# Accumulation of Vanillin during Barrel-Aging of White, Red, and Model Wines

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A method for the rapid and accurate analysis of vanillin in wine, using stable isotope dilution analysis and gas chromatography/mass spectrometry, has been developed and applied to 64 oak barrel-aged white, red, and model wines. Following barrel fermentation and maturation on yeast lees, the concentration of vanillin in the white wines was only about one-third of that in the model wines stored for the same period. Once the yeast lees were removed, however, the white and model wines accumulated vanillin at a similar rate, which indicated that biological reduction of vanillin occurred only prior to racking. After 93 weeks in barrels, the concentration of vanillin in the red wines was less than one-half that in the model wines, and vanillin was further depleted during subsequent bottle storage of the red wines for 2 years at cellar temperature. For the model and red wines, the mean concentration of vanillin in barrels made from French oak, seasoned and coopered in Australia, was significantly higher than that for wines stored in barrels made from the same wood, but seasoned and coopered in France. In the white wines, extensive biological transformation of vanillin associated with yeast activity during the initial weeks of maturation appears to have nullified this seasoning/coopering effect. Oak origin had no significant influence on the final vanillin concentration in the wines.

**Keywords:** *Vanillin; analysis; wine; oak; seasoning; coopering*

## INTRODUCTION

The volatile phenol vanillin is the principal aroma-active constituent of natural vanilla (Clark, 1990). In oak barrels, vanillin is formed, as a lignin degradation product, mainly during coopering and is subsequently extracted into wines and spirits during barrel maturation. It is widely assumed that vanillin contributes to the flavor of barrel-aged alcoholic beverages, although in the case of wines, this is the subject of some dispute (Dubois, 1989; Chatonnet et al., 1991, 1992a). In the relatively low-alcohol milieu of wines, vanillin can be subject to biological reduction and further transformations (Chatonnet et al., 1992a), thereby reducing its concentration in wine.

In a detailed study of barrel-aged wines, carried out in our laboratory over several years, it had become apparent that, while vanillin in aqueous alcohol extracts of oakwood could be determined with acceptable accuracy by GC/MS, similar analysis of vanillin in red and white wines usually gave anomalously low results. Recoveries were variable and often less than 20%. It is possible that losses occurred due to acetal formation with wine glycols during the extraction of wines with organic solvents and during the subsequent concentration of these organic extracts. Such reactions would not take place with aqueous alcohol extracts of oak, which do not contain such glycols. Problems in measuring vanillin in wines are implied by the omission of data on this potentially important flavor-impact compound from several key studies of oak-derived wine volatiles (Chatonnet and Boidron, 1988; Chatonnet et al., 1990; Towey and Waterhouse, 1996). In most studies where vanillin in wines has been reported, the concentration has been determined by HPLC (e.g., Puech, 1987).

Stable isotope dilution assays have been applied successfully for the accurate determination of volatile compounds, including vanillin, in foodstuffs (e.g., Semmelroch et al., 1995 and references therein). The advantage of such assays is that the internal standard is virtually identical chemically to the substance being analyzed, and therefore the accuracy of the analysis is not reduced by inefficiency in isolation or by analyte decomposition.

We report here the analysis, by stable isotope dilution, of vanillin in 64 barrel-aged red, white, and model wines.

## MATERIALS AND METHODS

**Instrumental Analyses.** Extracts were analyzed with a Hewlett-Packard benchtop gas chromatograph/mass spectrometer (GC/MS). The Hewlett-Packard 5890A Series II gas chromatograph was fitted with a 30 m × 0.25 mm J&W fused silica capillary column DB-1701, 0.25 $\mu$m film thickness. The oven temperature was started at 60 °C, held at this temperature for 2 min, then increased to 250 °C at 10 °C/min, and held at this temperature for 20 min. The injector was held at 220 °C and the transfer line at 275 °C. The sample volume injected was 3 $\mu$L. The splitter, at 30:1, was opened after 36 s. Positive ion electron impact spectra at 70 eV were recorded in the range $m/z$ 35−450 for scan runs. For quantification of vanillin, mass spectra were recorded in the selective ion monitoring (SIM) mode. The ions monitored in SIM runs were $m/z$ 154, 155 for [$^2H_3$]vanillin (internal standard) and $m/z$ 151, 152 for vanillin. Selected fragment ions were monitored for 50 ms each.

