Vitis **26**, 27—36 (1987)

Australian Wine Research Institute, Glen Osmond, South Australia

Evolution of red wines
II. An assessment of the role of acetaldehyde

by

T. C. SOMERS and L. G. WESCOMBE

Die Entwicklung von Rotweinen
II. Eine Wertung der Rolle des Acetaldehyds

Zusammenfassung: Die Faktoren, welche die Bildung und Verwertung des Acetaldehyds bei der Rotweinherstellung beeinflussen, wurden geprüft, wobei vor allem seine Bildung während der Hauptgärung und sein Abbau zu Beginn der Weinreifung untersucht wurden.

Die in jungen Weinen zu erwartenden Aldehydkonzentrationen wurden durch Zusatz von 30—50 mg SO_2/l vor der Gärung auf niedrige Werte eingestellt. Hefestamm, pH oder Temperatur beeinflußten die Acetaldehydbildung nicht nennenswert. Während der Milchsäuregärung trat eine signifikante Abnahme von Acetaldehyd, α-Ketoglutarsäure und Pyruvat unter Freisetzung von SO_2 auf. In sterilgefiltertem Wein war der Acetaldehydverbrauch bei höherer Temperatur gesteigert, bei hohen Konzentrationen an freiem SO_2 verringert. Die fortschreitende Veränderung der Farbstoffzusammensetzung junger Weine wurde durch Schwankungen des gebundenen Acetaldehyds zwischen 2 und 103 mg/l nicht beeinflußt.

Bei der Mehrheit der Rotweine, die in gewerblichen Kellern lagerten, nahm die Aldehydkonzentration ebenfalls ab. Ein Anstieg wurde auf abnormen Luftzutritt zurückgeführt. Es wird angenommen, daß die Acetaldehydbildung im Wein in erster Linie ein Grenzflächenphänomen ist, wobei Autoxidation von Äthanol mit atmosphärischem Sauerstoff erfolgt. Die Zunahme von Acetaldehyd bei der Weinherstellung ist als nachteilig für die sensorischen Eigenschaften und die Stabilität von Rotwein anzusehen.

Key words: red wine, aldehyde, sulphur, phenol, fermentation, ageing, stabilisation.

Introduction

The changing sensory characteristics of red wines through maturation and ageing derive from the high reactivities of the anthocyanins and other flavonoid phenolics extracted from red wine grapes during fermentation. Although the general course of phenolic interactions is indicated by rapid change in the composition of wine colour, with progressive displacement of monomeric anthocyanins by more stable polymeric pigment structures, there is often little or no visual effect. This phenomenon, by which wine colour density and tint may remain scarcely altered despite gross changes in pigment composition during the first year after vintage, has been frequently noted in controlled experiments (SOMERS and EVANS 1979, 1986). It is, however, not necessarily the commercial experience.

For young red wines, the importance of variables affecting the physico-chemical equilibria between coloured and colourless forms of the anthocyanins (viz. pH and free SO_2) has been demonstrated (SOMERS 1978; SOMERS and WESCOMBE 1982; SOMERS *et al.* 1983). However, factors influencing the further development of red wines up to the stage of final bottling are poorly understood. Commercial maturation procedures vary greatly in significant aspects of technique (SOMERS and WESCOMBE 1982), and the normal aim of producing wines having stable colour and acceptable tannin finish, while retaining varietal fruit character, is not always achieved. Reasons for this are often obscure.

Recent studies (SOMERS and EVANS 1986) have indicated that reactions leading to the formation of polymeric pigments in red wines can proceed under anaerobic conditions, with more extensive reactions occurring in the presence of oxygen. The latter involve the formation of -$CH(CH_3)$- bridges between flavonoid structures by acetaldehyde arising from autoxidation of ethanol i. e. Baeyer reactions (WILDENRADT and SINGLETON 1974; TIMBERLAKE and BRIDLE 1976, 1977; NAGEL *et al.* 1982; BARANOWSKI and NAGEL 1983; RIBÉREAU-GAYON *et al.* 1983).

Although the intervention of acetaldehyde in wine conservation and its reaction with phenolics have long been recognised (SINGLETON and ESAU 1969), there is still controversy about its precise role and function in red vinification. Thus TRILLAT (1908 a) identified acetaldehyde as the causal factor in wine colour instability and formation of pigment deposits and showed that it is formed by aeration or exposure of wine, particularly in the presence of yeast or other micro-organisms (TRILLAT 1908 b). Increase in volatile acidity and bitterness in aged red wines were also associated with acetaldehyde formation (TRILLAT 1908 c). Broad description of its variable role in relation to distinctive table and dessert wine types has been presented by BARO and CARRASCO (1977).

