

Diagnosis and Rectification of Arrested Fermentations

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Abstract

Slow and incomplete or arrested yeast fermentations are a chronic problem for the wine industry worldwide. These fermentation problems arise due to the presence and impact of various stress factors in the yeast environment, some of which are unavoidable and others of which are the result of inappropriate fermentation management decisions. As the yeast adapt to these stress conditions, fermentation rates are adjusted to maintain cell viability. If conditions become so severe that continuation of metabolic activity will result in cell death, cells will arrest metabolism and cease consumption of sugar and enter a specific resting phase. There is a period during which this process of stress adaptation can be reversed or modified and the yeast encouraged to maintain or resume fermentation rates. The ability to effectively treat a slow or arrested fermentation depends upon both knowing the source of the stress and being able to correct the problem.

The fermentation profile represents the rate of sugar depletion from the juice or must. This profile is altered in response to stress and it is often possible to ascertain the most likely causes of the problem by determining the nature of the deviation from a normal fermentation profile. Combined with knowledge of the fermentation management decisions and the specific compositional issues of the fruit or microflora of the winery, the incidence of problem fermentations in the future can be greatly diminished. However, oftentimes the discovery of an arrested fermentation occurs after the time at which the stress condition can be altered. In this case the only option left to the winemaker is to attempt to restart the fermentation. Success in restarting of fermentations is also dependent upon understanding how and why the arrest occurred.

Introduction

Problems with the progression of the alcoholic fermentation occur sporadically in wine production. Slow yeast fermentations allow greater retention of aroma volatiles, but the finishing date is difficult to predict and needed tank space may be unavailable for an indefinite period of time. Only a fraction of sluggish fermentations actually go on to arrest, but for those that will complete the process may take weeks if not months. During this time care must be taken to make sure the wine is protected against oxidative damage, as the wine might not be blanketed with sufficient carbon dioxide if the fermentation is slow [3]. Slow fermentations also give spoilage organisms the opportunity to become established in the partially fermented wine. We have routinely seen non-*Saccharomyces* yeasts, such as *Candida*, *Pichia* and *Torulaspora*, bloom in wines that are fermenting sluggishly. Lactic acid bacteria can also flourish under these conditions. The growth of these organisms can further stress *Saccharomyces*, leading to an arrest of fermentation. The lack of anaerobic conditions on the surface can further encourage the growth of aerobic spoilage organisms such as *Acetobacter*. Yeast surface films may also form. The characters produced by these organisms, acetic acid, organic acids and aldehydes, are generally not desirable in a table wine. To prevent the growth of these organisms, the wine must be either artificially blanketed with CO₂, argon or nitrogen, or careful attention must be paid to the levels of free SO₂ and other antimicrobial agents. Thus, dealing with a sluggish fermentation may cause the winemaker to make specific decisions that will have an impact on the style and quality of the wine.

It is often difficult to determine the difference between a fermentation that is merely slow, but will complete, and one that is or soon will be arrested. Arrested fermentations are subject to the same problems as noted above with sluggish fermentations, but action must be taken by the winemaker to assure completion of the process of sugar consumption, unless a wine with high residual sugar is desired. In a typical year the incidence of stuck fermentations in California is between 1-5%. Some varieties, such as Chardonnay and Zinfandel, seem more prone to arrest than others. In a bad year,

the incidence of stuck and arrested fermentations may reach 20%, and impact a broad range of varieties. Some wineries report more problems with arrested fermentations than others in the same region. On average, the incidence of arrest seems higher in cooler climates than in very warm regions. These observations underscore the importance of the condition and composition of the fruit in the incidence of fermentation arrest, as well as of fermentation management decisions. There are also important seasonal influences. In some vintages, many wineries simultaneously will have difficulty with completion of fermentations. In this case a variety of winemaking techniques have been used so it is clearly some environmental influence on the fruit that is the root cause of the problem. There are numerous causes of fermentation arrest [1,2,3,12], so determining the exact cause may be quite challenging.

