GRAPE MATURITY

Section 4.

Berry Sensory Analysis (BSA)

Berry sensory analysis (BSA) follows a standardized set of 20 descriptors, assessing the ripeness of wine grapes by judging fruit stems, skin, pulp, and seeds separately (Winter et al., 2004). It uses a four-point scoring system to determine relative ripeness and the change in ripeness over time. As with any maturity analysis, this system is most advantageously used in conjunction with other assays.

An aroma evaluation of the fruit is important in assessing relative maturity. A typical progression of aroma descriptors for Cabernet Sauvignon grapes includes the following:

- green, under-ripe
- lightly herbaceous
- herbaceous
- minty–black currant
- blackberry
- jam–prune-like

Aroma/flavor masking, and the fact that many compounds are present as conjugated bound precursors, makes fruit aroma/flavor evaluation only a rough approximation of the aroma/flavor potential of the wine. The following should be noted:

- Most aroma/flavor compounds are likely synthesized independently of each other in the berry.
- High concentration of one aroma volatile is not necessarily correlated with high concentration of another.
- Synthesis of most aroma/flavor molecules varies dramatically with the season and vineyard management practices.
- Grape aroma/flavor compounds have different rates of loss in the fruit.

Because of differences in detection thresholds among evaluators, it is important to have as many evaluators as possible. It is also important to use contrasts when evaluating fruit. The best approach is to freeze a sub-sample of the fruit collected. At the next sensory evaluation, the frozen sub-sample from the previous review is thawed and the sensory features compared with the current sample. Contrasting allows for the detection of changes occurring with time, and the presence or absence of undesirable aroma/flavor, textural, and visual characteristics.

Optimal sensory evaluation involves an understanding of the following:

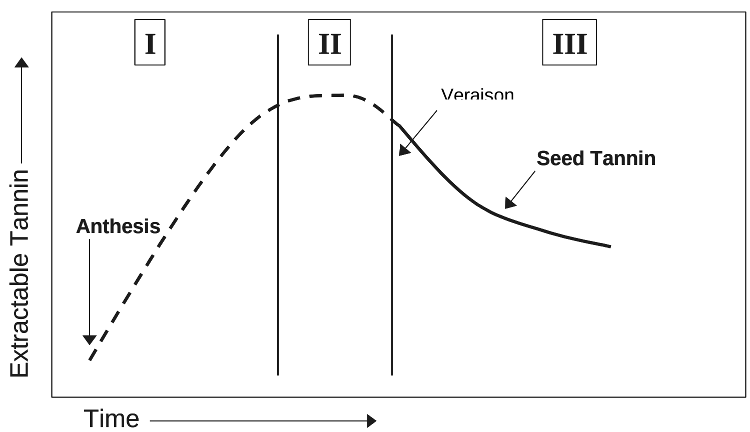
- standardized and controlled environment
- representative sample
- optimal sample temperature
- elimination of bias
- importance of sample contrasts
- use of skilled evaluators
- number of evaluators and evaluations required to gain a true picture
- minimize presentation effects (adaptation)

- minimize physiological effects (time of day, not tasting for a period after eating or drinking)
- using the proper testing method

In addition to berry aroma/flavor, cluster stems can also be evaluated to aid in the assessment of berry ripeness. Stems undergo a change from green or unripe, to brown or ripe, to overripe or brittle. These changes are seasonal and varietal-specific. Green or un-lignified stems, including cap stems, which enter the fermentor, can negatively influence the tannin profile of the resultant wine.

During fruit maturation, seeds may “mature” at a different rate than Brix changes. As seeds mature, they change color from green to brown to dark brown. This color change represents oxidative reactions and corresponds to the degree of extractable tannins (Figure 6).

Figure 6. Changes in Seed Tannin Extractability



Source: J. Kennedy (2000)

Tannin extractability decreases during phases II and III of berry development. In conventional red wine production, seed tannins make up over 60% of the total tannin concentration (Singleton, 1988). It should be noted that changes in tannin maturity can occur late in the season, when it would appear that no additional ripening can transpire.