In recent reports from Bordeaux, acetaldehyde was assigned a primary role in phenolic condensation reactions of red wines, and aerobic treatment was recommended to initiate and promote ageing reactions (PONTALLIER and RIBÉREAU-GAYON 1983; RIBÉREAU-GAYON *et al.* 1983). Other investigations have, in contrast, indicated the main reactions to be acid-catalysed (anaerobic) condensations, with influence from acetaldehyde limited by the amount available (BARANOWSKI and NAGEL 1983; SOMERS and EVANS 1986).

Whereas white wine quality is generally protected by anaerobic procedures during conservation, there is wide variation in this aspect of red wine technology. Significantly, maintenance of a positive level of free SO_2, ensuring fixation of free acetaldehyde with favourable influence on varietal flavour, is recommended practice for all table wine types. Thus the need repeatedly to add SO_2 may be interpreted as indicating progressive formation (and on-going reactions) of acetaldehyde. Sensory effects, in microbiologically sound wines, could include pigment instability, increase in volatile acidity, and a gradual impression of bitterness. These effects are often associated with aged red wines, particularly those matured in small oak cooperage. It is relevant to note here that the presence of free SO_2 does not inhibit the non-enzymatic oxidative formation of acetaldehyde in wine (KIELHÖFER and WÜRDIG 1960).

It is in any case evident from the technical literature that all sources of acetaldehyde stem from aspects of the vinification method. In this paper, we examine variables affecting the origin and fate of acetaldehyde during fermentation and early conservation, and speculate about its influence on the evolution of red wines.

Materials and methods

Experimental wines

Red Shiraz juice (80 l, $E_{280\,nm}^{10\,mm} = 37$), commercially produced via heat processing, was obtained from Waikerie Co-operative Winery Ltd in 1981. All procedures were conducted under CO_2 blanket. A half-portion (40 l) was adjusted to pH 3.50 by tartaric acid addition; pH of the untreated juice was 4.16. Each half was divided into four lots, and these were treated with 10 % aq. sodium metabisulphite to give 0, 50, 100, 200 mg/l total SO_2. After standing overnight at about 20 °C, each lot was analysed for total SO_2, then divided into half-portions, each of which was inoculated with starter culture (200 ml) of

either AWRI yeast strain 729 or AWRI strain 350. This gave 16 red juice samples with all combinations of two pH values, four total SO_2 levels and two yeast strains. Each sample was analysed spectrally at this stage, then halved again; one half portion (2 l) was fermented at 25 °C, the other at 15 °C, all under non-return gas valves. When residual sugar levels fell to about 2 g/l ('Dextrocheck'), which occurred after 8 d at 25 °C and after 14 d at 15 °C, the wines were centrifuged, filtered through a 0.45 µm membrane into 375 ml bottles, crown-sealed under CO_2 and stored at 15 °C before early analysis.

Commercial wines

Shiraz wines (2-3 l, n = 18) from large commercial productions (100—500 hl) in several wine regions (1981 vintage) were received immediately after primary fermentation while still saturated with CO_2. With exclusion of air, each wine was cold-stabilised (−5 °C, 7 d), then sterile filtered into two 375 ml bottles. The remainder of each wine lot was treated with SO_2 (50 mg/l) before bottling. The bottles were crown-sealed with minimal N_2 headspace. Samples of each original wine were stored at −4 and 20 °C, and those with added SO_2 were stored at 20 °C. Each sample was analysed before bottling and again after storage for one year.

Analytical and other observations of wines during storage for 1 year under commercial conditions came from data and cellar records for young red wines surveyed during 1980—81 (SOMERS and WESCOMBE 1982).

Analyses

Acetaldehyde, α-ketoglutaric acid and pyruvic acid were analysed by enzymatic procedures (Boehringer Mannheim GmbH) after decolourisation with polyvinylpolypyrrolidone (1 g with 10 ml). Free SO_2 and the phenolics age index $E_{520}^{SO_2}/E_{520}^{CH_3CHO}$ were determined by spectrophotometric procedures (SOMERS and EVANS 1977). Total SO_2 was measured by the aspiration method (RANKINE and POCOCK 1970).

