
Recognition of wine off-flavours and taints

It is essential that people who are called upon to assess the quality of wine must be able to accurately recognise the common sensory off-flavours and taints that occur in wines. One criticism levelled at the Australian Wine Show system and at Australian wine judges is that they pay too much attention to faults and not enough attention to the intrinsic quality of the wine being judged. The Australian wine industry, however, has set an objective of being able to produce wines free of off-flavours and taints, so that the flavours derived from fully ripened grapes, high quality oak and other winemaking procedures are not compromised.

An off-flavour or taint occurs when a contaminant is present in a wine (or any food product) at a concentration higher than its odour or taste threshold. The terms 'taint' and 'off flavour' have often been used interchangeably in the past. However, it is now common to use the term 'taint' to describe unacceptable flavours arising from external contamination of the product, whereas the term 'off-flavour' is used to describe an unacceptable flavour which develops within the food, through chemical or microbial action on food components.

An important aspect of taints and off-flavours is that there is a large range of sensitivity between individuals in their ability to detect some of these off-characters. Consequently, the lack of sensitivity of a winemaker to a particular taint or off-flavour can be the reason for difficulties encountered in preventing them and positively identifying the causes in some cases.

It is impossible to show all the winemaking off-flavours that are encountered in the many wine shows conducted in Australia each year and the taints that are sometimes observed in the assessment of wines. No attempt will be made to show wines that are grossly unbalanced, i.e. the acid content is too high for the level of fruit and alcohol sweetness in the wine, various faults due to over-extraction of the phenolic substances, or red wines made from overripe grapes and thus smell and taste like port.

The course will concentrate on the major sensory off-flavours that eliminate 5–15% of wines in the major Wine Shows and the taints that are encountered in wines submitted to the AWRI for investigation of sensory problems.

The major off-flavours encountered include:

• Oxidation	• Disulfides
• Acetaldehyde	• Dimethyl sulfide (DMS)
• Volatile acidity	• Sulfur dioxide (SO ₂)
• Ethyl acetate	• Diacetyl
• Mousiness	• Geranium
• Hydrogen sulfide	• 4-Ethylphenol
• Mercaptans	• Indole

The major taints encountered include:

- Cork-type taints :
 - 2,4,6-Trichloroanisole (TCA)
 - 2,4,6-Tribromoanisole (TBA)
 - 2-Methoxy-3,5-dimethyl pyrazine (Fungal must)
- Geosmin
- Chlorophenols:
 - 2,4-Dichlorophenol
 - 2,6-Dichlorophenol
 - 2-Chloro-6-methylphenol or 6-chloro-*o*-cresol (6CC)
- Guaiacol

These taints and off-flavours are discussed below, including descriptions of their sensory properties, their origins, mechanisms of formation and their detection thresholds.

Off-flavours

Oxidation

Oxidation, particularly of white wines, was a common fault in Australian white wines 40 years ago when our table wine technology was reasonably primitive, compared to that of today. Oxidation is much less common today with the application of refrigeration, inert gas blanketing during the production and packaging operations and effective sulfur dioxide management. The oxidation flavour is due to a number of compounds, including a range of aldehydes.

Some wines are more sensitive to oxidation than others. Thus the white wines made from the 'floral' varieties such as Riesling are very prone to oxidation, whereas red wines can withstand significant oxidation during handling due to the higher content of phenolic compounds, which are natural antioxidants. The sensory characteristics of oxidation range from a dulling of the aroma, to 'cardboard', 'straw' and 'hay-like' aromas, to 'sherry-like' and 'maderised'. In extreme cases a 'wet wool', 'wet dog' or 'varnish-like' aroma may be evident. Of course for some wine styles, such as sherry, oxidation is deliberately encouraged.

Acetaldehyde

The sensory threshold for acetaldehyde ranges from 100-125 mg/L. Immediately after fermentation, table wines generally have acetaldehyde levels below 75 mg/L. However, above 125 mg/L acetaldehyde can impart odours described as over-ripe bruised apples, stuck ferment character or sherry and nut-like characters. Yeast can oxidise ethanol to acetaldehyde under oxidative conditions, therefore ullaged tanks can lead to surface yeast infection where acetaldehyde is produced (note that high levels of acetic acid and ethyl acetate may also be produced under these conditions). Ethanol represents the primary source of carbon in aerobic film-yeast growth.

Acetaldehyde levels increase as wines age due to chemical oxidation of ethanol. Acetaldehyde is also an intermediate in the bacterial formation of acetic acid and under low-oxygen conditions and/or alcohol levels greater than 10 % v/v, acetaldehyde tends to accumulate instead of being oxidised to acetic acid.