Some winemakers taste seeds in order to assess grape maturity. However, seed bitterness may be overwhelming, and many are not able to distinguish levels of seed bitterness. The physical characteristics of the seeds, including color, uniformity of color, brittleness, and texture, are important indicators of fruit maturity. Because of the quantitative and qualitative role of seed tannins in red wines, seed evaluation is highly important.

Non-Conventional Maturity Evaluation Tools

Because of the difficulties associated with sensory evaluation, there is a need for a simple, reliable, and objective technique for evaluation of fruit maturity. If the optimal aroma composition of fruit at harvest could be defined, instrumentation analysis, such as an electronic nose, would be a useful tool for routine assessment of optimal maturity.

A major challenge for the grape and wine industry is to replace time-consuming laboratory analyses, used in process and control quality monitoring, with new application techniques that are fast, precise, and accurate. For example, red grape color measurements represent the need for rapid analytical methods that may be used as objective indicators of grape quality, grape ripeness, and/or uniformity of ripeness. Substantial progress has been made in this area.

Many of the new technologies being developed for component analysis are spectroscopic techniques that operate in the visible (Vis), near infrared (NIR) and mid-infrared (MIR) wavelength regions of the electromagnetic spectrum. Additionally, research in non-invasive testing using fluorescence or photoluminescence, T-rays (terahertz radiation, or the far infrared region of the spectrum just before microwaves), X-ray and gamma rays for some grape and wine components may prove successful (Smith, 2006).

The analysis of grape and wine volatiles represents a substantial challenge. Conventional analyses of volatiles are mostly conducted using gas chromatographic (GC), GC mass spectrometry (GC-MS), and GC olfactory (GCO) methods, and involve very expensive equipment, time- and labor-intensive steps, methods development, sample preparation, separation of specific volatile compounds using appropriate chromatographic columns, and chromatogram interpretation.

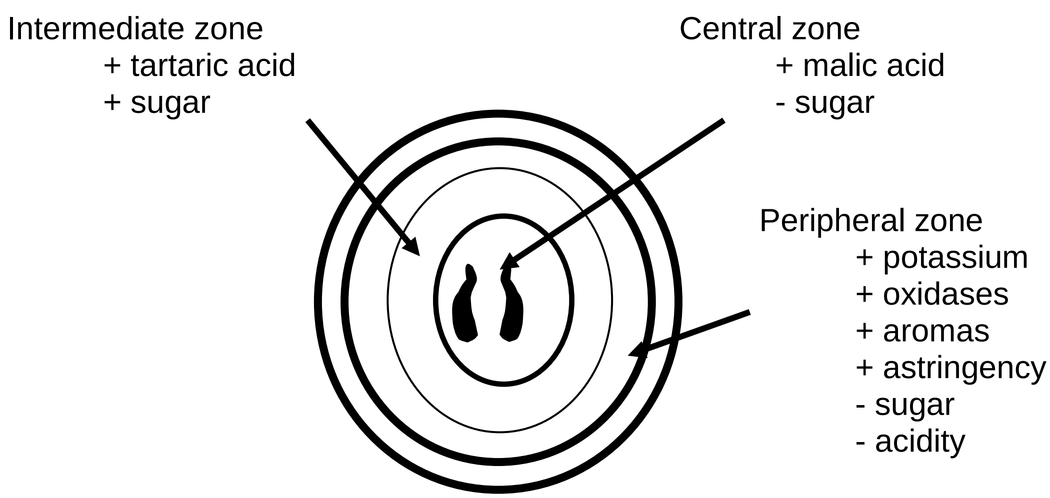
Electronic nose (ENose) technology represents a possible alternative to volatile measurement, at least in some applications. These are multi-sensor arrays designed to measure head-space volatiles. Each sensor type has a greater or lesser affinity for a particular chemical class or group of compounds. The adsorption of volatiles on the sensor surface causes a physical or chemical change in the sensor, allowing a specific reading for that sample in a unique pattern or “fingerprint” of the volatiles (Mallikarjunan, 2005).

Using chemometric techniques and multivariate statistical analysis of ENose data, it is possible to distinguish among groups of samples, to possibly identify individual sample components. Electronic nose systems are so-named because their methods of operation are analogous to the way the human sense of smell operates, where multiple nerve cells in the olfactory epithelium provide responses so the brain can identify and characterize aromas.