Diagnosis of Fermentation Problems

The first step in diagnosing a problem fermentation is to be familiar with what a normal fermentation profile looks like for that winery or vineyard and yeast strain [4]. In a typical fermentation, glucose will be fermented more quickly than fructose, due to the differing affinities of the sugar transporters for these two sugars. *Saccharomyces cerevisiae* race *bayanus* strains generally display a faster fermentation with shorter lags than strains of *Saccharomyces cerevisiae* race *cerevisiae*, (Figure 1A, 1B) and both races of *Saccharomyces* differ in profile from *Saccharomyces bayanus*. It is important to note that *Saccharomyces cerevisiae* race *bayanus* is not the same as *Saccharomyces bayanus*. The two are easily confused given the similarity of their names and native environments.

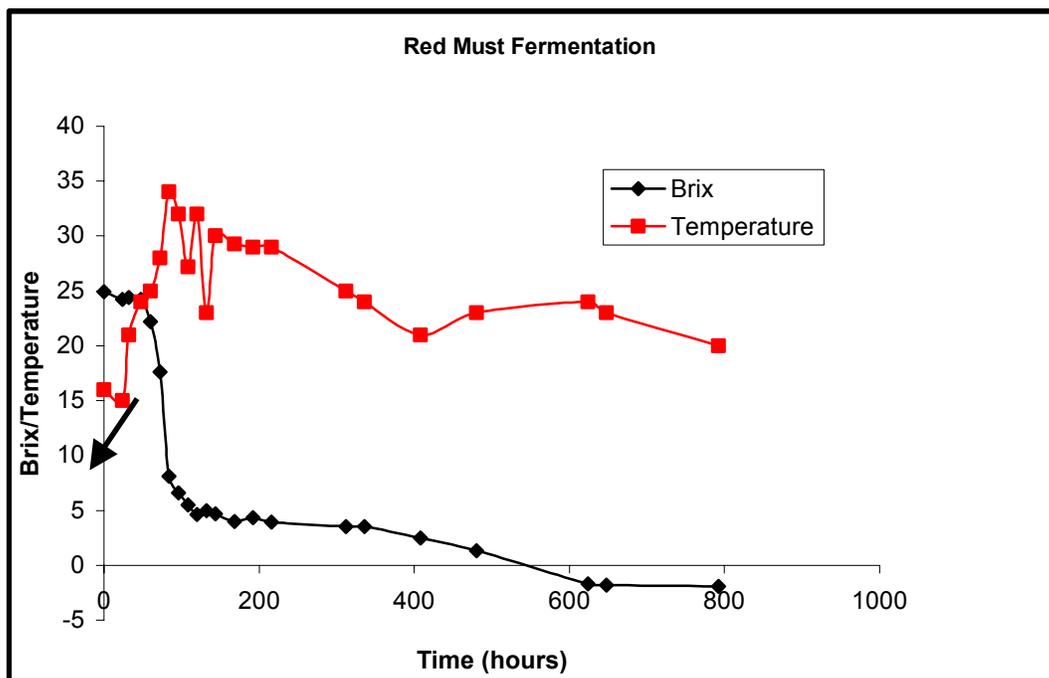


Figure 1A. Typical fermentation profile of *Saccharomyces cerevisiae* race *cerevisiae*. Arrow marks the transition point.