Apart from chemical and microbiological formation, winemaking practices can influence the level of acetaldehyde present in wine: addition of SO₂ during fermentation can increase the concentration of acetaldehyde, as can increases in pH and fermentation temperature.

Volatile acidity

Volatile acidity (VA) is a term that probably represents the wine industry's first measure of wine quality, although in a negative sense.

As a result the measure of volatile acidity is still prominent in the wine regulations of most countries, even though the components of volatile acidity represent no threat to health and the amount of volatile acidity tolerated will vary with the style of wine and the individual. The legal maximum content of volatile acidity in Australian wines, excluding SO₂ and expressed as acetic acid, is 1.5 g/L.

Volatile acidity is a measure of the low molecular weight, or steam-distillable, fatty acids in wine, with by far the major acid being acetic acid (>93%). However, other contributors to VA include carbonic acid (from carbon dioxide), sulfurous acid (from SO₂), as well as lactic, formic, butyric and propionic acids. Note that sorbic acid is also steam-distillable and should be taken into account if it has been added to wine (usually as potassium sorbate).

Given that acetic acid accounts for >93% of the measure of VA, it is not surprising that, sensorially, VA is generally perceived as the odour of vinegar. The aroma threshold for acetic acid in wine has been reported to be as low as 0.1–0.125 g/L, depending on the style of wine and the individual. However, the concentration at which the acid is regarded as detrimental is usually greater than 0.7 g/L. The VA is more easily detected if a small amount of ethyl acetate is also present, and in some cases ethyl acetate aroma can dominate.

During the alcoholic fermentation, yeast produce small amounts of acetic acid and the VA of a sound wine immediately after fermentation is usually in the range 0.1–0.4 g/L. However, native or wild yeasts such as *Hansenula* and *Kloeckera* can produce high concentrations of acetic acid before and during the early stages of fermentation. In addition, *Brettanomyces* can produce elevated levels of VA when grown under aerobic conditions. Some strains of *Saccharomyces* can also produce large amounts of acetic acid when placed under stress, i.e. during low or high temperature fermentations, during fermentation of high sugar musts, when available nitrogen is low or when the pH is low (i.e. <3.2). In addition, the AWRI has found that addition of vitamin mixtures to white grape juice fermentations increased the acetic acid concentration in the wines. The increase was highly variable and depended on the grape juice with the magnitude of the increase varying from 30% to 375%. Nicotinic acid and thiamine were the vitamins which most affected the increase in VA.

Increased levels of acetic acid in stored wines are usually attributable to growth of acetic acid bacteria (generally of the genus *Acetobacter*). These bacteria convert alcohol to acetic acid in the presence of oxygen. In fact until Pasteur's work in the mid-19th century a high proportion of wines spoiled through this mechanism before they could be consumed. Acetic acid bacteria are often isolated from red wines analysed at the AWRI, however, spoilage problems related to the growth of these bacteria only occur when the wines are exposed to air. In addition to lactic acid and carbon dioxide, heterolactic LAB may also produce elevated amounts of acetic acid when growing on glucose. Small amounts of acetic acid may also be produced during wine storage in new oak barrels due to hydrolysis of acetyl groups in the wood hemicellulose. In addition, it has been reported that acetic acid can result from the reaction of hydrogen peroxide, generated from coupled oxidation of wine phenolics, with ethanol to generate acetaldehyde, which is in turn oxidised to acetic acid.

Ethyl acetate

Various acetate esters, especially ethyl acetate, can contribute to the sensory perception of VA, as indicated above. Ethyl acetate is perceived as the odour of nail polish remover or airplane glue and has a reported sensory threshold of 12.3 mg/L. Ethyl acetate is the major ester produced by yeast and at low levels may contribute 'fruity' properties and add complexity to wine. The concentration of ethyl acetate ranges from about 30–60 mg/L in 'normal' wines, to about 150–200 mg/L in defective wines.

Factors that can influence ethyl acetate formation by yeasts include the yeast strain employed, temperature of fermentation, the amino nitrogen content of the juice and sulfur dioxide levels. As with acetic acid discussed above, native or wild yeasts such as *Hansenula* and *Kloeckera* can produce high concentrations of ethyl acetate before and during the early stages of fermentation. Ethyl acetate is also produced by acetic acid bacteria and is related to dissolved oxygen levels in the wine. It has been reported that growth of acetic acid bacteria under conditions of low oxygen tension can lead to higher levels of ethyl acetate.