**Preparation of [$^2H_3$]Vanillin (i.e., 4-Hydroxy-3-[$^2H_3$]-methoxybenzaldehyde).** 4-Methyl-2,6-di-*tert*-butylphenol

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(232 mg) followed by 3,4-dihydroxybenzaldehyde (5.01 g) and then [$^2H_3$]methyl iodide (4 mL) was added to a solution of sodium hydride (2.49 g) in 2-propanol (200 mL) under nitrogen. The mixture was stirred at 25 °C for 17 h, then acidified with concentrated aqueous hydrogen chloride to pH < 7, and evaporated to dryness *in vacuo*. The product was dissolved in diethyl ether (200 mL) and washed with water (3 × 10 mL), 10% aqueous sodium bisulfite (3 × 1 mL), and a solution of 15 drops of saturated sodium bicarbonate in saturated aqueous NaCl (5 mL). The ethereal extract was dried ($MgSO_4$) and the ether evaporated giving crude product (6.08 g) which was purified by dry column chromatography using 230−400 mesh silica gel as the stationary phase and dichloromethane as the eluant. Column fractions were washed with aqueous sodium bisulfite and dried ($MgSO_4$). Removal of the solvent and recrystallization of the major product from ethyl acetate/hexane gave [$^2H_3$]vanillin (3.2 g, purity > 99%) as white crystals. Mass spectrum: *m*/*z* 155 ($M^+$, 95), 154 (100), 126 (11), 109 (10), similar to that reported by Semmelroch et al. (1995).

**Preparation of Samples for Analysis.** A solution of [$^2H_3$]-vanillin (2 μg) in ethanol (200 μL) was added to the wine (10 mL) in a test tube. Ether (2−3 mL) was added, and the mixture was shaken briefly. A portion of the ether layer was then placed in a vial ready for instrumental analysis. Extraction and GC/MS analysis of all wines were carried out in duplicate. Several experiments to determine the effect of wine pH on the analytical method were also carried out. (a) The pH of a red wine sample was adjusted to 6.0 with 2 M sodium hydroxide solution, with or without nitrogen blanketing of the headspace above the wine. The internal standard was then added and the sample analyzed as described above. (b) The internal standard was added to the red wine sample. The pH was then adjusted to 6.0 or 8.5 with 2 M sodium hydroxide solution without nitrogen blanketing of the headspace above the wine and the sample analyzed as above.

**Validation.** The analytical precision of the method was determined by standard addition. A range of additions (50−1000 μg/L, $n = 7$) were made to one of the red wines. These 'spiked' wines were extracted and analyzed and the results submitted to an unweighted regression analysis of *y* on *x* ('vanillin measured' on 'vanillin added'); 99.94% of the measurement variation was accounted for by the addition variation (covariance = 0.9994). The slope of the line (1.0005 ± 0.0276, 95% confidence) was sufficiently close to unity to assume a one-to-one relationship between the recovery of the analyte and the internal standard.

**Data Analysis.** The standard addition experiment regression analysis was performed using Microsoft Excel V5.0 spreadsheet software. Treatment effects were explored using two-factor analyses of variance (ANOVAs) (fixed factors), and except for the wine-type effect at 11 weeks (see below), a nonsignificant interaction term was required before concluding that a significant effect existed.

Seasoning/coopering effects on the French oak treatments were explored for each wine type at each sampling time, using two-factor (3 oak origins × 2 seasoning/coopering locations) ANOVAs, with replication (Microsoft Excel V5.0 spreadsheet software). All other ANOVAs, for examining wine-type (white, red, and model), American oak seasoning, and oak origin effects, involved unequal cell numbers so an unweighted means model was employed [Kirby (1993), see pp 318−323], using SYSTAT V5.0 (SYSTAT, Inc.) statistical software.