Results and discussion

1. Residual acetaldehyde levels after primary fermentation

Investigations of sulphite-binding equilibria in white wines and ciders had indicated that acetaldehyde production during fermentation is regulated by the level of total SO_2, with an approximately equimolar relationship between the two components (RANKINE and POCOCK 1969; BURROUGHS and SPARKS 1973). Analyses of many young red commercial wines suggested that this might not be generally true (SOMERS and WESCOMBE 1982). The influences of yeast strain, initial SO_2 level, pH and temperature on acetaldehyde concentration in new Shiraz wine were therefore examined (Table 1). The data are summarised as follows:

1. There was no appreciable effect from yeast strain, pH or temperature on the level of acetaldehyde attained.
2. After SO_2 addition before fermentation, there was an approximately equimolar ratio between acetaldehyde and total SO_2 residual in the new wine. Somewhat higher ratios were found in wines fermented at the higher temperature.
3. In the absence of any added SO_2 before fermentation, the presence of free acetaldehyde was indicated by high molar ratios acetaldehyde/total SO_2, particularly in wines fermented at higher temperature.
4. Concentrations of free SO_2 in the new wines increased with higher SO_2 additions before fermentation.

Measures of α-ketoglutaric acid and of pyruvic acid were also made but, with emphasis on acetaldehyde as by far the most significant carbonyl metabolite from fermentation, those data are omitted from the Table. Levels of α-ketoglutaric acid and pyruvic acid were not influenced by yeast strain, and there were gradual trends (towards maximal increases of 30 %, 75 %, respectively) with increasing SO_2 levels. The concentration of α-ketoglutaric acid was much increased by higher pH and higher temperature; maximal levels were in the range 141—217 mg/l, minimal levels in the range 19—43 mg/l. The concentration of pyruvic acid was increased by higher pH, but was not influenced by temperature; maximal levels were in the range 49—101 mg/l, minimal levels in the range 16—40 mg/l. Because of their relatively much weaker binding capacities for SO_2, levels and variabilities of these two components were considered to have only minor influences on the equilibrium concentration of free acetaldehyde in the new wines. All sulphite-binding components are in equilibrium with the free SO_2 level, and partial bleaching of anthocyanins is in fact fundamental to the spectral measure of free SO_2 in young red wines (SOMERS and EVANS 1977).

It is clear from Table 1 that the initial acetaldehyde concentration can be rather closely controlled, at low levels, by limiting the amount of SO_2 added before fermentation, and such acetaldehyde is largely bound to SO_2. Where SO_2 is not used, there is the likelihood of free acetaldehyde particularly in warm fermentations, as indicated by the molar ratios (Table 1).

These observations generally explain the wide range in acetaldehyde content of new wines. In related studies of young red wines from many commercial sources in the Australian industry, acetaldehde concentations were found to range from 2 to 94 mg/l (mean 22.7 mg/l, $n = 63$) and were strongly correlated ($P < 0.001$) with measures of total SO_2 in those wines (SOMERS and WESCOMBE 1982).

2. Decline in acetaldehyde levels during wine storage

a) Under sterile conditions

New red wines of different commercial origins, having acetaldehyde levels ranging from 2 to 103 mg/l, were stored under sterile, anaerobic conditions at −4 and 20 °C. Although free SO_2 concentrations varied widely (Table 2), portion of each wine was treated with 50 mg/l free SO_2 to ensure excessive free SO_2 levels in one set stored at 20 °C. Compositional changes after 1 year are shown in Table 2. Note that, as for the experimental wines (Table 1), free SO_2 measures were made by the spectral method, which gives much lower but more realistic readings for red wines than does the commonly used aspiration procedure. The range 0—6 mg/l (spectral) corresponds to about 0—35 mg/l free SO_2 by aspiration (SOMERS and WESCOMBE 1982).

Inspection of the varied data shows rate of consumption of acetaldehyde to have been decreased at low temperature and in the presence of high free SO_2 levels. It is significant, however, that acetaldehyde depletion does occur under the latter conditions, in which the acetaldehyde is strongly bound to SO_2; this is a consequence of the equilibrium which allows that trace amounts of free acetaldehyde are always available for reaction.