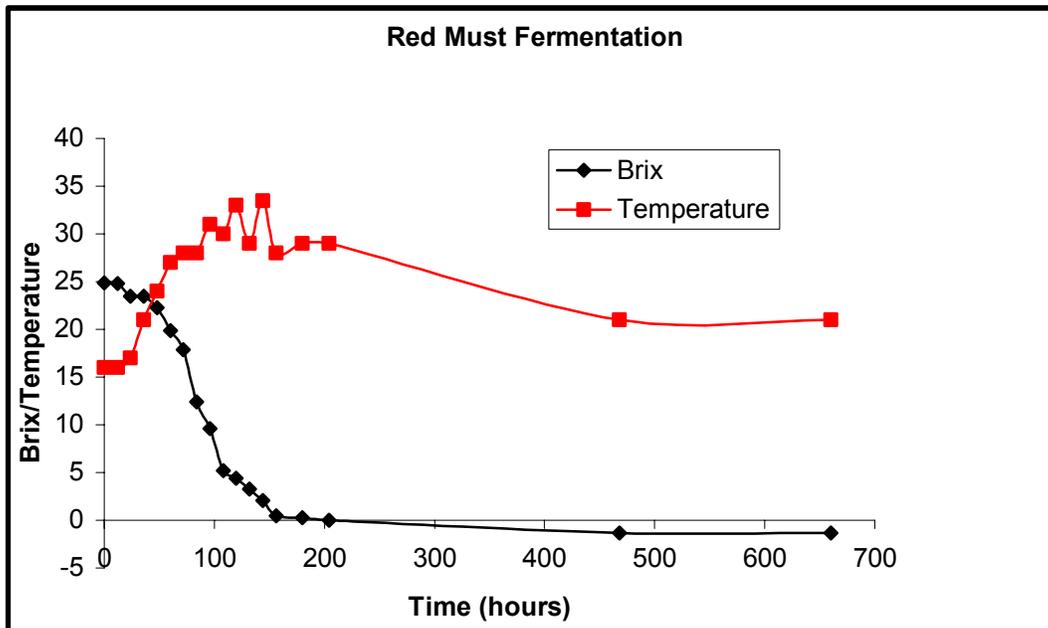


Figure 1B. Typical fermentation profile of *Saccharomyces cerevisiae* race bayanus.

Routine fermentation monitoring is necessary so that a normal profile can be developed for the conditions specific to a given winery or vineyard. It may be difficult to compare the kinetics of one must to that of another even if nutrient parameters, such as nitrogen levels, are known. There may be a range of acceptable fermentation profiles that are consistent with a complete fermentation from fruit from the same vineyard. This can only be determined by having a historical data set of fermentation profiles for that vineyard or fruit source. The more information available, the better the ability of the winemaker to differentiate quickly between normal and problem fermentations.

A strain described as a fast fermentor in one winery may be the slowest fermentor in another. This is due both to the differing composition of the juice but also to the differing fermentation management and must or juice processing strategies used by the two wineries. These include factors such as inoculation practices, nutrient supplementation practices (amounts and timing of addition), level of aeration, temperature of fermentation (average and range), juice composition factors, sulfur dioxide use, sanitation protocols and winemaking practices such as cold soaks and hot cap extractions, both of which will alter the composition of the microbial flora in addition to the yeast strain used [5,8,9,10].

The correct diagnosis of a problem fermentation is crucial towards both getting that arrested ferment to complete and for preventing the arrest from occurring in the future. There are four basic profiles of problem fermentations (Figure 2) [4]. In the first case, a long lag occurs which could lead to further problems or not, depending upon fermentation conditions. The second profile depicts a fermentation with a long lag that remains sluggish throughout. These fermentations never really attain a “normal” rate of progression. The next two classes of fermentations appear to start normally. In one case the fermentation gradually slows, as the fermentation rate is not simply not maintained. In the second case there is an abrupt and unexpected arrest of the fermentation.

