Optimal grape maturity criteria is multi-faceted. Several important classes of compounds are biosynthesized during the berry growth period, before and/or after véraison (aromatic precursors, phenolics, hormones, organic acids, etc.), while others are provided by roots and/or leaves (water, minerals, sugar, etc.). Several of these compounds change during the ripening stage of the grape berry.

These changes do not occur in a highly coordinated fashion, and, instead, suggest a series of independently regulated pathways of synthesis. These pathways differ between cultivars and are also influenced by seasonal climatic factors and vineyard practices. To add to this complexity, each berry within a bunch has its own dynamic of growth and maturation.

The question therefore can be raised as to how to explain and manage this complexity at both the scientific and practical levels? There are several methods already used by viticulturists and winemakers to choose an appropriate harvest date. All of these methods are highly relevant when put in the context of a winery’s strategy.

The different methods are:

A. harvest according to previous knowledge of a specific cultivar and vineyard, without any analysis but through visual observations, building up personal experience as a producer (or a traditional grower);

B. harvest according to one criteria that requires simple, routine analysis, such as Brix (the most commonly used indicator in the wine industry today);

C. harvest according to berry tasting, which can be efficient but is also very subjective; the decision depends on the personal experience and training of the taster;

D. harvest using a series of indicators and appropriate analysis methods. This implies that the necessary apparatus is available at the estate, or in an appropriate nearby laboratory. Knowledge in interpreting analytical results to take the appropriate action is required. The cost per acre has to be considered;

E. harvest using new tools and taking into consideration new scientific findings. This implies the ability to access the information, understand, assimilate it, and implement it successfully. In addition, the ability to afford this new technology, which may be expensive, has to be considered.

This list is not complete. When scientific indicators are used to determine harvest date, it is important that appropriate skills and information be transferred to the people who are using them. For example, such skills include being able to interpret analytical data, using analytical tools properly with a standard protocol, and sampling correctly. The important question of transfer, which has many facets, will not be discussed

Figure 2: White cultivars berry aromatic model (from Vivelys, France). The method uses the berry color evolution from véraison to harvest (berry hue or tint angle in degree: y-axis) and the berry sugar loading concept (x-axis). According to the evolution of the berry hue, the method allows to predict the wine style (see Table I). The Sauvignon Blanc berry aromatic model for the Western Cape region is under development and calibration by Distell group within a collaboration with the Department of Viticulture & Oenology (Stellenbosch University).
**Optimal grape ripeness**

Optimal grape ripeness is defined according to the style of wine required, which in turn is dictated by market demand or by the objective to produce a wine that respects the expression of a typical terroir-related character. Professionals working within the sector are therefore obliged to accurately characterize the grapes in order to make an informed decision to optimize the harvest date and adapt fermentation practices to obtain a target wine style. This characterization also provides important information on vine growth patterns.

One of the most important and difficult parts of a viticulturist and winemaker’s job is to predict wine style from the berries and the enological process. Classical indicators like Brix, malic and tartaric acids, titratable acidity, tannins, anthocyanins, etc. are strongly related to the perception of the taste of the wine. It would also be very useful to be able to predict or predetermine the future wine style in terms of aroma. This is one reason why the question of fruit maturity and optimal ripeness is still a relevant subject in the scientific community and the wine industry.

Grape quality is a crucial determining factor in the quality of the finished wine, and is fundamentally linked to optimum ripeness. But how is grape quality determined? What are the relevant parameters of the berry that enable the dynamics of ripening to be monitored?

**Berry color development for white cultivars**

Berry color is a new and important indicator, notably of the ripening of white varieties, because a proven relationship exists between berry color and their aromatic potential. Carotenoids, phyto-protective pigments produced by photosynthesis, are localized in the skin and are considered as biogenetic precursors of C$_{13}$norisoprenoid glycosides. Certain aromas are derived from the degradation of such skin pigments.

The technology to measure berry skin color has been developed by Vivelys Society (France) in partnership with Montpellier SupAgro (France) and is currently being used in the Northern and Southern Hemisphere. The method uses the development of the berry tint angle (berry color evolution), which is determined using optical technologies, as an indicator of berry ripening versus wine aromatic profile.

This method is based on an indirect relationship between the evolution of the berry tint angle (according to the HSL model – Hue, Saturation, Luminescence; Figure 1) and the wine aromatic profile.