Mousiness

Mousiness is an off-flavour reminiscent of caged mice or cracker biscuit, and in sensitive individuals renders the wine undrinkable. The off-flavour is generally perceived late on the palate or after the wine has been swallowed or expectorated and usually takes a few seconds to build. It tends to linger and leave a most obnoxious taste in the mouth for some time. If you move quickly to the next wine in a line-up, you may miss a mousy wine. Mousiness is rarely detected by sniffing because the compounds involved are not volatile at wine pH. Note that there is considerable variation in the sensitivity between individuals to the taint.

The compounds responsible for mousiness are the N-heterocyclic volatile bases 2-acetyl tetrahydropyridine (ATHP), which is the main compound responsible, 2-ethyl tetrahydropyridine (ETHP) and 2-acetyl pyrroline (APY). The sensory thresholds of these compounds in water and the ranges found in wine (Grbin et al 1996) are given in Table 3 below.

Table 3. Sensory thresholds of the compounds responsible for mousy off-flavour in water and the ranges found in wine.

Compound	Threshold in water (µg/L)	Range in wine (µg/L)
ATHP	1.6	4.8 – 106
ETHP	150	2.7 – 18.7
APY	0.1	trace – 7.8

The origin of mousy off-flavour is usually microbial, with most strains of lactic acid bacteria (LAB) being capable of producing the mousy character, particularly the heterofermentative species. These include *Lactobacillus hilgardii*, *Lactobacillus plantarum*, *Lactobacillus brevis*, and *Oenococcus oeni*. The yeast *Dekkera/Brettanomyces* are also capable of producing mousy compounds. In addition to microbial origin, empirical observation has shown that some wines develop mousy off-flavour when exposed to air or oxygen. The mechanism by which oxidation enhances mousy off-flavour is currently unknown. There is no satisfactory method to remove mousy off-flavour, which is more likely to occur in wines with low concentrations of SO₂ and low acidity.

The AWRI observed an increased incidence of mousy wines during the 1990s when winemakers moved to a lower sulfur dioxide regime for the production of red wines in particular. Many red wines and some full bodied white wines had no sulfur dioxide added until the completion of the malolactic fermentation. Such a regime demands a fastidious approach to cellar hygiene to prevent unwanted microbial growth and the possible formation of mousiness. The AWRI has recommended to winemakers that they should work at between 50 and 75 mg/L total sulfur dioxide (more for wines of high pH) for red wine production if they have any doubts about their cellar sanitation.

Hydrogen sulfide

Most winemakers will be familiar with the aroma of hydrogen sulfide (H₂S) or rotten egg gas. The threshold of detection of H₂S in wine is about 1–2 µg/L (parts per billion) and it has been reported that levels below the sensory threshold might play a role in wine complexity. The various forms of sulfur (e.g. sulfate, sulfite and sulfur-containing amino acids) are important for yeast biosynthesis. During alcoholic fermentation, yeast will excrete hydrogen sulfide into the fermenting juice when placed under stress, e.g. when the yeast starts to run out of nitrogen. Australian juices can be low in nitrogen and winemakers often supplement the juice with a soluble nitrogen source, such as diammonium phosphate.

Hydrogen sulfide can be produced in excess by yeast during fermentation due to the presence of elemental sulfur on grape skins (from sulfur sprays), inadequate levels of free α-amino nitrogen (FAN), added SO₂, a deficiency of B-complex vitamins (pantothenic acid or pyridoxine), unusually high levels of cysteine in the juice or a high concentration of metal ions. The production of H₂S can also be yeast strain dependent.

Winemakers minimize the formation of excess H₂S in white wines by either settling, centrifuging or filtering the must before fermentation, which removes high-density solids which might contain elemental sulfur. Some winemakers remove excess H₂S from red wines by aerating at the first racking, thus volatilising the H₂S. Aeration may also oxidise H₂S to elemental sulfur (S), however, the

S precipitate must be removed (centrifugation or filtration) otherwise it might later reform H_2S , when conditions become favourable for reduction. Note that SO_2 can also convert H_2S to S. Many winemakers remove objectionable H_2S in red and white wines by fining with copper sulfate (CuSO_4). Copper sulfate reacts with H_2S to form copper sulfide, which is highly insoluble. However, careful laboratory trials should precede any CuSO_4 additions to bulk wine, as an instability can result if the copper concentration in the wine exceeds approximately 0.5 mg/L (even lower in some wines).