Grape Sample Processing

There are three distinctive juice zones in the fruit (Figure 7). Due to compartmentalization within the fruit, it is essential that growers and winemakers standardize fruit sample processing. Without such standardization, it is impossible to compare results.

Figure 7. The Three Zones of a Grape Berry, Showing the Relative Concentration of Berry Components



Adapted from Dunsford & Sneyd, 1989

Sample processing should be performed to duplicate what is expected to occur in the cellar. Therefore, the use of a laboratory hand press would duplicate whole cluster pressing, while a blender may provide a level of extraction similar to red fruit fermented on the skins to dryness. Common systems used to process fruit samples include the following:

- stomacher bag
- blender
- press

Fruit Quality Evaluation

At the winery, representative grape samples are collected and examined for material-other-than-grapes (MOG; e.g., leaves, cane fragments), rot, fruit composition, juice aroma, and flavor.

Diseases and Fruit Rots

Molds are saprophytic (living on dead matter) filamentous fungi. When conditions permit, their growth may lead to fruit deterioration, as well as exposing fruit to secondary activity of spoilage yeast and bacteria. Common molds involved in vineyard spoilage include *Penicillium*, *Aspergillus*, *Mucor*, *Rhizopus*, and *Botrytis*.

The nature and concentration of microbial metabolites differ as a function of living and environmental factors. Quantification of mold, yeast, and bacterial metabolites in collected juice samples is the best procedure for evaluation of potential impact on wine quality factors. Key indicators of fruit rot, such as the presence and concentration of ethanol, glycerol, gluconic acid, galacturonic acid, citric acid, laccase, acetic acid, ethyl acetate, and ochratoxin A (OA) can be determined by contract laboratory services.

Many grape growers attempt to quantify rot based on visual assessment of the incidence. This is frequently done as a percentage of clusters impacted, or a percentage of incidence per cluster. Regardless, most premium wineries, in regions where fruit rot potential is great, conduct fruit sorting. This is generally a combination of field culling and winery sorting.

Mold growth on grapes is considered undesirable, except for the association of *Botrytis cinerea* in the production of certain sweet wines. In some cases, mold growth and associated degradation of fruit stimulate the activity of acetic and lactic acid bacteria and wild yeast, producing a wide range of metabolites. Evaluation of the potential impact of fruit rots on subsequent wine is best achieved by the quantification of rot metabolites.

Penicillium *and* Aspergillus. After early fall rains, *Penicillium* may develop in berry cracks, making the fruit unfit for wine production. *Penicillium* spp. are frequently referred to as cold-weather molds, growing well at temperatures between 15 and 24°C (59-76°F).

Aspergillus is a common vineyard fungus found on damaged fruit. This mold is more abundant in warmer climates, and can metabolize sugars to produce citric acid, increasing the acid content of the juice. Mold metabolites may not only impact wine quality, but can make wines unacceptable, with regard to health concerns. For example, some species of *Aspergillus* can produce ochratoxin A (OA).

Botrytis cinerea. *Botrytis cinerea* is unique in its parasitology. Frequently, its development results in a decrease in grape quality, referred to by the French as *pourriture grise* (grey rot), or by German winemakers as *graufaule*. Only under certain conditions does *Botrytis* produce an overmaturation termed *noble rot* or *edelfaule*, indispensable in the production of the great sweet Sauternes in France, Trockenbeerenausleses in Germany, and Tokay Aszu in Hungary.

Under cold and wet conditions, *Penicillium*, *Mucor*, and *Aspergillus* spp., as well as other fungi and yeast, may overgrow *Botrytis* (Nair, 1985), causing *vulgar rot* (*pourriture vulgaire*). Breakdown of the grape integument provides a substrate for the growth of native yeasts and acetic acid bacteria, and may produce a condition called *pourriture acide*, or *sour rot*.