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**Grape quality – a complex and relative concept**

Grape quality is not a simple concept, that depends on several vineyard parameters and on the wine style goal. A classic example is Chardonnay grapes produced for making Champagne and Burgundy respectively. The ideal ripening conditions of this variety will not be the same for production of these two quite different wines.

In other words, a specific wine style demands a particular set of ripening conditions, and the concept of grape quality at harvest should be considered in terms of the required wine composition and sensorial properties – in short, what grape quality for which type or style of wine? Particularly, what is meant by grape berry quality?

Apart from the hygienic quality that depends on grape bio-aggressors (fungi such as Botrytis cinerea, yeast such as Brettanomyces, insects etc.), a discussion of the grape berry profile in terms of harvest potential would be more pertinent than the quality of the grape berry itself which is a far more ambiguous concept.

Grape berry profile is a combination of different biochemical parameters of the fruit, associated with other factors, such as berry skin color development for white cultivars, extractability during fermentation and fruit compartmentalization. Harvest potential describes the potentiality of a vineyard block in terms of grape profile, whereas typicality is the reproduction of a given grape profile based on its conformity to a specific type in an identified terroir.

The aim of this paper is to describe and propose the use of a recent indicator to monitor ripening of white cultivars in relation with the desired wine style (for red cultivars see Deloire, 2011).

A new indicator should be used in conjunction with other classical indicators of berry ripening. Berry color development and the associated reasoning for the method will be presented below as a relevant new indicator.
sensory analysis (Figure 2), and as can be seen, has potential to be very useful for profiling berry maturation, harvest potential, and selection of the most appropriate harvest dates for white cultivars.

In addition, measurements can be taken with relative ease and, in a short time, should the instrumentation be available. This technology is currently being refined and used for the wine regions of the Western Cape coastal area of South Africa, within a collaboration with Distell group and Winetech financial support. Table 1 shows examples of berry hue thresholds and related style of wine for Sauvignon Blanc in the Western Cape region.

The first results of research conducted in South Africa in 2009 show different rates of berry color evolution, from green to yellow, which seem to be mainly related to temperature (meso- and micro-climatic levels) and light at the bunch level (micro-climatic level). The wine style (tropical/citrus/grapefruit or green/herbaceous/asparagus characteristics) is mainly related to the climate of a specific region (hot or warm versus cool). For the Western Cape area, a cool area is characterized by fresh nights during the ripening period (fresh night index,21) and by the sea breeze effect,12,3,4,6 which cool down the berry temperature during the ripening period.7 No direct relationship has yet been established between berry color development from veraison to harvest, and Brix and titratable acidity. Although berry color monitoring will give a far better understanding of berry aromatic sequence evolution during ripening, it is therefore still recommended that at least two of the other classical indicators are used to monitor sugar and acidity in order to achieve the correct wine style.

This text was edited from the original publication in Wineland magazine, April, 2011.

Acknowledgements

WINETECH and THRIPS for funding support. VIVELYS France (MM Nicolas Bernard and Emmanuel Bronen) for helpful, important technical support and for providing the Dyostem machines to US-DVO and Distell. DISTELL group for relevant support regarding the calibration and development of the berry color evolution method from 2009 onwards (Isabel Habets, MM MP Botes, P. Van Rensburg, V. Bonnardot, M. Lambrecht). 2009 “Preliminary results on the effect of temperature on Sauvignon Blanc (Vitis vinifera L) berry ripening. Comparison between different macro climatic wine regions of the Western Cape Coastal area of South Africa.” 31st conference of the South African Society for Enology & Viticulture, Somerset West, November 18-19.


Berry ripening, and wine aroma

BY Alain Deloire, Department of Viticulture & Oenology, Stellenbosch University, South Africa

Optimal maturity of grapes depends on multi-faceted criteria. Several important classes of compounds are biosynthesized during the berry growth period, before and/or after véraison (aromatic precursors, phenolics, hormones, organic acids, etc.), while others are provided by roots and/or leaves (water, minerals, sugar, etc.).

Several of these compounds change during the ripening stage of the grape berry. These changes do not occur in a highly coordinated fashion, and instead, suggest a series of independently regulated pathways of synthesis. Each pathway is influenced by seasonal climatic factors, vineyard practices, and cultivar.

