, a refrigerant and a computer system are used to set the exact temperatures of the tanks internally. This is extremely helpful for regulating temperatures during fermentation and storage. These systems utilize jacketed tanks (Figure 3), a glycol refrigeration and heating unit, thermostats, pipes, and a chilling unit to the tank (Pisoni and White 2002). While the input of this system is relatively expensive at approximately $10,000, these systems offer winemakers the capability to make small and accurate temperature changes inside the tank.
Tank insulation is a basic form of temperature control that can be useful when purchasing jacketed tanks is too high of an initial investment. The most common form of insulation is a ~75 mm thick polystyrene insulation (Nordestgaard 2011), as shown in Figure 4. Insulation helps maintain internal tank temperatures and prevents condensation from forming on exterior tank surfaces (Smyth 2011). Condensation occurs when the tank surface temperature is below dew point temperature of the cellar (Delfini and Formica 2001). The reduction of condensation lowers latent heat, or energy absorbed or released during a phase change (i.e. gas to liquid, liquid to solid). Since state changes absorb a great amount of energy, this will decrease the stress on the refrigeration system and increase the efficiency of maintaining temperature (Smyth 2011). While insulation systems may not be ideal, they offer an alternative solution for wineries committed to improving wine quality by use of temperature management.

Stainless steel snakes (Figures 5 and 6) are another alternative way to control internal tank temperature at a reasonable cost. The snake, composed of vinyl tubing within corrugated stainless steel tubing, is placed in the wine tank. Glycol or chilled water flows through one tube and back through the other, and this recirculation alters wine temperature. This method requires either a glycol system or a source of cold or hot water for temperature fluctuations. A snake unit ranges in price, but is about a $200-500 investment depending on the style and size selected, in addition to supplier. The flexible snake variety (Figure 6) can easily be inserted through the top of a fermenter or small tank. For barrel usage, a bar-type snake can be employed (Figure 5).
Conclusion

Many notable wine regions have been recognized with an integrated use of temperature control, as this processing aid has been shown to improve wine quality dramatically. Temperature control is an essential tool when crafting high-quality wines, but winemakers are encouraged to monitor its use. White, rosé, fruit, and aromatically delicate wines have a greater need for temperature control during fermentation to enhance aroma and flavor retention. Red wines require higher temperature fermentations for color and tannin extraction, but can still benefit from temperature control throughout wine production.

There are a number of solutions for temperature control, based upon winery size and financial flexibility. These options provide incremental improvement steps directly related to wine quality, overall. Over time, wineries can slowly enhance temperature control steps to impact wine quality as economic means are retained.

References

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