Mercaptan and disulfides

Mercaptan is a general term applied to the aroma of a range of compounds containing a terminal –SH moiety (thiols) and are variously described as cabbage, garlic, onion and rubber and many other colourful terms. Their presence in wine above the threshold is generally regarded as a defect; however, the odour of these sulfur compounds is important to many foods.

Thiols (mercaptans) are thought to be formed via chemical reaction between H_2S and wine components, possibly aldehydes and/or alcohols. However, it is known that methanethiol can be formed directly as a result of yeast metabolism. Both methanethiol (methyl mercaptan) and ethanethiol (ethyl mercaptan) may be rapidly oxidised to dimethyldisulfide (DMDS) and diethyldisulfide (DEDS), respectively. Therefore, if a wine containing methanethiol and ethanethiol is aerated to remove H_2S , the thiols may be oxidised to DMDS and DEDS, which do not react with copper. Removal of DMDS and DEDS requires the creation of reducing conditions, with the addition of ascorbic acid and SO_2 , in order to reduce these compounds back to the reactive species (methanethiol and ethanethiol), which may then be removed by treatment with copper. Note that copper is not as effective at removing thiols as it is at removing H_2S , therefore, it is best to remove H_2S before it reacts further to form thiols. The sensory thresholds of some thiol and disulfide compounds, including some odour descriptors, are given in Table 4 below.

Table 4. The sensory thresholds and odour descriptors for some thiol and disulfide compounds.

Sulfur compound	Threshold ($\mu\text{g/L}$)	Odour description
Methanethiol	0.02-2	rotten eggs, cabbage
Ethanethiol	1.1	onion-like, rubber-like
Dimethyl disulfide	29	onions, cooked cabbage
Diethyl disulfide	4.3	burnt rubber, garlic

Dimethyl sulfide

Dimethyl sulfide (DMS) is one of the major compounds found in aged wines and is formed during the maturation of wine in the bottle, however, the mechanism of formation of DMS is not clearly known. At low concentrations it might contribute toward the body of aged white wines and has a 'vegy' or 'blackcurrant' character. At higher concentrations, the aroma of DMS is described as a fault and is described as 'asparagus', 'cooked corn', 'cooked tomato' or 'molasses'. The sensory threshold for DMS is between 30-60 $\mu\text{g/L}$. As dimethyl sulfide does not bind to copper it can be difficult to remove the aroma, however, removal might be possible by sparging with nitrogen or by using reverse osmosis.

Excess sulfur dioxide

Sulfur dioxide is one of two preservatives permitted for use in wine production in most winemaking countries—the other preservative is sorbic acid. Most countries set a legal maximum for the total sulfur dioxide content of wine. In Australia the maximum is 250 mg/L of total sulfur dioxide in products containing less than 35 g/L sugars, or 300 mg/L of total of sulfur dioxide for other products.

Winemakers add SO_2 to wine to minimise the effects of oxidation and also to inhibit microbiological activity. Winemakers refer to three categories of SO_2 : free, bound and total. The free SO_2 is defined as the sum of the unreacted ionic forms, which are the molecular, bisulfite and sulfite forms. The bound SO_2 involves the portion of the bisulfite form which binds with particular wine components (to form bisulfite addition compounds) and which can be released by hydrolysis and/or by heat and distillation. Total SO_2 represents the sum of the free and bound fractions (Sneyd et al. 1993). The sulfite form (SO_3^-) of SO_2 in wine is the form that reacts with molecular oxygen, however, at wine pH this form is the least abundant. At wine pH the most abundant forms of SO_2 are the molecular (SO_2) and bisulfite (HSO_3^-) forms. Neither of these forms reacts with oxygen, however, molecular SO_2 does react quickly with hydrogen peroxide (H_2O_2). This reaction is responsible for the removal of H_2O_2 produced by the reaction of oxygen with polyphenols and the retardation of acetaldehyde formation and browning in wines. In addition, it is the molecular form that is responsible for the anti-microbial effect of SO_2 and is the form that we can smell when too much is added.

Sulfur dioxide has a pungent penetrating aroma which reacts strongly with receptors in the nose causing sneezing and often a choking sensation—a high content of free sulfur dioxide can be life threatening to a small proportion of asthmatics. A content of free sulfur dioxide up to 15 mg/L has no adverse sensory effect.

Diacetyl

Diacetyl (2,3-butanone) is produced by both yeast and bacteria and low levels (1–4 mg/L) in wine usually add complexity (buttery or butterscotch characters), but high levels (>5 mg/L) might be considered objectionable, such that the wine might be regarded as defective.