Botrytis and other molds use ammonia nitrogen, reducing the levels available for yeast metabolism. Additionally, thiamine (vitamin B_1) and pyridoxine (vitamin B_6) are depleted. Like other fungi, *Botrytis cinerea* produces laccase (Dubernet et al., 1977), which catalyzes phenolic oxidation. Ewart et al. (1989) reported significant reduction in total anthocyanins in Pinot noir infected with *Botrytis*, even when the laccase activity was low.

In addition to laccase, pectolytic enzymes and esterases, produced by the mold, break down grape tissue (Sponholz and Dittrich, 1985). Additionally, formation of polysaccharides produced by fruit rots can create wine clarification problems.

Agrochemical Residue

Spray diaries should be kept by all grape growers and be part of the viticultural HACCP plan. Such records help assure compliance with regard to maximum residue limits, and help provide the winemaker with the knowledge that fermentations will not be compromised by spray residues.

Practical Summary of Winemaking Issues

- The knowledge of grape quality parameters is of cardinal importance, since wine quality is directly and strongly correlated to the quality of the vintage.
- This review outlined fruit components which may influence wine, particularly in regard to fruit maturity.
- While grape maturity can have a profound impact on wine, other factors impacting fruit composition, including cultivar, climate, soil, and notably vine water status, vineyard management, and winemaking protocols are also important.
- The challenges for the grape and wine industry include prediction of optimal fruit maturity for the types and styles of wines desired, and

understanding the relationships between fruit composition and consumer wine preferences.

- Additional challenges include replacing time-consuming grape sampling and evaluation methods with new techniques that are fast, precise, and accurate.
- Technologies, including remote sensing, may provide objective, non-destructive measures of grape composition, grape ripeness, and/or uniformity of ripeness.

Study Questions

1. What are the factors impacting fruit quality in Virginia?

2. Why is it difficult to determine and define fruit quality?

3. Explain the importance of berry size (weight) in winemaking and the changes that occur with this parameter during maturation.

4. What are the major factors effecting fruit maturation that can be modified or impacted by the viticulturalist?

5. What are the advantages and disadvantages of berry vs. cluster sampling?

6. How can asymmetric ripening be monitored?

7. Why is an understanding of potential alcohol so critical?

8. What are the major factors impacting the final alcohol of a wine?

9. Explain the difference between TA and pH, and the factors that influence both.

10. Which is most important, the development of fruit phenols, temperature, or light? Explain.

11. What is glutathione and why is it important?

12. You are buying fruit from a new Virginia vineyard that has not provided you with a copy of its spray program. You are concerned that there may be some residual pesticide that could impact the fermentation and/or resulting wine. Design a method of determining if there is a problem.

13. You have just done a juice analysis on a recently processed tank. You note that your analytical results are strikingly different from the fruit analysis report given to you by the grower at the time of harvest. Outline the factors that could explain those differences.

14. Why is sensory analysis of grape aroma best done with the use of enzymes?

References

Allen M S, Lacey M J and Boyd S J (1995), 'Methoxypyrazines in red wines: the occurrence of 2-methoxy-3-(1-methylethyl)pyrazine', *J Agric Food Chem*, 43, 769-772.

Allen M S, 2006, personal communication.

Amerine M A and Joslyn M A (1970), *Table wines, the technology of their production*, 2nd edition, Berkeley, California, The University of California Press.

Amerine M A and Ough C S (1980), *Methods for analysis of musts and wines*, New York, Wiley.

Amerine M A, Berg H W, Kunkee R E, Ough C S, Singleton V L and Webb A D (1980), *The technology of wine making*, 4th edition, Westport, Connecticut, AVI Publishing.

Baldwin J G (1964), 'The relation between weather and fruitfulness of the Sultana vine', *Austral J Agricult Res*, 15, 920-928.

Bergqvist J, Dokoozlian N and Ebisuda N (2001), 'Sunlight exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the Central San Joaquin Valley of California', *Am J Enol Vitic*, 52, 1-7.

Bisson, L (2001), 'Optimal grape maturity', *Pract Winery Vineyard,* July/Aug, 32-43.

Blouin J and Cruège J (2003), *Analyse et composition des vins: comprendre le vin*, Paris, Editions La Vigne, Dunod.

Boulton R (2005), 'The general relationship between potassium, sodium and pH in grape juice and wine', *Am J Enol Vitic*, 31, 182-186.