Wine-type effects were explored at 11 weeks and for the 11−55 week period for the model and white wines and at 93 weeks for the model and red wines (8 barrel treatments × 2 wine types). In the case of the wine type effect at 11 weeks, the main effect of wine-type was highly significant (*F*-value = 307, $p < 0.001$). There was a significant interaction term (*F*-value = 5.7, $p = 0.002$), but because of the disparity of the size of the *F*-ratios and the fact that the model wine barrel treatment means were all substantially higher than the corresponding white wine treatment means, the wine-type effect at 11 weeks was considered real, despite the interaction term.

Seasoning effects alone were examined for the American oak (2 seasoning locations × 3 wine types). Oak origin effects were explored using only those barrels coopered in Australia from oakwood seasoned in Australia, and these involved the four oak origins (America, Limousin, Tronçais, and Vosges) and the three wine types. The 95% confidence intervals were calculated using individual cell variances when $n > 1$ for every cell; otherwise, they were calculated using the pooled variance of the cells [Kirby (1993), see pp 268−270].

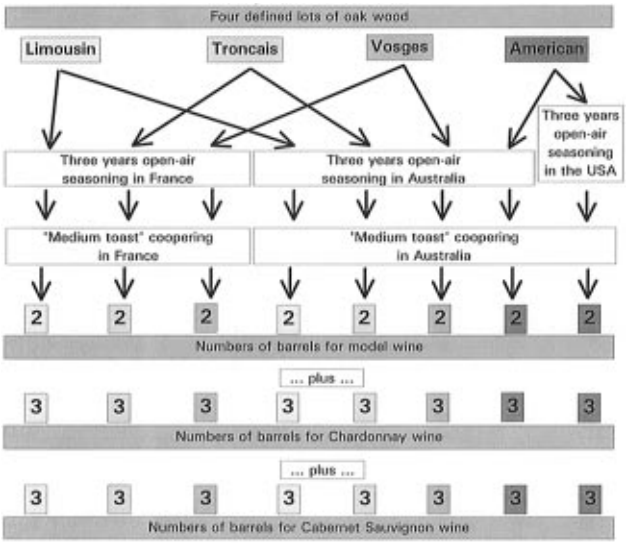


**Figure 1.** Oak source, seasoning, coopering, and usage.

**Analyses of Other Oak-Derived Volatiles.** These were carried out as described in Sefton et al. (1993a).

**Barrel Maturation of Wines.** The oak used for the barrels was harvested from the Tronçais forest, the Vosges and Limousin regions of France, and Ohio in the United States. Half of the oak was open-air-seasoned for 3 years in the country of origin, while the other half was shipped to and seasoned in Australia. The French- and Australian-seasoned lots were coopered by a French and an Australian cooper, respectively. The Australian cooper also coopered the American-seasoned oak. 'Medium toast', consisting of 45 min of slow toasting over a fire of oak offcuts, was specified for all barrels. Eight 300 L barrels were constructed from each of these eight oak lots (Figure 1) The wood used to make the barrels was the same as that reported previously (Sefton et al., 1993a); further details of oak selection and seasoning are given in that study.

Three barrels from each oak lot were used to mature a white wine, three a red wine, and two a model wine (12% aqueous ethanol, saturated with potassium hydrogen tartrate, pH adjusted to 3.45 by addition of tartaric acid and containing 28 mg/L free $SO_2$). The white wine, a 1991 Coonawarra (South Australia) Chardonnay, was transferred to barrel halfway through alcoholic fermentation (at 6 °B). After 11 weeks, each of the barrels was separately racked to remove yeast lees, rinsed, and refilled with the same wine. Malolactic fermentation in the white wine was discouraged, i.e., no inoculation was carried out and free $SO_2$ levels were periodically adjusted to 30 mg/L, but nevertheless occurred to varying degrees in some of the white wine barrels (Sefton et al., 1993b). The red wine, a 1991 Coonawarra Cabernet Sauvignon, underwent alcoholic and malolactic fermentation in a stainless steel tank before being transferred to the barrels for maturation. The model wines in barrels were screened on seven occasions during the 93 week storage period for the presence of yeast and bacteria. Samples (50 mL) were filtered through sterile 0.45 μm membranes (Gelman Sciences Inc., 47 mm GN-6 Grid S-Pack) which were then plated on WL nutrient media ('oxoid') for yeasts and on MRS broth ('oxoid'), supplemented with 20% clarified apple juice and 10 mg/L cycloheximide, for bacteria. The plates were incubated at 25 °C for 2 weeks. When yeast or bacteria colony-forming units (cfu) were detected, the contents of the barrel were sterilized by the addition of 0.15 mL of dimethyl dicarbonate/L of model wine, together with maintenance of free $SO_2$ concentrations of *ca.* 30 mg/L. One