There was no evidence, however, that the rate of change of pigment composition was affected by the availability of acetaldehyde. Consumption of acetaldehyde at 20 °C ranged from 1 to 27 mg/l (mean 12.5 mg/l) for this diverse group of wines during 1 year. Consumption was apparently a function of the amount available, though also affected by free SO_2. These observations generally fit well with the proposition

Table 1

Influence of yeast strain, pH, temperature and SO_2 concentration on acetaldehyde production in red vinification

Der Einfluß von Hefestamm, pH, Temperatur und SO_2-Konzentration auf die Bildung von Acetaldehyd bei der Rotweinherstellung

Yeast strain	pH	SO_2 addition before fermentation (mg/l)	Acetaldehyde (mg/l)		Total SO_2 (mg/l)		Free SO_2 (spectral, mg/l)		CH_3CHO/total SO_2 (molar ratio)	
			15 °C	25 °C	15 °C	25 °C	15 °C	25 °C	15 °C	25 °C
729	4.2	0	17	11	9	2	0.3	0	2.7	8.0
729	3.5	0	13	10	8	1	0.2	0	2.4	14.5
350	4.2	0	11	11	4	1	0.1	0	4.0	16.0
350	3.5	0	10	11	2	1	0	0	7.2	16.0
729	4.2	50	24	28	32	34	0.8	0.6	1.1	1.2
729	3.5	50	27	30	34	29	0.6	0.4	1.2	1.5
350	4.2	50	22	23	28	18	0.8	0.4	1.1	1.8
350	3.5	50	23	22	27	18	0.4	0.3	1.2	1.8
729	4.2	100	50	58	77	69	1.6	1.4	0.9	1.2
729	3.5	100	60	56	83	52	1.2	0.8	1.0	1.6
350	4.2	100	45	48	69	57	1.5	0.9	0.9	1.2
350	3.5	100	53	47	76	59	1.1	0.8	1.0	1.2
729	4.2	200	94	108	156	154	3.0	1.9	0.9	1.0
729	3.5	200	119	125	190	179	2.4	1.7	0.9	1.0
350	4.2	200	91	105	152	148	2.8	1.8	0.9	1.0
350	3.5	200	108	102	173	149	2.2	1.6	0.9	1.0

that acetaldehyde interaction with phenolics is an extremely variable secondary influence on wine ageing reactions, with implications that the primary condensations are direct acid-catalysed interactions between anthocyanins and other flavonoids (SOMERS and EVANS 1986).

Data in Table 2 refer to wines in which available acetaldehyde is bound to varying degree, so that Baeyer reactions with phenolics are inevitably constrained. As first demonstrated by TRILLAT (1908a), there is more rapid effect in the presence of significant levels of free acetaldehyde. The consequences may be adverse change in wine aroma, colour instability, increase in volatile acidity. Maintenance of free SO_2 levels ensures low rate of change in acetaldehyde-related reactions, but does not prevent their occurrence.

b) During malolactic fermentation

The trend towards increased free SO_2 levels in newly fermented wines as a consequence of higher SO_2 additions before fermentation (Table 1) has been considered significant in relation to inhibition of lactic acid bacteria and to late onset of malolactic fermentation (HOOD 1983, 1984). Surveys of commercial winemaking practice, in which usage of SO_2 proved to be extremely variable, have shown onset of malolactic fermentation to be irregular, sometimes prolonged and incomplete, even delayed for up to 12 months after primary fermentation (SOMERS and WESCOMBE 1982).

In the above investigation (1982), analyses of 25 young red wines before and after malolactic fermentation showed rather precipitate decreases in all three SO_2-binding carbonyl components. Mean decreases in concentrations of acetaldehyde, α-ketoglutaric acid and pyruvic acid were 47, 30 and 68 %, respectively. Similar observations have been reported from studies of growth of lactic acid bacteria in white wines (FORNACHON 1963; MAYER *et al.* 1981).

Depending mainly on the quantity of acetaldehyde catabolised by lactic acid bacteria, there may be relatively large increases in free SO_2. In addition to partial bleaching of anthocyanin colour, with visible effect on red wine tint, sensory inspection of wines undergoing malolactic fermentation has indicated an association between increased levels of free SO_2 and taints on nose and palate, strongly suggestive of reduced-sulphur compounds (SOMERS and WESCOMBE 1982). These effects appear to be dissipated during prolonged maturation, contributing eventually to complexity in aged red wine, but they are certainly significant in relation to wines intended for early marketing.