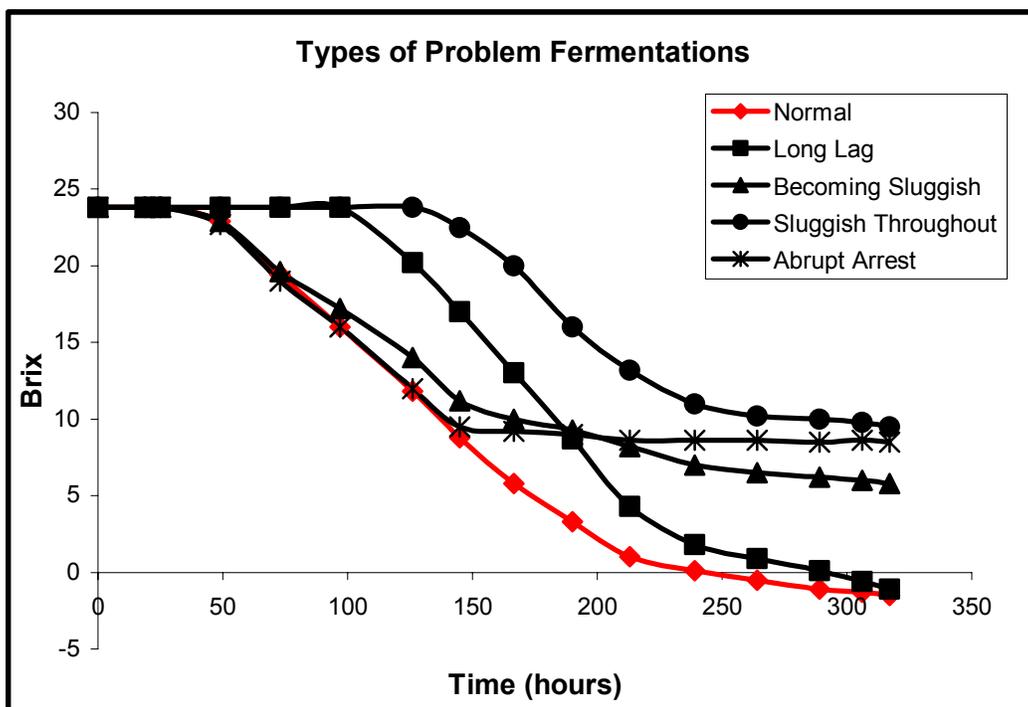


Figure 2. Types of fermentation problems observed in California production conditions

Long Lag

The length of initiation of a fermentation is dependent upon many factors. During this time cell division occurs and cell biomass builds. At the end of this time typically between 5×10^7 to 1×10^8 cells/mL have formed. The more cells present, the faster the fermentation will occur. If the wine is experiencing a long lag, a quick estimate of population numbers using a microscope or other cell counting method is a good diagnostic tool. This will allow the winemaker to determine if the lag is simply due to too few cells and the length of time required to build up a population of healthy cells. If this is the case, then once the population reaches a maximal level the fermentation will proceed normally. Low initial populations can be due to the low number of yeast naturally occurring on the fruit if the fermentations are not inoculated. If the fermentations are inoculated then low populations may be due to inappropriate rehydration of the culture or to the presence of inhibitory conditions or toxic compounds in the must or juice. If the fermentation was inoculated yet has not started in 24-48 hours, then it may be necessary to plate the cells or perform some other test of viability rather than just counting of the number of cells.

A common inhibitory condition concerns the temperature of the must or juice. If the juice was subjected to cold settling before inoculation or the must to cold extraction and the tank is not warmed up sufficiently the yeast can suffer a temperature shock. Similarly, if the must or juice has been subjected to thermovinification or to an HTST (high temperature short time) treatment to inhibit laccase or other unwanted enzymatic or microbial activities, and not sufficiently cooled before the yeast are added, a long lag may result. It is important for cellar workers to be trained and to understand the limitations of yeast physiology to avoid establishing conditions that negatively impact yeast viability.

Inhibitory conditions are factors such as the presence of significant grape berry damage so that the bioload of the juice or must is very high. The yeast is inhibited simply because of the greater level of microbial competition. If the fruit damage is great, then the wild microbes may have consumed many of the nutrients needed by the yeast resulting in a deficient juice. In other cases, the lag is caused not

by total numbers of other microbes but by the presence of specific organisms that may be making inhibitory substances such as organic acids. Frequently a mistake in addition of sulfur dioxide has been made and the levels are high (over 100 mg/L). In this case the yeast will lag until they are able to reduce the SO₂ content through detoxification.

If fermentations are inoculated from an already fermenting tank it is important to take the inoculum before it has produced too much ethanol. If the fermentation has accumulated more than 7-8% ethanol, the cells will have already adapted to ethanol and the shock of being placed back in a high sugar solution will lead to a long lag while they adapt to their new growth conditions. The incidence of long lags can usually be greatly reduced by paying careful attention to the conditions of inoculation. Native flora fermentations can have as few as 100 cells/mL or less, depending upon winery sanitation practices. If the yeast cell count is low, the long lag merely reflects the extra time needed to build the yeast population. In these cases it is often difficult to evaluate yeast counts since it is difficult to distinguish some of the wild yeasts from *Saccharomyces* under the microscope. A good way to determine the population density of *Saccharomyces* versus the other yeasts is to use a differential medium like WL agar. The non-*Saccharomyces* yeasts have very distinctive colony morphologies on this medium and are readily differentiated from *Saccharomyces*.