barrel at one sampling showed 36 yeast cfu/mL, but all others showed less than 7 (usually zero) yeast or bacteria cfu/mL. All barrels were stacked in a temperature-controlled warehouse at 15 °C. The model wine was sampled after 6, 11, 55, and 93 weeks of storage. The white wines were sampled at racking (i.e., after 11 weeks) and after 55 weeks of storage, and the red wines were sampled after 93 weeks only. The red wines had a mean pH of 3.52 and a mean alcoholic strength of 13.6% (v/v) after 93 weeks, while the mean pH and alcoholic strength of the white wines after 55 weeks were 3.32 and 13.4%, respectively. The model wines had a mean pH of 3.12 and 3.22 and a mean alcoholic strength of 12.3% and 12.6% at 55 and 93 weeks, respectively. All wine samples taken for analysis were stored under carbon dioxide at −10 °C. Following the 93 week barrel maturation period, some samples of the red wines were also stored in glass at cellar temperature (*ca.* 10−20 °C) for a further 2 years.

## RESULTS AND DISCUSSION

**Analytical Method.** $^2H_3$-Methylation of the dianion of 3,4-dihydroxybenzaldehyde took place mainly on the less stable and therefore more reactive phenoxide anion meta to the aldehyde group, giving [$^2H_3$]vanillin (the internal standard) in good yield. When the reaction was carried out using standard conditions for methylating phenols (methyl iodide and potassium carbonate in dimethylformamide) iso-vanillin was the major product. In comparison to the technique of Freon extraction and concentration, previously used in our laboratory (Wilson et al., 1984), analysis of vanillin by stable isotope dilution coupled with selected ion monitoring was both accurate and rapid (sample preparation time was reduced from several days to 2−3 min) and required only a small sample of wine.

Several experiments were carried out to determine whether vanillin could be generated as an artifact or consumed during isolation or analysis. When extractions were carried out at wine pH, excellent reproducibility (generally ±1%) was obtained, regardless of the GC injector block temperature or of the delay time before opening the GC injector block splitter. This indicates that vanillin was not generated as an artifact during analysis, when wine pH was not adjusted.

When the pH of a red wine was adjusted to 6.0, and this was then followed by addition of the internal standard, the concentration of vanillin determined by GC/MS decreased. This decrease did not occur, however, when the wine sample was protected by a nitrogen blanket during pH adjustment. This indicates that the observed decrease in vanillin at pH 6.0 was due to oxidative processes, rather than to a 'freezing' of chemical equilibria between vanillin and vanillin adducts such as acetals.

No change in vanillin concentration was measured if the internal standard was added before the pH of the wine was adjusted to 6.0; presumably the extent of oxidative degradation of vanillin and its deuterated analogue are identical. However, if the internal standard was added to the wine and the pH then adjusted to 8.5 without inert gas protection, an apparent increase in vanillin concentration was measured and reproducibility was poor. This increase was greater at higher GC injector block temperatures (up to 250 °C), which indicates that at pH 8.5, precursors to vanillin, possibly oxidized lignins, were being generated, and these then decomposed to vanillin during sample injection. A similar phenomenon was observed when ether extracts of a red wine plus internal standard were held for a week prior to analysis; a slight (10%) increase in apparent vanillin concentration in the wine was detected.