3. Increase in acetaldehyde levels during wine storage

Review of analytical data and cellar records for commercial red wines surveyed during the 1980—81 vintages (SOMERS and WESCOMBE 1982) has shown that there was continual decrease in acetaldehyde content (with more rapid decline during malolactic fermentation) in a majority of the wines. All wines had been subjected to various racking, filtration and transfer operations during the year of observation. Approximately 30 % of the 67 wines, however, showed increases in acetaldehyde at some stage. Such increases are considered to be abnormal and to have arisen from aeration of the wine under conditions favourable to autoxidation of ethanol, e. g. the presence of yeasts or other microorganisms, possibly at warm temperatures (TRILLAT 1908 b). In our recent surveys, increase in acetaldehyde was frequently associated with wines from hot regions and with high total SO_2 in samples received for analysis.

Laboratory investigations of acetaldehyde formation by aerobic treatment of wine are noted to have involved the use of extreme forcing conditions, viz. ample exposure of

Table 2

Influence of temperature and free SO_2 level on acetaldehyde consumption and colour composition during sterile conservation of red wines for 1 year [1]

Der Einfluß der Temperatur und des Gehaltes an freiem SO_2 auf den Acetaldehydverbrauch und die Farbzusammensetzung von Rotwein bei 1jähriger steriler Lagerung

Total acetaldehyde (mg/l)				Free SO_2 (spectral, mg/l)				Age index ($E_{520}^{SO_2}/E_{520}^{CH_3CHO}$)			
New wine	After 1 year			New wine	After 1 year			New wine	After 1 year		
	−4 °C	20 °C	20 °C (SO_2)		−4 °C	20 °C	20 °C (SO_2)		−4 °C	20 °C	20 °C (SO_2)
2	1.5	0.9	1.6	0.7	0	0	3.1	0.21	0.25	0.51	0.37
6	5	4	5	0	0	0	3.8	0.23	0.27	0.51	0.34
7	7	5	7	4.4	2.0	1.2	5.8	0.20	0.23	0.46	0.36
15	11	9	12	2.0	1.5	1.0	5.5	0.23	0.24	0.44	0.33
22	17	10	20	0.1	0	0	3.8	0.23	0.30	0.67	0.42
22	19	12	21	0.9	0.2	0.2	5.4	0.26	0.31	0.56	0.36
23	17	11	18	1.5	0.6	0.5	5.3	0.17	0.26	0.46	0.28
25	17	3	19	0	0	0	2.6	0.30	0.36	0.66	0.45
29	25	22	27	2.9	1.2	1.0	6.2	0.13	0.16	0.47	0.28
32	28	20	30	0.4	0.2	0.5	3.2	0.11	0.19	0.56	0.33
38	34	25	38	0.6	0.4	0.5	5.4	0.17	0.22	0.50	0.26
39	29	20	33	1.8	1.4	0.7	4.1	0.28	0.38	0.57	0.41
41	38	28	38	0.8	0.2	0.3	4.9	0.20	0.25	0.49	0.29
42	39	27	42	0.8	0.4	0.4	6.8	0.18	0.25	0.54	0.26
51	46	37	46	0.6	0.3	0	4.5	0.43	0.46	0.69	0.54
69	64	48	63	1.1	0.7	0.7	4.2	0.17	0.23	0.57	0.33
77	72	50	71	1.2	0.9	0.8	4.9	0.13	0.15	0.47	0.22
103	93	85	93	3.6	1.5	1.1	4.7	0.33	0.35	0.53	0.37
36	31	23	32	1.3	0.6	0.5	4.7	0.22	0.27	0.54	0.34

[1] Individual wines were stored at −4 °C and 20 °C. A sample of each wine was also treated with additional SO_2 (50 mg/l) before storage at 20 °C.
[2] Mean values are listed across bottom line.

wine in bottle or vial at temperatures up to 50 °C for several weeks (WILDENRADT and SINGLETON 1974; RIBÉRAU-GAYON *et al.* 1983). Even so, free acetaldehyde is also formed in sterile red wine at 3 °C during aerobic storage in ampoule (SOMERS and EVANS 1986). High wine surface to volume ratio for prolonged periods was, however, a significant feature of those experiments, the aeration and wine exposure being much more severe than are encountered in normal conservation of table wines.