The amount of diacetyl produced by yeasts is typically less than 1 mg/L, which is below the sensory threshold. Bacterial production of diacetyl during malolactic fermentation (MLF) represents the primary source of this compound and arises mainly from catabolism of citric acid. Under winemaking conditions, this generally occurs after all of the malic acid has been converted.

Formation of diacetyl is dependent on a number of factors, including the bacterial strain, the oxygen (O_2) tension of wine (increase in O_2 concentration favours the oxidation of α -acetolactate to yield diacetyl), the citric acid concentration and temperature.

Geranium off-odour

Geranium off-odour is attributable to the ether 2-ethoxyhexa-3,5-diene, which has an odour reminiscent of crushed geranium leaves. This compound has a reported threshold of 100 ng/L and

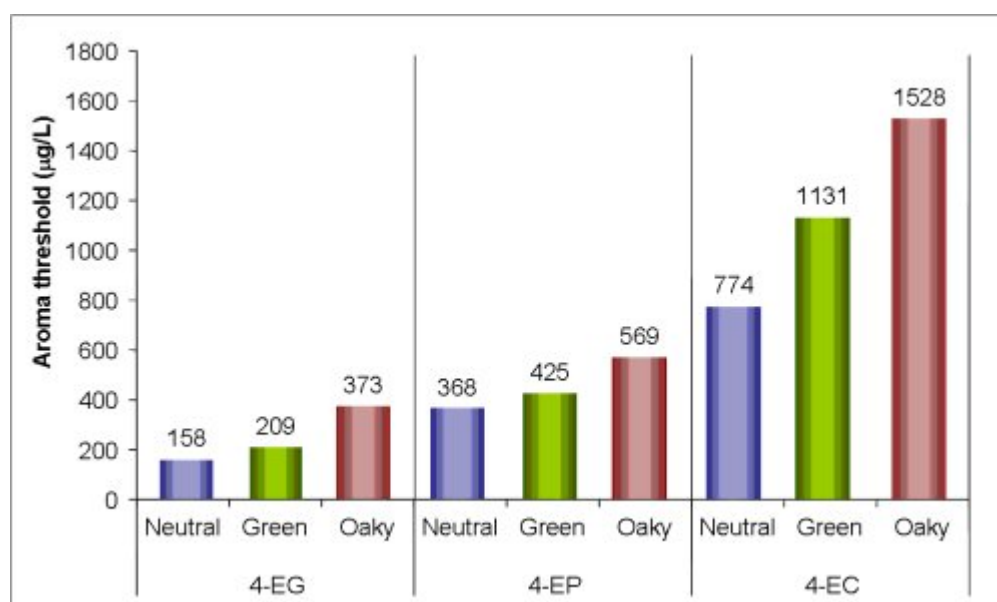
its formation is the result of metabolism of sorbic acid by lactic acid bacteria (LAB). Sorbic acid (the other wine preservative mentioned earlier) is a short-chained unsaturated fatty acid and is widely used as a fungistat in sweet wines at bottling. Whilst sorbic acid is generally effective in the inhibition of *Saccharomyces* yeast, it has little activity toward *Dekkera/Brettanomyces* and *Zygosaccharomyces* yeast, or LAB or acetic acid bacteria.

At the relatively low pH of wine, some LAB are able to reduce sorbic acid to sorbyl alcohol which undergoes rearrangement to yield the alcohol 2,4-hexadiene-1-ol. This alcohol is able to react with the ethanol present in wine to produce 2-ethoxyhexa-3,5-diene, which imparts the 'geranium tone'.

4-Ethylphenol

The volatile phenol 4-ethylphenol is one of the major spoilage compounds associated with the growth of *Dekkera/Brettanomyces* yeast in wine. This compound imparts a "Band aid®", "medicinal" or "pharmaceutical" character to wine. A concentration of 425 µg/L of 4-ethylphenol has been reported to have a negative impact on the quality of many wines (Chatonnet et al 1992, 1993). Recent Australian sensory studies conducted at the AWRI have shown the aroma threshold in to be 368 µg/L in a neutral red wine (Figure 1) (Curtin et al. 2008).

Figure 1. Aroma thresholds of 4-ethyl guaiacol (4-EG), 4-ethyl phenol (4-EP), and 4-ethyl catechol (4-EC) in three different Australian Cabernet Sauvignon wines.