Bravdo B., Hepner Y, Loinger C, Cohen S and Tabacman H (1985), 'Effect of irrigation and crop level on growth, yield and wine quality of Cabernet Sauvignon', *Am J Enol Vitic*, 36, 132-139.

Bureau S M, Baumes R L and Razungles A, (2000), 'Effects of vine or bunch shading on the glycosylated flavor precursors in grapes of Vitic vinifera L. cv. Syrah', *J Agric Food Chem* 48, 1290-1297.

Buttrose, M S, (1974), 'Climatic factors and fruitfulness in grapevines', *Horticult. Abstr* 44, 319-326.

Clingeleffer E R, (1983), 'Minimal pruning - its role in canopy management and implications of its use for the wine industry', in Lee T H and Somers T C, *Proceedings 5th Australian Wine Industry Technical Conference, Perth, Australia*, The Australian Wine Research Institute, Urrbrae, 133-145.

Conde C, Silva P, Fontes N, Dias A C P, Tavares R M, Sousa M J, Agasse S, Delrot S and Gerós H (2007), 'Biochemical changes throughout grape berry development and fruit and wine quality', *Food*, 1, 1-22.

Coombe B G and McCarthy M G (1997), 'Identification and naming of the inception of aroma development in ripening grape berries', *Aust J Grape Wine Res*, 3, 18-20.

Coombe B G and IIand P G, (2004), 'Grape berry development and winegrape quality', in Dry P R and Coombe B G, *Viticulture, Volume 1 - Resources* (2nd edition) Winetitles, Adelaide, 210-248.

Davies C, Shin R, Liu W, Thomas M R and Schachtman P (2006), 'Transporters expressed during grape berry (*Vitis vinifera* L.) development are associated with an increase in berry size and berry potassium accumulation', *J Exper Bot*, 57, 3209-3216.

Delteil D (1998), 'Tannin management: a premium Mediterranean approach', *Practical Winery Vineyard*, July/August, 36-39.

Dokoozlian N K and Kliewer W M (1996), 'Influence of light on grape berry growth and composition varies during fruit development', *J Am Soc Hort Sci*, 121, 869-874.

Dubernet M, Ribereau-Gayon P, Lerner H R, Harel E and Mayer A M (1977), 'Purification and properties of laccase from *Botrytis cinerea*', *Phytochem*, 16, 191-193.

Dubourdieu D, Tominga T, Masneuf I, Peyrot des Gachons C and Murat M L (2000), 'The role of yeasts in grape flavor development during fermentation: the example of Sauvignon Blanc', in Rantz J, *Proceedings of the 50th Anniversary Annual Meeting of the American Society for Enology and Viticulture*, Davis, CA, American Society for Enology and Viticulture, 196–202.

Dunsford P A and Sneyd T N (1989), 'Pressing for quality,' in Williams P J, Davidson D M and Lee T H, *Proceedings of the Seventh Australian Wine Industry Technical Conference*, Adelaide, South Australia, Australian Industrial Publishers, 89-92.

Ewart A J W, Haselgrove N J, Sitters J H and Young R (1989), 'The effect of *Botrytis cinerea* on the color of *Vitis vinifera* cv. Pinot noir', in Williams P J, Davidson D M and Lee T H, *Proceedings of the Seventh Australian Wine Industry Technical Conference*, Adelaide, Australian Wine Research Institute.

Francis I L, Sefton M A and Williams P J (1992), 'Sensory descriptive analysis of the aroma of hydrolysed precursor fractions from Semillon, Chardonnay, and Sauvignon Blanc grape juices', *J Sci Food Agric*, 59, 511–520.

Freeman B M, Lee T H and Turkington C R, (1979), 'Interaction of irrigation and pruning level on growth and yield of Shiraz vines', *Amer J Enol Vitic*, 30, 218-223.

Gallander J F, (1983), 'Effect of grape maturity on the composition and quality of Ohio Vidal blanc wines', *Amer J Enol Vitic*, 34, 139-141.