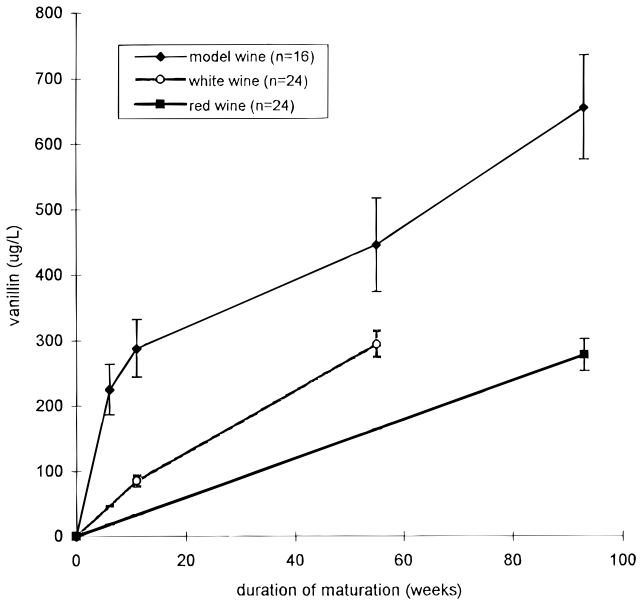


**Figure 2.** Vanillin accumulation in red, white, and model wines during oak-barrel maturation; 95% confidence intervals are shown.

The data indicate that vanillin can be both simultaneously generated and consumed in wines when the pH is 6.0 or higher. Such conditions, which are sometimes used to determine other oak volatiles in wine (e.g., Marsal and Sarre, 1987; Chatonnet and Boidron, 1988), should not be used when vanillin concentration is determined.

**Accumulation of Vanillin.** *In the White Wines (Figure 2).* Following barrel fermentation and maturation on yeast lees, which took place over an 11 week period, the mean vanillin concentration in the white wines was only about one-third that of the model wines stored for the same period (significance of difference, $p < 0.001$). The role of active yeast in transforming vanillin to vanillyl alcohol and further to other products is well known (Chatonnet et al., 1992a), and this is the most likely reason for the difference between the white and model wines.

In contrast, between week 11 and week 55 (i.e., following racking of the white wines) the mean increase in vanillin concentration in the white wines was slightly higher than that of the model wines, but this difference was not significant. This indicates that little or no biological reduction of vanillin took place once the yeast lees were removed. These results contrast with those reported by us earlier (Sefton et al., 1993b) which were based on Freon extracts of the wines. We have subsequently shown that such extracts give inconsistent data for vanillin determination in red and white wines (unpublished data).

Spontaneous malolactic fermentation took place in some barrels of the white wine following racking (i.e., between weeks 11 and 55), and this was associated with a corresponding reduction of furfural to furfuryl alcohol (Sefton et al., 1993b). There was, however, no corresponding association between malolactic fermentation and final concentration of vanillin. Apparently, at least some strains of lactic acid bacteria are less effective at reducing vanillin than they are at reducing furfural.

*In the Red Wines (Figure 2).* After 93 weeks of maturation, the mean concentration of vanillin in the

red wines was less than one-half that in the model wines stored in oak for the same period (significance of difference, $p < 0.001$).

Biological transformations may account, at least in part, for the comparatively low level of vanillin in the red wines. Although the wine had completed both alcoholic and malolactic fermentation prior to the commencement of barrel maturation, growth of other microorganisms in the wine during barrel maturation was likely. Chatonnet et al. (1992b) have shown that yeasts of the *Brettanomyces/Dekkera* genus can flourish in red wines, producing 4-ethylphenol from coumaric acid. In this study, 4-ethylphenol was found in all 24 barrels of red wine at significant concentrations (approximately 500−1000 $\mu$g/L). Acetic acid bacteria may also be active in red wines during barrel maturation, as demonstrated by Millet et al. (1995). The ability of *Brettanomyces* yeasts or acetic acid bacteria to reduce aromatic aldehydes is unknown. However, there was a negative correlation ($p < 0.01$) between the concentration of 4-ethylphenol and vanillin in the red wines (Spillman et al., 1996), and this suggests that *Brettanomyces* activity may have been responsible for the loss of some vanillin. 4-Ethylphenol was not correlated with any other oak-derived components.