Evidence from sensory assessments and analyses conducted at the AWRI suggest that the sensory perception threshold of 4-ethylphenol depends very much on the style and structure of the wine. For example, the aroma threshold of 4-ethylphenol in a full bodied red wine with intense methoxypyrazine green character was 425 µg/L and considerable oak influence increased the aroma threshold to 569 µg/L (Figure 1). That is, the extent to which the sensory properties of a wine may be affected by 4-ethylphenol will depend on the concentration and intensity of other wine components that may mask (e.g. volatile oak compounds), or accentuate (e.g. 4-ethylguaiacol), the aroma of 4-ethylphenol.

4-Ethylphenol is produced by the enzymatic decarboxylation and reduction of *p*-coumaric acid (an hydroxycinnamic acid), by *Dekkera/Brettanomyces* sp. yeast. The hydroxycinnamates are an important group of phenolic acids present naturally in grapes and must, including the derivatives of *p*-coumaric acid. *p*-coumaric acid is actually present as the ester of tartaric acid in grapes, however, postharvest hydrolysis, especially by pectin esterase, frees up the *p*-coumaric acid. The *p*-coumaric acid undergoes enzymatic decarboxylation to the corresponding vinylphenol due to the presence of cinnamate decarboxylase in yeast (not just *Dekkera/Brettanomyces* sp.). The last step, the conversion of 4-vinylphenol to 4-ethylphenol, is affected by the enzyme vinyl-phenol reductase, which is present in *Dekkera/Brettanomyces* but is totally absent from *Saccharomyces*.

Although some microorganisms, such as bacteria, may be capable of volatile phenol production under some conditions (e.g. model medium enriched with certain phenols), the amounts produced are very small compared to those produced by *Dekkera/Brettanomyces*. Therefore, it is generally accepted that *Dekkera/Brettanomyces* is the only microorganism responsible for the phenol off-odour in red wines, and 4-ethylphenol is now a recognised marker compound for presence of this yeast.

Other 'Brett' compounds

- **4-Ethylguaiacol**

4-ethylguaiacol is another major spoilage compound associated with the growth of *Dekkera/Brettanomyces* yeast in wine and has been described as having a 'clove', 'spicy' or 'smoky' aroma. It is derived in the same fashion as 4-ethylphenol but from a different precursor: ferulic acid. The aroma threshold for 4-ethylguaiacol is reported to be 110 µg/L, and was found to be 158 µg/L in Australian wine styles (Bramley et al. 2007). Whilst this concentration is much lower than for 4-ethylphenol, 4-ethylguaiacol is generally found in lower quantities in red wines, often 10 times less for Cabernet Sauvignon wines. Relative concentrations of 4-ethylphenol and 4-ethylguaiacol affect the overall perception of 'Brett' spoilage.

- **4-Ethylcatechol**

4-ethylcatechol is another spoilage compound reported to be associated with the growth of *Dekkera/Brettanomyces* yeast in wine and has been described as having a 'horsey' aroma. The aroma threshold for 4-ethylcatechol was found to be 774 µg/L in a neutral Australian red wine (Bramley et al. 2007). 4-Ethylcatechol is derived in same fashion as 4-ethylphenol but from a different precursor (caffeic acid). A survey of European wines found concentrations of 4-ethylcatechol similar to 4-ethylguaiacol (in Pinot and Cabernet wines).

Indole

The AWRI's tasting panel have used terms such as 'styrene', 'mothballs', 'reduced' and 'rubber/plastic' to describe the off-character produced by indole. Whilst indole has been implicated in the phenomenon known as untypical or atypical ageing (Zoecklein 1995), it has been the AWRI's

experience that high levels are associated with stuck or sluggish fermentations and secondary fermentations in sparkling winemaking.

Indole is formed by yeasts and is related to the metabolism of the amino acid tryptophan. The ability of wine yeast to transform tryptophan to indole during fermentation was recently investigated at the AWRI (Arevalo-Villena et al. 2010). All ten yeast strains investigated were able to produce indole in the presence of tryptophan. The indole concentration peaked when approximately half of the sugar had been consumed, and then decreased in concentration through catabolic metabolism as the fermentations continued. This study concluded that the metabolism of tryptophan and indole might be altered during sluggish fermentations, causing the accumulation of indole. Given that indole off-odour has also been observed after the secondary fermentation during sparkling wine production, yeast stress might also be a factor associated with the production of indole.

The AWRI determined the aroma detection threshold of indole in a neutral, dry white wine to be 23 µg/L (Coulter et al. 2008; Capone et al. 2010). A preliminary survey of a number of commercially available Australian wines was also conducted and the indole concentration was found to range from approximately 1 µg/L to 10 µg/L, with a mean concentration of approximately 5 µg/L. Investigations at the AWRI have shown the concentration of indole in wines affected by this off-flavour to range from approximately 30 µg/L to 500 µg/L.