The concept of terroir needs to be considered in relation to harvest and the desired wine style. The concept of terroir is a complex notion because, apart from climate and soil, it includes people, social organizations, and activities such as agricultural practices.

Geographical origin is important for products that lay claim to a terroir-linked typicity. Measuring the terroir effect on an agri-food product remains difficult for both trained experts and consumers, for whom the appreciation of the product or lack thereof remains the principal criterion in their evaluation. This does not exclude the ability to recognize the product’s properties, but it should be remembered that the perceived taste and aromas will be transformed by the individual’s experience into a unique overall sensory impression.

Fruit maturity and wine style

It would seem that development of the terroir concept over centuries is a strong indication of its increasing social importance. Terroir-derived food products, the preservation of landscapes, and development and encouragement of people are important values that merit current support and advocacy in the future.

Optimal grape ripeness is defined according to the wine style goal, which in turn is dictated by market demand or by the objective of producing a wine that respects the expression of a typical terroir-related character. Professionals working within the sector are therefore obliged to accurately characterize the grapes in order to make an informed decision about optimum harvest date, and to adopt fermentation practices to obtain a target wine style.

The quality of the grapes is a determining factor in the quality of the finished wine. But how is grape quality itself determined? What are the relevant parameters of the berry that enable the dynamics of ripening to be monitored?

One of the most important and difficult parts of a viticulturist and winemaker’s job is to predict the wine style from the berries and the enological process. The classical indicators such as Brix, malic and tartaric acids, titratable acidity, tannins, anthocyanins, etc. are strongly related to the perception of the wine’s taste (mouth feel). Therefore, it is also highly useful to be able to predict or predetermine the future wine style in terms of aroma from the fruit itself.

The Department of Viticulture & Oenology (Stellenbosch University, South Africa) and the National Wine and Grape Industry Centre (Australia) are leading an ambitious project to study the berry aromatic sequence during fruit maturation in relation to wine flavor profiles. The scientific aim is to better understand fruit growth and composition (fruit quality) and to develop practical tools and methods to predict or predetermine wine style in terms of aromatic characteristics.

Berry ripening, wine flavors, and the elaboration of low-alcohol wines are among the priorities of the worldwide wine industry today, mainly in the context of climate change (increase of temperature and evapotranspiration) and water scarcity.

The research program (financed by WINETECH, THRIP, and DISTELL), has allowed the transfer of two methods to the wine industry, for red and white cultivars respectively, to predict harvest date and the associated wine style. The research in Australia is starting at NWGIC (Charles Sturt University).

How to predict harvest date

The method for red cultivars uses the concept of berry sugar loading and the method for the white cultivars uses the berry color evolution (Deloire, Wineland, January 2011). Both methods are based on the fact that, the berry aromatic sequence seems to be preprogrammed from veraison onwards, and therefore it can be predicted. The berry aromatic sequence could be explained as follows:

Red cultivars — When sugar per berry reaches a plateau (or slows down), there are four stages which progress in the same sequence (Figure 1),

Stage 1: Fresh fruit/green plant-like aroma/unripe plum;
Stage 2: Neutral/spicy like aroma or pre-ripe (mature berry aromas);
Stage 3: Mature berry aromas such as blackcurrant, raspberry, cherry;
Stage 4: Over-ripe aromas such as dried fruit, prune.

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Stage 1 always occurs from 10 to 20 days onwards after sugar per berry has reached a plateau (stopping of berry sugar loading or slowdown of berry sugar accumulation), respectively for Merlot and Cabernet Sauvignon (Figure 1).

Stage 3 always occurs from 20 to 40 days onward after sugar per berry has reached a plateau. Between fresh and mature fruit stages, stage 2 is called neutral/spicy or premature (according to the terroir units) and may vary according to the situation. Stage 2 has to be avoided, when it is considered neutral and could be determined/predicted using the sugar-loading method.

The terroir (soil and climate) and cultural practices will play a role mainly on the intensity of the fruit’s aromatic profile. There is no direct relationship between fruit, Brix or titrable acidity levels and the berry aromatic sequence stages, meaning that fresh, neutral, and mature stages can be reached at the same Brix value. In those regards, the model shows that harvest using only Brix value is not relevant.