Transformations of vanillin in wine are normally considered to be enzymatic, but purely chemical (i.e., nonenzymatic) reactions of vanillin in the wines could also have taken place. Following the 93 week period of barrel maturation, further depletion of vanillin in the red wines continued during 2 years of bottle storage at cellar temperature. The decrease of vanillin in all 24 samples during this time ranged from 27% to 57%, with a mean of 47%. There were no significant differences among oak types for this decrease. Most samples showed a similar reduction in vanillin concentration during this period, indicating that the depletion may have been due more to purely chemical (i.e., nonenzymatic) reactions of vanillin in the wines rather than to enzymatic processes. No changes in the concentration of 4-ethylphenol took place during bottle storage.

**Seasoning Location and Cooper Effects.** The American oak was seasoned in different locations (United States and Australia) but then coopered to the same specifications by one cooperage, in Australia (Figure 1). One barrel of model wine was classified as an outlier and excluded from treatment effect tests; the final vanillin concentration in this barrel was between one-half and one-quarter of the concentrations in the other 15 barrels of model wine. Relatively low concentrations of furfural, 5-methylfurfural, cyclotene, maltol, guaiacol, and 4-methylguaiacol—all compounds generated by coopering heat—were also found in this barrel. These observations indicate that the barrel was subjected to much lower levels of heat during the coopering process than any of the other 15 model wine barrels. While the coopers endeavored to 'toast' every barrel to a 'medium' level, control over the process is subjective and can result in some significant variability.

There was a trend ($p = 0.070$) toward a higher concentration of vanillin in the wines stored in the American oak barrels made from wood seasoned in Australia compared to the wines stored in the American oak barrels made from wood seasoned in the United States (Figure 3), but the effect was not significant. In this experiment, the wine type least affected by microbial activity—the model wine—was least replicated. A

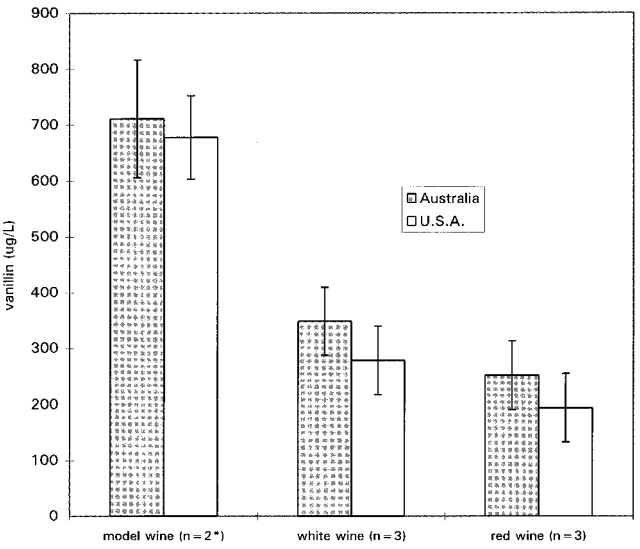


**Figure 3.** Effect of the location of seasoning of American oak on the final concentration of vanillin in wine; 95% confidence intervals are based on pooled variance. *$n = 1$ for Australian-seasoned model wine barrel due to omission of outlier.