Taints

Cork-type taints

- **2,4,6-Trichloroanisole**

The main compound responsible for cork taint is 2,4,6-trichloroanisole or TCA. It is one of the most odour intense compounds known and has a distinct musty, mouldy aroma (Amon & Simpson 1989). One study determined the aroma threshold of TCA in a Pinot Noir wine as 1.4 ng/L (Duerr 1985), however, the aroma threshold may be lower in dry, white wines, or higher in full-bodied red wines. Prescott et al. (2005) reported that the consumer rejection threshold for TCA was 3.1 ng/L whilst the consumer detection threshold was 2.1 ng/L. Some tasters at the AWRI are able to detect TCA present in wines at less than 1 ng/L. The AWRI found that the presence of TCA at a concentration as low as 1 ng/L suppressed the ratings for overall aroma intensity and of positive fruit-derived characters of a particular Semillon wine during sensory evaluation.

The AWRI has found several other odour-intense compounds present in wines that have musty, earthy or mouldy aromas, and these are shown in Table 3.

Table 3. Odour-intense compounds, present in wines, imparting a musty, earthy or mouldy aromas.

Compound	Threshold	Odour description
2-methylisoborneol	30 ng/L	camphor-like, earthy
geosmin	25 ng/L	earthy, muddy
1-octen-3-ol	20 µg/L	mushroom, metallic

1-octen-3-one	20 ng/L	mushroom, metallic
2-methoxy-3,5-dimethylpyrazine	2.1 ng/L	"fungal must"

The AWRI has also shown that TCA can be formed in oak, and as a result wines can have a cork taint without any contact with cork.

TCA is generally formed as a result of moulds growing on cork and coming into contact with trichlorophenol. Trichlorophenol and related chlorophenols are excellent biocides and have been and appear to be still used by industry as general disinfectants. Some moulds can detoxify the trichlorophenol and related chlorophenols by inserting a methyl group on the benzene ring to form TCA and related anisoles. The chlorophenols can arise in the cork by aerial contamination or by the chlorination of phenol which is a natural component of cork.

- **2,4,6-Tribromoanisole (TBA)**

Another compound responsible for cork taint is 2,4,6-tribromoanisole. It behaves similarly to TCA and has a similar distinct musty, mouldy aroma. Chatonnet et al. (2004) reported that the aroma of TBA was perceptible at a concentration of 4 ng/L in wine, and that it could be detected at lower concentrations by tasting. A range of exceedingly low detection thresholds in water have been reported including 0.008 ng/L (Saxby et al. 1992), 0.02 ng/L (Whitfield et al. 1997) and 0.03 ng/L (Malleret and Bruchet 2001).

Chatonnet et al. (2004) indicated that TBA can be formed in wineries by the microbial breakdown of 2,4,6-tribromophenol (TBP), which is widely used as a flame retardant and as a fungicide or wood preservative, and can also be formed in wastewater. TBA has also been detected in barrels, plastics (including synthetic closures), natural corks, wood structures including walls, floors and ceilings, and in the atmosphere of wineries. Additionally TBA is also known to be readily absorbed by plastic materials and corks.

- **2-Methoxy-3,5-dimethyl pyrazine (fungal must)**

2-Methoxy-3,5-dimethyl pyrazine or 'fungal must' (FM) is possibly the second most important form of cork taint after TCA. The threshold of FM in a neutral white wine was determined to be 2.1 ng/L, which is comparable to that of TCA.

FM has been described by Mottram et al. (1984) to be responsible for an obnoxious odour present in certain machine cutting emulsions used in engineering workshops. It was described as 'musty', 'foul drains', or 'sour dishcloths'. It has also been identified in coffee where it was described as having an earthy aroma. It was important to both raw and roasted coffee and produced an intense aroma with an aroma threshold of 0.4 ng/L in water.

Mottram et al. (1984) concluded that FM was likely to be a relatively common cause of off-odour in the environment. However, there has been no further report of it as a cause of off-odour in the published literature over the following 20 years, and only one report of its occurrence in a food product.

Chlorophenols

- **2,4-dichlorophenol**

2,4-dichlorophenol (2,4-DCP) is one of a number of chlorophenol compounds. There are several types of chlorophenols that include mono, di, tri, tetra and pentachlorophenols and mixtures of these classes of chlorophenols have been widely used as biocides and are now considered general environmental contaminants. The aroma detection threshold of 2,4 DCP in wine was determined at the AWRI to be greater than 896 ng/L. Chlorophenols are generally described as contributing toward the odours of 'plastic', 'paint', 'medicinal' or 'phenolic'.