**White cultivars** — The method is using the berry color evolution (Table 1).

- > 80 = green/asparagus/citrus/unripe
- 80 and > 70 = tropical/grapefruit/citrus/boxtree
- < 70 = fermentative/neural/terpene

This text was edited from the original publication in Wineland magazine, January 2012. Many thanks to Marianne McKay, Jeanne Brand, Nina Muller (University of Stellenbosch), Drs Sulette Malherbe and Leanie Louw (Distell) and Dr. Dominique Valentin (Dijon, France) for their relevant input in sensory science.

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**Table 1: Thresholds of berry hue (in degree) according to the HSL model of color representation and expected style of wine for most white cultivars. Simplified thresholds (berry color evolution occurs irrespectively of Brix and titratable acidity to a certain extent).**

<table>
<thead>
<tr>
<th>Berry hue thresholds (in degree)</th>
<th>Expected wine aromatic profiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 90</td>
<td>Green/unripe</td>
</tr>
<tr>
<td>90 – 85</td>
<td>Green/asparagus</td>
</tr>
<tr>
<td>85 – 80</td>
<td>Asparagus/citrus</td>
</tr>
<tr>
<td>80 – 75</td>
<td>Asparagus/Tropical fruit/ grapefruit/citrus</td>
</tr>
<tr>
<td>75 – 70</td>
<td>Tropical fruit</td>
</tr>
<tr>
<td>70 – 65</td>
<td>Fermentative/terpene</td>
</tr>
<tr>
<td>65 – 60</td>
<td>Phenolic/neural/terpene</td>
</tr>
</tbody>
</table>
Sugaring loading can be defined as the accumulation of the quantity of sugar per berry, expressed as milligrams (mg) per berry, from veraison onward. Veraison corresponds with the onset of fruit maturation.

In the grapevine, fruit maturation starts with an abrupt softening of the berry (within 24 hours). This softening goes hand-in-hand with sugars being actively introduced into the berry (sucrose rapidly hydrolyzed into hexoses: glucose and fructose). In red and black cultivars, veraison is characterized, after softening, by skin coloring as a result of the biosynthesis of anthocyanins.

Accumulation of sugar loading in grape berries gives an indication of the ripening process from a new perspective and is a novel approach to identify practical indicators to obtain particular styles of grapes and wine. Sugar loading may also provide information about ripening kinetics and enable the principal phases of ripening to be distinguished. This information provides a greater understanding of how grape quality develops in the vineyard.

**Sugar loading calculation**

Phloem sugar transport, principally to the flesh cells, has been characterized in studies of plant-to-berry sugar loading and phloem sugar unloading, notably by the peripheral vascular system of the berry. Phloem sugar unloading into cell vacuoles occurs mainly via an apoplastic mechanism, which requires the intervention of hexose transporters.

From the above-mentioned studies, it can be concluded that sugar loading into the berry, coupled with the dynamics of sugar concentration changes, may be considered a useful indicator of grape quality. It takes into account the accumulation of sugar per berry (mg per berry) and therefore enables the kinetics of sugar concentration changes to be monitored.

Kinetic monitoring of the quantity of sugar per berry may be considered as a method of measuring the vine's physiological functioning and in particular photosynthesis, which is a reliable indirect indicator of temperatures to which the vine is subjected under given conditions over a specific time period and grapevine water status.

Active sugar loading is calculated on the basis of berry volume (or berry fresh mass) and sugar concentration.

**Example of sugar loading calculation**

For a berry with a ripeness level of 25° Brix:

1. **Convert 25° Brix to probable alcohol:**
   
   $25 \times 0.59 = 14.75°$ in probable alcohol, where 0.59 is the coefficient used for yeast activity to convert Brix to probable alcohol (this coefficient to be adapted to the probable alcohol level).

2. **Determine mg of sugar per ml probable alcohol:**
   
   To obtain 1° probable alcohol, 17 g/L of sugar is required.
   
   $14.75° \times 17 g/L = 250.75 g/L$, which is equivalent to 250 mg of sugar per ml (in this example).

3. **Calculate quantity of sugar per berry:**
   
   In addition to measuring °Brix, the volume of a berry (or berry fresh mass thereof) should also be measured so that the quantity of sugar per berry can be calculated. Approximately 50 berries should be used to determine berry fresh mass so that the single berry fresh mass is an average of a berry population.

   To determine quantity of sugar per berry, multiply 250 mg x the volume of a berry (or the berry fresh mass thereof), because for many varieties there is a linear correlation between berry volume and fresh mass.