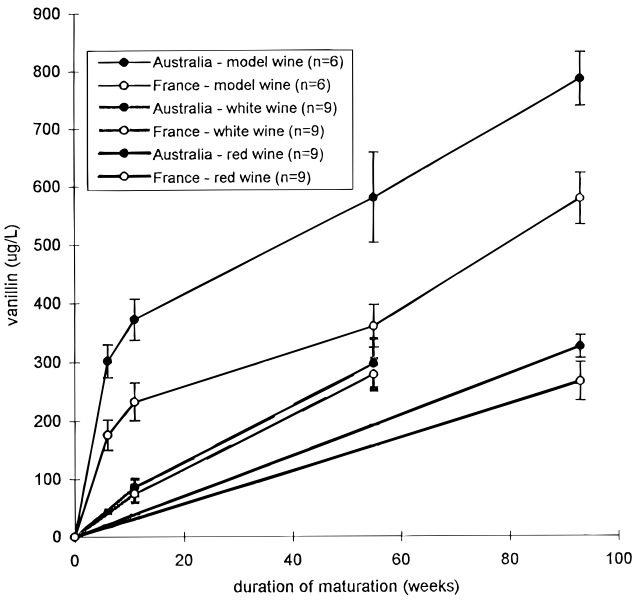


**Figure 4.** Influence of seasoning location and/or cooper on vanillin accumulation during maturation of wine in French oak barrels; 95% confidence intervals are shown.

larger number of barrels containing model wines would need to be studied to confirm the existence of a seasoning effect.

A highly significant seasoning location and/or cooper effect (these two variables were imposed simultaneously, Figure 1) was found among the French oak barrels (Figure 4). This effect was first measured among the model wines at 6 weeks ($p < 0.001$), then again at 11 weeks ($p = 0.001$), 55 weeks ($p = 0.001$), and 93 weeks ($p < 0.001$). The same effect was measured in the red wines at 93 weeks ($p = 0.007$) but not in the white wines at either 11 or 55 weeks. The difference in the rate of vanillin accumulation between the seasoning location/cooper treatments in the model wines occurred most substantially in the first 6 weeks (Figure 4). The lack of an effect in the white wines is probably a result of the extensive biological transformation of vanillin associated with yeast activity during these initial weeks. Because differences in seasoning location and cooper were imposed simultaneously on the French oak, it has

not been possible to determine with certainty whether this treatment effect resulted from seasoning or coopering conditions alone, or from a combination of conditions.

Vanillin concentration is known to vary significantly with variation in coopering heat (Chatonnet et al., 1989), and the variability of vanillin among the model wines (93 weeks) was positively associated with that of furfural, 5-methylfurfural, cyclotene, maltol, guaiacol, and 4-methylguaiacol—all compounds generated by coopering heat (Spillman et al., unpublished data).

In the red, white, and model wines matured in the French oak barrels, the concentration of 'total furfural,' i.e., furfural plus its transformation product furfuryl alcohol, was significantly higher in the Australian seasoned and coopered barrels than in those seasoned and coopered in France (Spillman et al., unpublished data). Thus, both vanillin and 'total furfural' responded in the same way to the seasoning/coopering treatments. Considering that these two compounds arise from chemically unrelated precursors in oakwood, it seems that the nonspecific action of coopering heat is likely to be implicated in these treatment effects.

Both vanillin and furfural are formed at relatively moderate heat levels. Compounds formed at higher temperatures, i.e., guaiacol and 4-methylguaiacol, did not differ significantly between the seasoning/coopering treatments for the French oak. Thus, if coopering technique was a factor in the difference between treatments, it is likely to have been as a result of differences in heat penetration through the wood, rather than the intensity of the toasting fire (Spillman et al., 1996).

The possibility of a combined seasoning and coopering effect should not be overlooked. The water content of the wood—a variable affected by the humidity and, if exposed, the rainfall of the seasoning site—could absorb some of the heat energy applied to the wood during coopering and, therefore, reduce the impact of a given amount of heat.

With the red wines, microbiological production of 4-ethylphenol took place to a significantly greater extent in the wines matured in the French seasoned and coopered barrels than in the wines matured in the Australian seasoned and coopered French oak barrels ($p = 0.002$). The reasons for this observation are unknown but do not appear to be related to differences in coopering intensity as there was no correlation of the content of 4-ethylphenol with that of any of the volatile products of coopering other than vanillin. Nevertheless, the treatment effect observed for vanillin in the red wines may have been determined by microbiological as well as coopering and seasoning factors.