Mono-, di- and trichlorophenols can easily be generated by the chemical chlorination of phenol. Chlorine-based sterilising agents, such as hypochlorite solutions, can react with traces of phenol present in materials such as plastic or fibreglass tanks or linings, phenolic-based resins, paints and fittings. Chlorophenols are also generated when wood is treated with hypochlorite solutions and are formed in the bleaching of wood pulp for paper manufacture. Sometimes wooden pallets loaded with cartons are stored near processing areas where disinfectants containing available chlorine are used. In situations such as this, chlorophenols can be generated in the cartons or pallets if they contact chlorine. It is interesting to note that Saxby (1992) indicates that the presence of dichlorophenols might indicate spillage of phenolic herbicides on the wooden floors of shipping containers. In addition, products such as fibreboard and paper made from recycled materials can often contain relatively high levels of chlorophenols, which can then contaminate food products or processing aids packaged in the fibreboard or paper (Mottram 1984).

- **2,6-Dichlorophenol**

2,6-Dichlorophenol (2,6-DCP) is one of the more potent and sensorily important chlorophenol compounds and tasters use the typical chlorophenol aroma descriptors to describe 2,6-DCP, such as 'plastic', 'paint', 'medicinal', 'chlorine' and 'phenolic'. Tasters have also use terms such as 'hot, burning finish', 'bitter, metallic finish' and 'chemical aftertaste' to describe the palate effects of 2,6-DCP.

The AWRI determined the aroma detection threshold of 2,6-DCP in a neutral white wine to be 32 ng/L, which is considerably lower than the thresholds (22 µg/L and 200 µg/L) determined for this compound in water by Young et al. (1996) and Dietz and Traud (1978), respectively. Concentrations of 2,6-DCP up to 236 ng/L have been found in tainted wines investigated at the AWRI.

- **2-Chloro-6-methylphenol or 6-chloro-o-cresol (6CC)**

6CC has been reported to be responsible for taints in chicken meat (Patterson 1972), biscuits (Griffiths and Land 1973), soft drinks (Whitfield 1983) and more recently in wine from the use of contaminated yeast hulls. Contamination of products or processing aids with 6CC has been reported to be the result of exposure to airborne contaminants due to proximity to agrichemical plants or due to the use of disinfectants containing 6CC in the food processing plant. The AWRI determined the aroma detection threshold of 6CC in a neutral, dry white wine to be 70 ng/L.

Geosmin

Geosmin has an 'earthy', 'musty', 'muddy' aroma with a sensory threshold of 25 ng/L. Both geosmin and 2-methylisoborneol are primarily known as metabolites of soil bacteria and algae, such as actinomycetes or cyanobacteria, and are responsible for off-flavours in town water supplies and fish (Young et al 1996). However, several moulds amongst those isolated from corks are also capable of their biosynthesis. Geosmin has also been reported as a metabolite of *Botrytis cinerea*. Although geosmin may be present in wines, a relatively high concentration might be tolerated.

Guaiacol

Guaiacol is a component of smoke and has been described as 'smoky', 'phenolic' and 'medicinal'. The AWRI recently determined the aroma threshold of guaiacol to be 23 µg/L and the taste threshold to be 27 µg/L in a red wine.

Guaiacol is formed during the barrel toasting process and can then be extracted into wine at a typical concentration of 10–40 µg/L. Guaiacol has been reported to be a possible component of cork taint, as it is the primary off-flavour compound in faulty corkwood affected by a yellow discolouration. Guaiacol is formed by soil bacteria such as *Streptomyces* sp. (which grow on lignin in the corkwood) and other microflora including some moulds. However, cork producers are aware of this and normally cut off any affected sections of the cork slabs. Although guaiacol is present in corkwood, the quantities formed by the degradation of lignin under normal processing conditions for wine corks would be insufficient to cause a taint in cork. Therefore, guaiacol is not a significant cause of cork taint in Australia. Guaiacol is often below its flavour threshold concentration and influences wine aroma by acting in combination with other components. (Synergism – response to several components is greater than the sum of the individual contributions).

Bushfires and controlled burning of bushland can impart a smoke taint to grapes in nearby vineyards. Smoke taint from bushfires has been found to impart a back-palate 'excessively drying' character to affected wines and a lingering retro-nasal 'ash' character, which appeared to be more pronounced in smoke-affected samples than in juices or wines spiked with similar concentrations of guaiacol.

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