Gawel R, Ewart A J W and Cirami R (2000), 'Effect of rootstock on must and wine composition and the sensory properties of Cabernet Sauvignon grown at Langhorne Creek, South Australia', *Aust NZ Wine Ind J*, 15, 67-73.

Gladstones J (1992), *Viticulture and environment*, Adelaide, Winetitles.

González-San José M L, Barron L J R, Junquera and Robredo M, (1991), 'Application of principal component analysis to ripening indices for wine grapes', *J Food Comp Anal*, 4, 245-255.

Gray J (2006), 'The basis of variation in the size and composition of Shiraz berries', in Oag D, DeGaris K, Partridge S, Dundon C, Francis M, Johnstone R and Hamilton R, *'Finishing the Job' - Optimal Ripening of Cabernet Sauvignon and Shiraz*, Adelaide, SA, Australian Society of Viticulture and Oenology, 30-35.

Günata Z Y, Bitteur S, Brillouet J –M and Cordonnier R E (1988), 'Sequential enzymatic hydrolysis of potentially aromatic glycosides from grapes', *Carbohydr Res*, 134, 139-149.

Hall A, Lamb D W, Holzapfel B and Louis J, (2002), 'Optical remote sensing applications in viticulture - a review', *Austral J Grape Wine Res*, 8, 36-47.

Hashizume K and Samuta T, (1999), 'Grape maturity and light exposure affect berry methoxypyrazine concentration', *Amer J Enol Vitic*, 50, 194-198.

Jackson D and Lombard P B, (1993), 'Environmental and management practices affecting grape composition and wine quality: a review', *Amer J Enol Vitic*, 44, 409-430.

Jordan A D and Croser B J (1983), 'Determination of grape maturity by aroma/flavour assessment', in Lee T H and Somers T C, *Proceedings of the Fifth Australian Wine Industry Conference*, Adelaide, SA, Australian Wine Institute.

Kasimatis A N and Vilas E P, (1985), 'Sampling for degrees Brix in vineyard plots', *Amer J Enol Vitic*, 36, 207-213.

Keller M and Hrazdina G, (1998), 'Interaction of nitrogen availability during bloom and light intensity during veraison: II. Effects on anthocyanin and phenolic development during grape ripening', *Amer J Enol Vitic*, 49, 341-349.

Keller M, Arnink K and Hrazdina G, (1998), 'Interaction of nitrogen availability during bloom and light intensity during veraison: I. Effects on grapevine growth, fruit development and ripening', *Amer J Enol Vitic*, 49, 333-340.

Kennedy J (2000), 'Grape seed tannins: impact on red wine', *Practical Winery Vineyard*, May/June, 39-44.

Kliewer W M and Dokoozlian N K (2005), ‘Leaf area/crop weight ratios of grapevines: influence on fruit composition and wine quality’, *Am J Enol Vitic*, 56, 170-181.

Krstic M, Moulds G, Panagiotopoulos B and West S (2003), *Growing quality grapes to winery specification: quality measurement and management options for grapegrowers*, Adelaide, SA, Winetitles.

Levengood, J (1996), ‘A survey of copigmentation in Cabernet Sauvignon wines’, M.S. Thesis, Davis, California, University of California, Davis.

Long (1984) Monitoring sugar per berry. Practical Winery and Vineyard 5(2):52-54.

Long Z R (1986), ‘Manipulation of grape flavour in the vineyard: California, North Coast region’, Lee T H, *Proceedings of the Sixth Australian Wine Industry Technical Conference*, Adelaide, South Australia, Australian Industrial Publishers, 82-88.

Mallikarjunan K (2005), ‘Electronic nose applications in the food industry’, in Irudayaraj I and Reh C, *Nondestructive testing of food quality*, Ames, Iowa, Wiley-Blackwell, 237-284.

Matthews M A, Cheng G and Weinbaum S A, (1987), ‘Changes in water potential and dermal extensibility during grape berry development’, *J Amer Soc Horticult Sci*, 112, 314-319.

Matthews M A, Ishii R, Anderson MM and O’Mahony M (1990), ‘Dependence of wine sensory attributes on wine water status’, *J Sci Food Agric*, 51, 321-335.