**Oak Origin Effects.** Among the oak samples seasoned and coopered in Australia, there was no significant difference in final vanillin concentration among the American, Limousin, Tronçais, and Vosges barrels (Figure 5). It should again be noted, however, that the samples least affected by microbial activity during barrel storage, and therefore those most sensitive to any possible oak origin effects (the model wines), were least replicated. Furthermore, one of the two American oak barrels of model wine was excluded as an outlier, as discussed above.

**Sensory Properties of Vanillin.** There is conflicting opinion in the literature on the importance of vanillin to wine flavor. Chatonnet et al. (1991, 1992a) have concluded that vanillin plays a significant role in the flavor of barrel-aged wines, although this role is much diminished when wines are fermented and stored on lees in oak. In contrast, Dubois (1989), citing lower values for typical vanillin concentration in barrel-aged red and white wines and a higher sensory threshold, concluded that vanillin plays no role in the flavor of barrel-aged wines. Dubois considered the perception of the 'vanilla—oak' character in wines to be due to the influence of oak components other than vanillin.

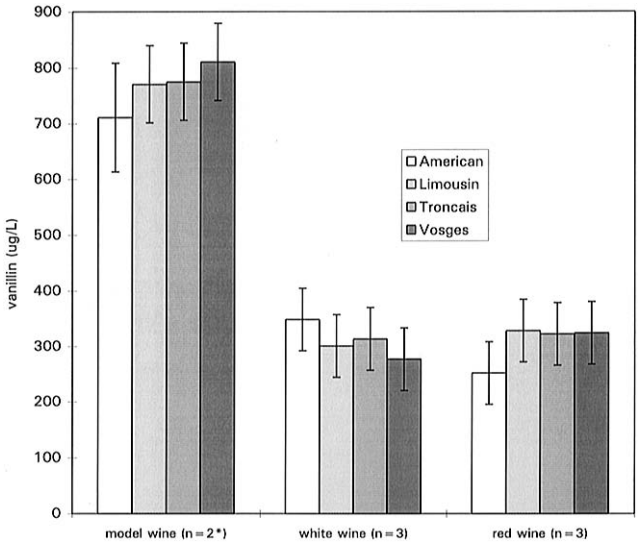


**Figure 5.** Effect of oak origin on final vanillin concentration in wine: American, Limousin, Troncais, and Vosges left to right, respectively. Barrels were made from oakwood seasoned and coopered in Australia; 95% confidence intervals are based on pooled variance. *$n = 1$ for American oak model wine barrel due to omission of outlier.

Generalizations on the sensory impact of vanillin in wines should be treated with caution. Barrel-toast levels, maturation time, the presence or absence of microbial activity in wines placed in wood, and perhaps also the strain of organism carrying out the primary and/or secondary fermentations might all have a profound influence on the final concentration of vanillin in a wine. Furthermore, the sensory impact of vanillin not only is likely to vary between individuals (Powers and Shinholser, 1988) but may also depend on the presence of other wine components which could modify, mask, or enhance its aroma and taste properties.

In a recent sensory study of the wines which are the subject of this report (Spillman et al., 1996), the concentration of vanillin in the white wines was positively correlated with 'smoky' and 'cinnamon' descriptors ($p < 0.05$ and 0.01, respectively) but only loosely associated with 'vanilla' ($p < 0.10$). In the red wines, vanillin was associated with the descriptor 'vanilla' ($p < 0.05$) but was most strongly associated with the descriptor 'coffee' ($p < 0.001$) and also with 'dark chocolate' and 'smoky' ($p < 0.01$). The descriptor 'vanilla' in the red wines was most strongly correlated with the concentration of *cis*-$\beta$-methyl-$\gamma$-octalactone ($p < 0.001$).

We are inclined to support the view of Chatonnet et al. (1991, 1992a) that vanillin can influence the flavor of some (but not necessarily all) wines matured in new oak. However, we also agree with Dubois (1989) that oak components other than vanillin probably influence the perception of the 'vanilla' character in wines.

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