Slow Rate Over the Entire Course of Fermentation

The second class of aberrant fermentation profile is one that displays a long lag but never really develops a normal fermentation rate. These fermentations are sluggish throughout their entire time course. This generally means that the cells have not attained a high biomass level, and may be present at levels between 10⁶ to 10⁷ cells/mL or lower. In other cases, the biomass level is normal but the fermentation rate per cell has been reduced. This type of profile can be generated in laboratory fermentations by severely limiting nutrients or using extreme conditions for the fermentation, either very high (30°C or higher depending upon the strain) or low (less than 12°C) temperatures. These fermentations can usually be prevented from occurring by supplementation with appropriate nutrients, but this is not always the case. It is common practice in California to add nutrients to any juice or must that is suspected of being deficient. The higher the initial sugar levels of the juice the higher the level of nutrients needed to assure a complete fermentation so the projected ethanol content must also be considered.

Sometimes fermentations are sluggish throughout because the strain is a slow fermentor. In these cases, biomass levels appear normal but the sugar consumption rate per cell is low resulting in a slow fermentation. This may be desirable under certain winemaking conditions. These types of fermentation profiles can also occur in mixed strain fermentations. In this case the strain or strains that dominate the biomass early are not ethanol tolerant and will arrest growth and fermentation. Most microbes when present in pure culture will grow to a specific maximal cell count or quorum. Once a high cell density has been reached, further growth is inhibited. If the ethanol intolerant strains retain the ability to contribute to the "quorum" number in the fermentation, subpopulations that are ethanol tolerant will not be able to grow until this population diminishes in number. The non-tolerant population will eventually settle to the bottom of the tank, which then allows the other cells to grow. In some cases filtering the wine can assist this settling process.

In some California vineyards the vines have been subjected to high stress conditions in order to reduce vigor and keep crop load low. Such highly stressed fruit often yields sluggish fermentation problems even with extensive nutritional supplementation and use of sulfur dioxide or other agents to inhibit competing microbes. The negative impact on fermentation progression may be due to an imbalance of nutrients in these juices or to the specific presence of inhibitors of yeast activity.

Rapid Rate Becoming Slow

The most common arrested fermentation profile observed under California production conditions is the profile that appears normal at the onset, but then becomes sluggish and eventually arrests. This fermentation pattern is most often associated with reduced ethanol tolerance of the yeast. The

fermentation rate is normal until the ethanol level accumulates to an inhibitory concentration. Reduced ethanol tolerance can be caused by a number of factors: nutrient deficiency, lack of survival factors, extremes of temperature or pH, use of a strain with poor ethanol tolerance, presence of inhibitors such as acetate, organic or fatty acids or acetaldehyde, or the presence of other types of inhibitors impacting the fermentation rate. Preventing these types of fermentation problems can be very difficult because the nature of the factor limiting ethanol tolerance needs to be determined. For example, if the problem is caused by the accumulation of inhibitory fatty acids, adding nitrogen will not help the cells.

The current trend towards late harvest or high Brix fruit means that ethanol levels at the point of dryness will be high. A calculation of expected ethanol levels should be done at the beginning of the fermentation prior to deciding which strain to use as an inoculum. Commercial strains vary in their tolerances from a low of about 12% (w/v) to a high of 17-19% ethanol. These are the tolerances at a normal pH (above 3.2) and temperature levels (20-28°C). If the pH is lower or the temperature outside of this range the ethanol tolerance of the strain will be reduced, sometimes significantly. If a poorly tolerant strain was used, then arrest should be anticipated.

There are times when the stress imposed on the fermenting yeast does not immediately lead to arrest but instead impacts ethanol tolerance. This can be the case with a high temperature exposure early in fermentation. Reduction of the temperature allows fermentation to resume at what seems to be a normal fermentation rate, but as ethanol levels increase the fermentation becomes more sluggish. If the sugar level is high, then an inhibitory level of ethanol may be attained before all of the sugar has been consumed. Often fermentations arrested in this manner are very difficult to restart. This is likely because the arrested yeast has sent out signals to the community of cells that it has arrested and conditions are not tolerable. This encourages any new yeast in a re-inoculation to shut down as well. Alternately, it could simply be that the arrested cells are still competent to contribute to the "quorum" so that any new inoculum will simply not grow because the yeast culture is too dense. Some wineries have had successful restarts of a fermentation only after removing the existing biomass via a mild filtration.