Matthews M A and Kriedmann P E, (2006), ‘Water deficit, yield, and berry size as factors for composition and sensory attributes of red wines’, in Oag D, DeGaris K, Partridge S, Dundon C, Francis M, Johnstone R and Hamilton R, *'Finishing the Job' - Optimal Ripening of Cabernet Sauvignon and Shiraz*, Adelaide, SA, Australian Society of Viticulture and Oenology, 46-54.

May E, (1972), ‘Forecasting the grape crop’, *Austral Wine, Brewing Spirit Rev*, 90, 46, 48.

McCarthy, M.G (1997), Effects of timing of water deficit on frit development and composition of *Vitis vinifera* cv. Shiraz. Thesis, Doctor of Philosophy, The University of Adelaide, Australia.

McCarthy, M.G. and Coombe, B.G (2001), Is weight loss in ripening berries cv Shiraz caused by impeded phloem. *Aust. J. of Grape and Wine Res*, 5, 17-21

McCloskey L P (1974), 'Gluconic acid in California wines', *Am J Enol Vitic*, 25, 198–201.

Mpelasoka B S, Schachtman D P, Treeby M T and Thomas M R (2003), 'A review of potassium nutrition in grapevines with special emphasis on berry accumulation', *Aust J Grape Wine Res*, 9, 154-168.

Okuda T and Yokutsuka K, (1999), 'Levels of glutathione and activities of related enzymes during ripening of Koshu and Cabernet Sauvignon grapes during winemaking', *Amer J Enol Vitic*, 50, 264-270.

Ollat N and Gaudillère J P (1996), 'Investigation of assimilate import mechanisms in berries of *Vitis vinifera* var. "Cabernet Sauvignon"', *Acta Hort*, 427, 141-149.

Rankine B C, Cellier K M and Boehm E W, (1962), 'Studies on grape variability and field sampling', *Amer J Enol Vitic*, 13, 58-72.

Reynolds, AG, Wardle DA, Naylor AP. (1996), Impact of training system, vine spacing, and basal leaf removal on Riesling vine performance, berry composition, canopy microclimate, and vineyard labor requirements, *Am. J. Enol. Vitic.,* 47, 63-76.

Robinson S P and Davies C (2000), 'Molecular biology of grape berry ripening', *Aust J Grape Wine Res*, 6, 175-188.

Rogiers S Y, Greer D H, Hatfield J M, Orchard B and Keller M (2006), 'Solute transport into cv. Shiraz berries during development and late-ripening shrinkage', *Am J Enol Vitic*, 57, 73-80.

Roessler E B and Amerine M A (1963), 'Further studies on field sampling of wine grapes', *Am J Enol Vitic*, 14, 144-147.

Roujou de Boubee D, Van Leeuwen C and Dubourdieu D (2000), 'Organoleptic impact of 2-methoxypyrazine on red Bordeaux and Loire wines. Effect of environmental conditions on concentrations in grapes during ripening', *J Agric Food Chem*, 48, 4830–4834.

Sefton M A, Francis I L and Williams P J (1993), 'The volatile composition of Chardonnay juices: a study by flavor precursor analysis', *Am J Enol Vitic*, 44, 359-370.

Singleton V L (1988), 'Wine phenols', in Linskens H F and Jackson J F, *Modern methods of plant analysis*, new series, volume 6, *Wine analysis*, Berlin, Springer-Verlag, 173-218.

Sipiora M and Granda M-J G, (1998), 'Effects of pre-véraison irrigation cutoff and skin contact time on the composition, color and phenolic content of young Cabernet Sauvignon wines in Spain', *Amer J Enol Vitic*, 49, 152-162.

Smart R E, (1992), ‘Canopy management’, in Coombe, B G and Dry E R, *Viticulture, Volume 2 - Practices*, Winetitles, Adelaide, 85-103.

Smart R E, Shaulis N J and Lemon E R, (1982), ‘The effect of Concord vineyard microclimate on yield. II. The interrelations between microclimate and yield expression’, *Amer J Enol Vitic*, 33, 109-116.

Smart R and Robinson M, (1991), *Sunlight into Wine: A Handbook for Winegrape Canopy Management*, Winetitles, Adelaide.