   Please take into consideration that this calculation is only an approximation of sugar loading into berries. This is due to many reasons, among others: seed volume and number, sugar distribution between skin and pulp. Despite the calculation being an approximation with shortcomings, it nevertheless is a useful indicator, and its use is becoming more common.
Profiles of sugar loading

It is possible to distinguish three principal sugar loading profiles:

1. **Continual and rapid loading** — This type of sugar loading occurs from veraison and is related to the active functioning of carbon production sources (leaves) that supply plant sinks (berries, secondary shoots etc.) during their growth phases. It is therefore often associated with significant vegetative growth and greater berry volume. Phenolic maturity is not affected. This type of loading is often considered beneficial for production of rosé, fresh fruity red wines or pleasant aromatic white wines.

2. **Slow sugar loading/inhibition of ripening** — Low sugar content per berry, associated with a slow loading rate, can be considered to “block” ripening, and this could be indicative of vine imbalance. If major physiological problems such as mineral deficiencies, viral diseases, etc., are excluded, blocked ripening can often be related to excessive water deficit, heat waves or an excessive crop load in relation to the exposed leaf surface. In all grape varieties, this type of situation is far from ideal in terms of standard vinification practices in white and dry red wine production. Furthermore, in relation to red and black grapes, this situation may be associated with blocked technological and phenolic maturities. Ultimately, it may be necessary to adapt the fermentation procedure to this type of grape, with thermovinification and short maceration with limited extraction being preferred options.

3. **Sugar loading presents a plateau phase** — Vines showing this tendency present a phase of active sugar loading in the berry (ripening), followed by a plateau representing a cessation of sugar loading (or a slowing down of sugar accumulation), and corresponding to maturity. In some cases, there is a third phase corresponding to a possible decrease of the quantity of sugar per berry (over-ripening). To date a probable explanation for the occurrence of this phase has not been identified.

Theoretical berry sugar loading curves (accumulation of berry sugar content over time) are presented in Figure 1. The implications of this curve in terms of defining the finished wine are important. Depending on whether grapes are harvested in the early, mid-, or later stages of the plateau phase, the wine will be characterized by fresh fruit, neutral-spicy/pre-ripe or mature fruit flavors, respectively (Figure 2).

**Berry Aromatic Sequence (BAS)**

The curve in Figure 2 demonstrates that selection of a harvest date according to the quantity of sugar per berry in conjunction with other indicators (titratable acidity, malic and tartaric acids, pH, berry volume, berry tasting, tannins, anthocyanins, etc.) enables different wine styles to be produced. Hence, for a balanced red wine, complete ripeness will be achieved between one and five weeks after the cessation of sugar loading (Figure 3).

Once the plateau phase of berry sugar loading has been reached, the evolution of ripening will depend on other factors such as cultivar, bunch microclimate, leaf/fruit balance, vine water status and the climate mainly during berry ripening (maximum temperature, night-time coolness, sea breeze, wind speed, late-season rains and various factors that are quantifiable).

It should be noted that the plateau phase in sugar loading may be reached at different sugar concentrations (Brix), depending on cultivar and environmental conditions. A red cultivar, with a very high sugar concentration (Brix) when the maturity plateau is reached, will not always be desirable for production of certain types and/or wine styles.

Monitoring ripening with various indicators, coupled with appropriate analytical data measurements such as berry fresh mass or volume, Brix, sugar load-
grape-growing, evolution of titratable acidity, malic acid, tartaric acid, pH, color evolution, anthocyanins, tannins, berry tasting, etc.) enable decision-makers to determine the optimum harvest date, a major consideration in determining grape quality.

Such monitoring provides a greater understanding of vine morphological and physiological parameters during ripening, and therefore vineyard practices can be adapted to production objectives.

There are, in most vineyards, several potential optimal harvest dates and optimal ripening levels according to the desired wine style. The wine is therefore created in the vineyard!

As the world becomes more technologically advanced, more advanced technology is being developed to monitor berry ripening. This technology is rapidly being adopted by large estates and cooperatives to enhance their marketing edge. PWV

This text was edited from its original publication in the January 2011 Wineland magazine.

Acknowledgements

Many thanks to Vivelys and Nicolas Bernard (Montpellier, France) for providing the data on berry sugar loading, WINETECH (South Africa) for funding and Distell for participating to the development of the method in South Africa.

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