Abrupt Stop

The last class of fermentation arrest that has been observed is an abrupt stop of the consumption of sugar. This usually accompanies some manipulation of the fermentation, either intentional or unintentional in the winery. Once ethanol levels exceed roughly 8% the ability of the cells to adapt to new conditions is limited. Abrupt arrest can accompany a temperature shock (high or low), a change in pH or sugar levels due to addition of juice, must or blending with another tank, acid adjustment, stress coming from the inoculation with malolactic bacteria, adjustment of SO₂. Sometimes these procedures are carried out because a tank is "nearly done" and more tank space is needed, but it can be difficult to know the existing stress level of the yeast and be able to predict if the manipulation will have an impact on completion of the fermentation. Many winemakers believe it is better if the malolactic inoculation is done before the yeast finish the fermentation as this gives both organisms the opportunity to use the remaining sugar. This occasionally works and both fermentations complete, but it also can lead to the arrest of the yeast fermentation due to the sudden introduction of a viable competing population or to any adjustment of the conditions that was done to accommodate the bacterial inoculum.

Most Common Causes of Fermentation Arrest

The emphasis on understanding the nutritional requirements of yeast during fermentation has virtually eliminated nutritional deficiency as a cause of fermentation arrest [1,5,12,13,14,15]. The main remaining causes of fermentation arrest would seem to also be preventable: temperature extreme, microbial inhibition, deficient yeast strains and poor management decisions. However some of these situations may be unavoidable given the limitations of technology and the conflict between keeping yeast under non-stressful conditions and winemaking style choices. For example, hot cap extraction has been shown to be important for the evolution of phenolic compounds and tannins. Cold soaks are also thought to positively impact wine quality yet at the same time elevates microbial loads [8,9,10].

The use of nutrients encourages spoilage organisms and may detract from aroma evolution from amino acid degradation. There are many issues that must be considered when determining the optimum fermentation management strategy to be employed at the winery. It is best to have thought this out beforehand so that appropriate strain or inoculation conditions are chosen at the beginning of fermentation rather than trying to correct a problem that has occurred.

The Most Important Fermentation Management Variables

There are several winery processes that impact fermentation progression [3,4]. These practices should be considered together as fermentation management variables rather than as independent operations, even though the reason for performing a given operation may be unrelated to the fermentation. In other words, if fermentation problems are to be avoided it is important to look at the overall process from the perspective of the microorganisms involved.

One of the most important variables that impact microbial activity is the level of aeration or oxygen exposure. Oxygen is an important survival factor, allowing yeast cells to synthesize sterols and unsaturated fatty acids needed for the construction of ethanol tolerant membranes. Other organisms and the enzyme polyphenol oxidase compete with *Saccharomyces* for available oxygen. Use of sulfur dioxide limits this competition with *Saccharomyces*. The timing of aeration is also important. Our studies and those of others have shown that the oxygen exposure is most effective when the cells are actively growing and actively synthesizing membrane components [15]. This allows the cells to construct the optimal membrane that they will need in order to complete the fermentation. Earlier or later aerations may serve to stimulate competing microbes thereby actually making conditions worse for *Saccharomyces*.

Mixing can also be an important variable. The impact of assisted mixing depends upon tank dimensions. In theory, mixing keeps yeast cells suspended and allows better access to nutrients. These factors may be important in some situations, such as when a vigorous fermentation is not occurring, but in many cases mixing for this purpose is not necessary as the fermentation process itself leads to adequate mixing. Mixing does serve to equilibrate temperature so that heat does not accumulate. This is in the best interest of the yeast, but can lead to reduced extraction. One of the main benefits of mixing is that aeration usually accompanies any mixing operation. Yeast cells tend to settle once they are no longer metabolically active. If cells are settling to the bottom of the tank, there is clearly some nutritional problem, which should be corrected rather than just mixing the cells back up.

It is also important to consider the type of fermentation vessel as a component of the overall fermentation management strategy. Stainless steel can be more efficiently cooled, and, although it will build up a biofilm, can be more completely sanitized than wood. Wood may be beneficial if a biofilm is in fact desired. A healthy biofilm can be advantageous in reducing the numbers of competing organisms in a fermentation and in assuring dominance by *Saccharomyces*. Use of wood would also be important if the winery wished to develop a unique and specific winery microflora.