From these various observations, it seems likely that autoxidation of ethanol to acetaldehyde, which proceeds by way of coupled reactions with o-dihydroxy phenols (WILDENRADT and SINGLETON 1974) is strictly a s u r f a c e phenomenon initiated by atmospheric oxygen. This could mean that aeration of wine under normal cellar conditions (i. e. cool temperature, good hygiene and minimal ullage) occurs without generation of acetaldehyde. Testing of this hypothesis, and the realistic exploration of autoxidation reaction rates, appear to be worthy aims in oenological research. Present indications are that any increase in acetaldehyde concentration, whether stimulated by microbiological activity or not, is adverse in relation to sensory properties and stability of red wine.

Conclusion

For sound grapes, addition of SO_2 at 30—50 mg/l before fermentation will ensure low but controlled levels of bound acetaldehyde in the new wine, along with low levels of free SO_2. There is then unlikely to be any inhibition of lactic acid bacteria, and smaller risk of adverse compositional effects arising from catabolism of acetaldehyde during malolactic fermentation. If malolactic fermentation is not required to occur, maximal antibacterial benefit from further small SO_2 addition is provided in these circumstances of low acetaldehyde production in the primary fermentation.

The presence of acetaldehyde is apparently not an essential feature of dynamic change in wine colour composition during storage, but there is normal decline in acetaldehyde concentration by its interaction with phenolics. There is therefore the possibility of 'structuring' phenolic composition by anaerobic storage at elevated temperatures before use of traditional methods. It is noted that the f i n a l phase of red wine maturation depends primarily on absolute protection from oxidative influences and maintenance of low redox potential, i. e. during bottle ageing.

Wide variation in acetaldehyde formation and consumption (as a direct consequence of varied winemaking practice and different cellar conditions), with inevitable interactions and modification of total phenolic composition and related change in sensory properties, contributes largely to the range of red wine styles and quality. Thus increase in acetaldehyde content during vinification and conservation appears to be an adverse compositional factor in all table wines. Whereas progressive adjustment of free SO_2 levels, as during wood ageing, masks aldehydic influences on wine aroma and inhibits acetaldehyde reactions, the practice cannot prevent long-term cumulative effect of acetaldehyde consumption on wine composition and organoleptic charactersitics.

Summary

Factors influencing formation and utilisation of acetaldehyde during red vinification have been examined, with emphasis on its production during primary fermentation and depletion during early maturation.

Acetaldehyde concentrations in new wines were controlled at predictably low levels by addition of SO_2 at 30—50 mg/l before fermentation. There was no appreciable effect from yeast strain, pH or temperature on acetaldehyde production. Significant decrease in acetaldehyde, α-ketoglutaric acid and pyruvic acid, with release of free SO_2, occurred during malolactic fermentation. The rate of acetaldehyde consumption in sterile-filtered wine was increased at higher temperature and decreased by the presence of free SO_2 at high levels. Progressive change in pigment composition of new wines was not influenced by variation in bound acetaldehyde within the range 2—103 mg/l.

Acetaldehyde concentration also decreased in a majority of red wines during conservation in commercial cellars. Increases were attributed to abnormal conditions of wine exposure to air. It was concluded that acetaldehyde formation in wine is probably a surface phenomenon, involving autoxidation of ethanol at the wine interface with atmospheric oxygen. Increase in acetaldehyde during vinification was considered to be adverse in relation to sensory properties and stability of red wine.

References

BARANOWSKI, E. S.; NAGEL, C. W.; 1983: Kinetics of malvidin 3-glucoside condensation in wine model systems. J. Food Sci. **48**, 419—421, 429.

BARO, A. L. J.; CARRASCO, J. A. Q.; 1977: Les conditions de formation des aldéhydes dans les vins. Bull. O.I.V. **50**, 253—267.

BURROUGHS, L. F.; SPARKS, A. H.; 1973: Sulphite-binding power of wines and ciders. J. Sci. Food Agricult. **24**, 187—198.

FORNACHON, J. C. M.; 1963: Inhibition of certain lactic acid bacteria by free and bound sulphur dioxide. J. Sci. Food Agricult. **12**, 857—862.

HOOD, A. V.; 1983: Inhibition of growth of wine lactic acid bacteria by acetaldehyde-bound sulphur dioxide. Austral. Grapegrower Winemaker (232), 34—43.

— — ; 1984: Possible factors affecting SO_2-inhibition of lactic acid bacteria in newly fermented wine. Malolactic Fermentation: Proc. of a Seminar, 16 August 1984, Melbourne, Vic. 27—35. Australian Society of Viticulture and Oenology, Adelaide, S. A.