Smith F (2006), ‘How steroids control grape ripening’, *Wines Vines*, Nov., 52, 54, 56-57.

Smith J and Holzapfel B, (2003), ‘The post-harvest period, carbohydrate reserves and vine productivity’, *Austral NZ Grapegrower Winemaker*, 478, 29-32.

Sponholz W R and Dittrich H H (1985), ‘Uber die herkunft von Gluconsaure, 2- und 5-oxo Glucosaure sowie Glucuron- und Galacturonsaure in Mosten un Wienen’, *Vitis*, 24, 51-58.

Strauss C R, Wilson B, Anderson R and Williams P J, (1987), ‘Development of precursors of 13-carbon norisoprenoid flavorants in Riesling grapes’, *Amer J Enol Vitic*, 38, 23-27.

Strickland A G, Forster H C and Vasey A J, (1932), ‘A vine uniformity trial’, *J Dept Agric Victoria*, 30, 584-593.

Trought M C T, (1996), ‘Sources of variation in fruit composition in New Zealand vineyards’, in Stockley C S, Sas A N, Johnstone R S and Lee T H, *Proceedings 9th Australian Wine Industry Technical Conference, Adelaide, Australia*, Winetitles, Adelaide, 206-207.

Trought M C T and Tannock S J C, (1996), ‘Berry size and soluble solids variation within a bunch of grapes’, Henick-Kling T, Wolf T E and Harkness E M, *Proceedings 4th International Symposium on Cool Climate Viticulture and Enology, Rochester, New York*, New York State Agricultural Experiment Station, Geneva, NY, V-70-73.

Walker R R, Blackmore D H, Clingeleffer P R, Kerridge G H, Rühl E H and Nicholas P R (2005), ‘Shiraz berry size in relation to seed number and implications for juice and wine composition’, *Aust J Grape Wine Res*,11, 2-8.

Williams P J and Francis I L, (2000), ‘Wine flavor research: Experiences from the past offer a guide to the future’, in Rantz J, *Proceedings of the ASEV 50th Anniversary Annual Meeting, Seattle, Washington*, American Society for Enology & Viticulture, Davis, CA, 191-195.

Winkler A J (1965), *General Viticulture*, Berkeley, California, University of California Press.

Winter E (2004), 'Avoiding "green" characters in Cabernet Sauvignon', *Pract Wine Vineyard*, May/June, 9-11.

Winter E, Whiting J and Rousseau J, (2004), *Winegrape sensory assessment in Australia*, Winetitles, Adelaide, South Australia.

Wolpert J A and Howell G S, (1984), 'Sampling Vidal Blanc grapes. II. Sampling for precise estimates of soluble solids and titratable acidity of juice', *Amer J Enol Vitic*, 35, 242-246.

Zoecklein B W, Wolf T K, Duncan N W, Judge J M and Cook, M K (1992), 'Effect of fruit zone leaf removal on yield, fruit composition, and fruit rot incidence of Chardonnay and white Riesling (*Vitis vinifera* L.) grapes', *Am J Enol Vitic*, 43, 139-148.

Zoecklein, B, Wolf T K, Yoder C and Jasinski Y (1996), "Effect of crop level on Chardonnay and Cabernet Sauvignon', in Henick-Kling, Wolf T E and Harkness E M, *Proceedings for the Fourth International Symposium on Cool Climate Viticulture and Enology*, Geneva, N.Y., New York State Agricultural Experiment Station, V-58-65.

Zoecklein B W, Wolf T K, Duncan S E, Marcy J E and Yasinski Y W (1998), 'Effect of fruit zone leaf removal on total glycoconjugates and conjugate fraction concentration of Riesling and Chardonnay (*Vitis vinifera* L.) grapes', *Am J Enol Vitic*, 49, 259-265.

Zoecklein B W, Fugelsang K C, Gump B H and Nury F S (1999), *Wine analysis and production*, New York, Kluwer Academic/Plenum.

Zoecklein B W, Douglas L S and Jasinski Y W (2000), 'Evaluation of the phenol-free glycosyl-glucose determination', *Am J Enol Vitic*, 51, 420-423.