Inoculation practices are also important. Not only is the choice of organism itself significant, but how the inoculum is prepared is equally critical. If commercial preparations are to be used, then the instructions on the packet should be followed. Some yeast will lose viability if left rehydrating in water for too long, so the yeast suspension should be used promptly. It is also important to make sure the temperature of rehydration is what is recommended. Cold or hot rehydrations also reduce viability. It is also important that the suspension be mixed appropriately. Too little mixing leads to clumping and inefficient rehydration while mixing that is too vigorous can also lead to a loss of cell viability. If a fermenting tank is being used as the source of inoculum, then it is important to make sure that tank is not too far along in its own fermentation. If it is beyond about 8% ethanol, then those yeasts will have started adapting to the higher ethanol content. Transfer to a low ethanol high sugar situation will lead to a lag as they readapt cellular components to the new environment. If yeast from a fermenting tank is to be used as inocula, then it is important to be certain that they are not deficient in any micronutrients. Commercial strains are prepared under conditions that provide the cells with ample vitamins and co-factors that can take several generations to deplete. This assures the winemaker that

even if the juice or must is deficient in an essential nutrient, the strain will not be. However, if the yeast has been pre-grown under limiting conditions a micronutrient deficiency could emerge. The same is true of native flora fermentations. Micronutrient deficiencies may be more common if native flora is used.

The temperature selected for fermentation is obviously very important as the rate of enzymatic processes is directly influenced by temperature. Warmer fermentations will ferment faster unless the temperature reaches a high enough level to become inhibitory. The temperature of other wine production practices can also influence fermentation rate and progression. Cold soaks encourage the growth of low temperature tolerant organisms such as the yeasts *Metschnikowia* and *Hanseniaspora*. The concentrations of these yeasts can increase dramatically during cold soak of the must, resulting in greater competition for *Saccharomyces* and possible micronutrient depletion. Allowing the temperature of the cap to reach high levels (40-50°C) can strongly encourage bacterial growth and inhibit yeast.

Nutrient supplementation obviously is important in developing and maintaining a healthy yeast population. However, nutrient supplementation should be done with care. If the juice or must already contains adequate nutrients, adding excess nutrients can lead to very rapid fermentations. Also, if the yeast leave nutrients behind, then the wine is not stable against microbial spoilage. Supplementation should be used when warranted. This would be in situations where there is insufficient nutritional content of the juices. Higher Brix juices and musts require higher nitrogen levels for completion of the fermentation. The timing of addition is also important. If nitrogen is added too late, meaning the ethanol level is too high, the yeast will not gain the benefit of the addition. However, it is important to understand the dynamics of yeast subpopulations when considering nutrient additions. Nutrients should be added so that the population that will complete the fermentation gains the benefit of the addition. For example, in some fermentations different subpopulations dominate at different times. Early nutrient addition encourages the growth of a strain that dominates early, but might also delay the death of this subpopulation thereby delaying the growth of the population that will be able to complete the fermentation. Molecular tools are now becoming available that will allow monitoring of yeast subpopulations. If a winery has a large population that appears healthy but that does not complete the fermentation, inoculation with a robust commercial strain should be considered.

Other juice and must treatments, such as cold soaks, cold settling and the timing and nature of pump over operations also impact the progression of the fermentation [7,11,16]. Holding of the juice or must at a low temperature favors the growth of non-*Saccharomyces* yeasts and can deplete the must of micronutrients due to the growth of other organisms [10]. The manner in which the cap in a red fermentation is extracted (pump over, punch down, sprinkler irrigation) can affect the temperature profile of the tank as well as the amount of aeration that occurs, and thus impact the course of the fermentation. Acidity and pH adjustment practices can also impact the progression of the fermentation. Fermentation will be faster and more complete at higher pH values, but the microbial competition will also be greater.

Other practices such as the use of sulfur dioxide or other antioxidants or antimicrobial agents or treatments, can affect the progression of the fermentation. The use of antimicrobial agents serves to limit the populations of organisms that can compete with *Saccharomyces*, but are usually not necessary if a healthy strain is used and there is ample nutritional content. Sulfur dioxide does serve another important role and that is in the inhibition of polyphenol oxidase. This enzyme competes with *Saccharomyces* for oxygen early in the fermentation. Inhibition of the enzyme eliminates this enzymatic consumption of molecular oxygen so it is available for the yeast.