KIELHÖFER, E.; WÜRDIG, G.; 1960: Die an Aldehyd gebundene schweflige Säure in Wein. I. Acetaldehydbildung durch enzymatische und nicht enzymatische Alkohol-Oxydation. Weinberg u. Keller **7**, 16—22.

MAYER, K.; PAUSE, G.; VETSCH, U.; 1981: Biologischer Säureabbau in Wein: Einfluß auf die Gehalte an Glycerin und SO_2-bindenden Stoffen. Schweiz Z. Obst- Weinbau **117**, 387—390.

NAGEL, C. W.; BARANOWSKI, E. S.; BARANOWSKI, J. D.; 1982: Condensation reactions of flavonoids. Symp. Proc., Grape and Wine Centennial, 18—21 June 1980, Davis, CA, 235—239. University of California, Davis, CA.

PONTALLIER, P.; RIBÉREAU-GAYON, P.; 1983: Influence de l'aération et du sulfitage sur l'évolution de la matière colorante des vins rouges au cours de la phase d'élevage. Connaiss. Vigne Vin **17**, 105—120.

RANKINE, B. C.; POCOCK, K. F.; 1969: Influence of yeast strain on binding of sulphur dioxide in wines, and on its formation during fermentation. J. Sci. Food Agricult. **20**, 104—109.

— — ; — —; 1970: Alkalimetric determination of sulphur dioxide in wine. Austral. Wine Brew. Spirit Rev. **88**, 40—44.

RIBÉREAU-GAYON, P.; PONTALLIER, P.; GLORIES, Y.; 1983: Some interpretations of colour changes in young red wines during their conservation. J. Sci. Food Agricult. **34**, 505—516.

SINGLETON, V. L.; ESAU, P. 1969: Phenolic Substances in Grapes and Wines and their Significance. Academic Press, New York, London.

SOMERS, T. C.; 1978: Interpretations of colour composition in young red wines. Vitis **17**, 161—167.

— — ; EVANS, M. E.; 1977: Spectral evaluation of young red wines: Anthocyanin equilibria, total phenolics, free and molecular SO_2, 'chemical age'. J. Sci. Food Agricult. **28**, 279—287.

— — ; — —; 1979: 'April red' — one year later. Austral. Grapegrower Winemaker (184), 48—50.

— — ; — —; 1986: Evolution of red wines. I. Ambient influences on colour composition during early maturation. Vitis **25**, 31—39.

— — ; — —; CELLIER, K. M.; 1983: Red wine quality and style: Diversities of composition and adverse influences from free SO_2. Vitis **22**, 348—356.

— — ; WESCOMBE, L. G.; 1982: Red wine quality: The critical role of SO_2 during vinification and conservation. Austral. Grapegrower Winemaker (220), 68—74.

TIMBERLAKE, C. F.; BRIDLE, P.; 1976: Interactions between anthocyanins, phenolic compounds and acetaldehyde and their significance in red wines. Amer. J. Enol. Viticult. **27**, 97—105.

— — ; — —; 1977: Anthocyanins: Colour augmentation with catechin and acetaldehyde. J. Sci. Food Agricult. **28**, 539—544.

TRILLAT, A.; 1908 a: L'aldéhyde acétique dans le vin: son origine et ses effets. I. Formation des depôts et mécanisme de la fixation de résidu aldéhydique à la matière colorante du vin. Ann. Inst. Pasteur **22**, 704—719.

— — ; 1908 b: L'aldéhyde acétique dans le vin: son origine et ses effets. II. Étude des circonstances qui influent sur la formation de l'aldéhyde acétique. Ann. Inst. Pasteur **22**, 753—762.

— — ; 1908 c: L'aldéhyde acétique dans le vin: son origine et ses effets. III. Rôle de l'aldéhyde acétqiue dans quelques modifications du vin: vieillissement, jaunissement et amertume. Ann. Inst. Pasteur **22**, 876—895.

WILDENRADT, H. L.; SINGLETON, V. L.; 1974: The production of aldehydes as a result of oxidation of polyphenolic compounds and its relation to wine ageing. Amer. J. Enol. Viticult. **25**, 119—126.

Eingegangen am 22. 4. 1986

T. C. SOMERS
The Australian Wine Research Institute
Private Mail Bag
Glen Osmond, South Australia 5064
Australia