Lees contact is another variable that impacts the fermentation. Yeast fermentation is generally more rapid in the presence of the grape lees. There may be several reasons for this. The increase in nutritional content, the binding of tannins and polymeric pigments by the lees so less is bound to the surface of the yeast, the better retention of oxygen as bubbles, better nucleation of carbon dioxide bubbles, and enhanced mixing all ca stimulate fermentation. In addition to lees contact, the solids level is also important. Higher solids levels also stimulate yeast fermentation. Solids could function like lees in many respects. Excessive clarification of juices has been strongly correlated with sluggish and slow

fermentations. Solids contain esterases, so in many cases winemakers wish to reduce solids level to protect the aromatic qualities of the wine.

The winemaking practices discussed above are often employed for their positive effects on wine quality. Indeed, if the winemaker only considered the nutritional requirements of the yeast, the fermentations would be rapid but the wine would be of a much lower quality. It is important to balance good wine making practice with sound fermentation management strategies so that the best of both worlds can be attained. If a winemaker will be performing an operation that reduces yeast vitality or imposes stress, then a strain tolerant of those conditions should be used for the fermentation. Fortunately, numerous well-characterized commercial strains exist from which to select. Strain selection can be optimized for the specific conditions of the winery.

Restarting Stuck Fermentations

There are times when either yeast stress was unavoidable or an error was made that resulted in arrest of fermentation. This can happen in spite of the best intentions of the winemaker. In this case, it is important to have a solid strategy for restarting an arrested fermentation. It is a common practice in wineries that use native flora fermentations for a small fraction of the wine to be inoculated with a commercial strain. If the native fermentations begin to slow or to be problematic they can be inoculated from the fermentations that were inoculated with a robust strain. Many wineries take out this "insurance policy" when using conditions that may prove too stressful for a favorite yeast strain that gives the appropriate flavor characters to the wine.

If a robust strain was used and the fermentation arrested, it can be challenging to restart it. As noted above, it may be necessary to remove some of the biomass of the arrested strain so that a new inoculum will be able to grow and not receive the signal that a terminal cell density already exists in the environment. This could be done by racking if the yeast has settled or by a moderate filtration. If the ethanol level of the fermentation that needs to be restarted is high (over 8%) then the new yeast inoculum will need to be pre-adapted to the ethanol. This can be accomplished by the process of serial reinoculation. In serial reinoculation, a yeast starter culture is gradually adapted to the ethanol content of the arrested wine. The yeast is inoculated into juice, which is mixed 50:50 with the arrested wine. This fermentation is allowed to proceed to an ethanol content above that of the arrested wine, and then mixed 50:50 with more of the wine, allowed to ferment, and then mixed again in a 50:50 ratio with the arrested wine. In this manner the yeast is slowly adapted to the conditions of the arrested wine. This process is more successful if the conditions causing arrest in the first place are known and corrected for the second inoculum, such as adding nutrients, aerating, or maintaining proper temperature control. A successful restart depends upon the development of an active and robust inoculum adapted to the conditions of the arrested wine. If the inoculum has gone too far into stationary phase, that is, is no longer metabolically active then the arrested fermentation will likely stay that way after reinoculation.

Finally, there are several yeast strains commercially available that have been selected for their ability to complete arrested fermentations [6]. These strains have low nutritional requirements and high ethanol tolerance. Oftentimes they merely need to be rehydrated and inoculated into the arrested wine without prior adaptation. They are also quite temperature tolerant. Such strains can be routinely employed as late inocula if there is concern that an arrest might occur.

Conclusions

A significant amount of information is known about the causes and means to avoid sluggish and arrested fermentations. Indeed, if yeast stress is avoided fermentations should complete. However, this is often at odds with quality wine production. Many winemakers believe some stress to the yeast is necessary in order to have a more complex and interesting wine. There is a fine line between imposing stress that will lead to greater complexity of desired end products and stress that will result in arrest. If a winery routinely monitors sugar consumption rates and has a reasonable understanding of normal fermentation progression, then the nature of the fermentation profile can provide significant information on the cause of fermentation arrest. Many causes of arrest are fully preventable.

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However, often factors beyond the control of the winemaker yield yeast stress leading to a slow or incomplete fermentation. Arrested fermentations can be challenging to restart, but with a good understanding of the yeast adaptation process, many arrested fermentations can be completed.

Artículo publicado en Tópicos de Actualización en Viticultura y Enología (CEVIUC). 22 y 23 de julio de 2004, Santiago de Chile, Chile.

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