Sauvignon blanc Cultivar Aroma – A Review

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The typical cultivar aroma of Sauvignon blanc may be described as containing vegetative, grassy, herbaceous, gooseberry, asparagus and green pepper nuances. The chemical components responsible for these aromas are reviewed. The most important components are methoxypyrazines, especially 2-methoxy-3-isobutylpyrazine. Other components, such as 4-methyl-4-mercapto-pentan-2-one, monoterpenes, C_{13}-norisoprenoids, C_6-alcohols and C_6-aldehydes may also contribute to the complexity of Sauvignon blanc aroma. Factors affecting methoxypyrazine levels and therefore the typical Sauvignon blanc cultivar aroma are, amongst others, origin/climate and level of grape ripeness. Methoxypyrazine concentrations decrease with grape ripening and under increased sunlight and temperature conditions. To produce Sauvignon blanc wines with typical aromas, vines should be cultivated in cool areas and wines stored in dark rooms to retain these aromas.

Wine aroma is an important aspect of wine quality to which aroma components typical of the grape cultivar often make an important contribution. Sauvignon blanc is a cultivar of which the typical aroma may be described as containing vegetative, grassy, herbaceous, gooseberry, asparagus and green pepper nuances. These typical nuances are not unique to Sauvignon blanc, but are also part of Cabernet Sauvignon and Semillon grape and wine aromas (Allen & Lacey, 1993; Allen, Lacey & Boyd, 1994). These nuances, considered as typical of Sauvignon blanc aroma, are caused by a specific group of chemical components, namely methoxypyrazines. Other chemical components may, however, also contribute to the complexity of Sauvignon blanc aroma.

There are differences of opinion concerning the acceptability of the typical Sauvignon blanc aroma among producers and consumers. An intense aroma may be sought-after or unacceptable. The general feeling, however, is that the typical grass-like aroma is a positive quality parameter, as long as it is not one-sided or dominant, but complemented by other herbaceous and fruity aromas.

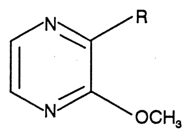
In South Africa the area planted to Sauvignon blanc has increased from 0,2% in 1980 to 4,0% in 1993 (Anon., 1994). This represents approximately 4000 hectares. Although high-quality wines with the typical cultivar aroma are produced, a high percentage of wines still show a neutral character. Against this background, the purpose of this review is a discussion of the typical Sauvignon blanc cultivar aroma and the factors which affect it. By applying this knowledge, more typical Sauvignon blanc wines may be produced.

AROMA COMPONENTS

Methoxypyrazines: Methoxypyrazines are nitrogen-containing ring substances and are secondary products of amino acid catabolism (Murray & Whitfield, 1975; Maga, 1989). Valine, glycine and methionine are considered to be precursors of 2-methoxy-3-isopropylpyrazine (Cheng *et al.,* 1991). However, the exact pathway for the formation of methoxypyrazines is not known (Rizzi, 1988). According to Allen (1993), indications are that the biosynthetic pathway for the formation of methoxypyrazines differs completely from that of monoterpenes and C_{13}-norisoprenoids.

Methoxypyrazines generally occur in raw vegetables such as peas, green peppers, potatoes and beetroot (Murray & Whitfield, 1975). Data tentatively indicating the presence of methoxypyrazines in Cabernet Sauvignon grapes were first published by Bayonove, Cordonnier & Dubois (1975). Subsequently two methoxypyrazines were identified in Sauvignon blanc juice by Augustyn, Rapp & Van Wyk (1982). Since then techniques for the determination of these compounds have been refined and the low concentrations at which they occur in grapes and wine determined quantitatively (Harris *et al.*, 1987; Lacey *et al.*, 1991). One methoxypyrazine is important in Sauvignon blanc grapes and wine, namely 2-methoxy-3-isobutylpyrazine (ibMP), while 2-methoxy-3-isopropylpyrazine (ipMP) and 2-methoxy-3-sec-butylpyrazine (sbMP) are generally present (Fig. 1). These components have extremely low threshold values and ibMP, which normally occurs in higher concentrations than the other two, can be perceived sensorially at a concentration of 2 ng/ℓ (2 parts per trillion) in water (Buttery *et al.*, 1969). This can be compared to one grape berry in 500 000 tons of grapes (Allen *et al.*, 1988).

Methoxypyrazines differ with respect to their aromas with green pepper-like aromas being typical of ibMP and pea-/asparagus-like aromas typical of ipMP (Allen *et al.*, 1988). Therefore, the complexity and nuances of Sauvignon blanc aroma will depend on, amongst other things, whether these components occur at levels above their threshold values.



2-Methoxy-3-isobutylpyrazine [R = $CH_2CH(CH_3)_2$] (ibMP)
2-Methoxy-3-isopropylpyrazine [R = $CH(CH_3)_2$] (ipMP)
2-Methoxy-3-sec.butylpyrazine [R = $CH(CH_3)CH_2CH_3$] (sbMP)

FIGURE 1
2-Methoxy-3-alkylpyrazines in Sauvignon blanc grapes and wine.

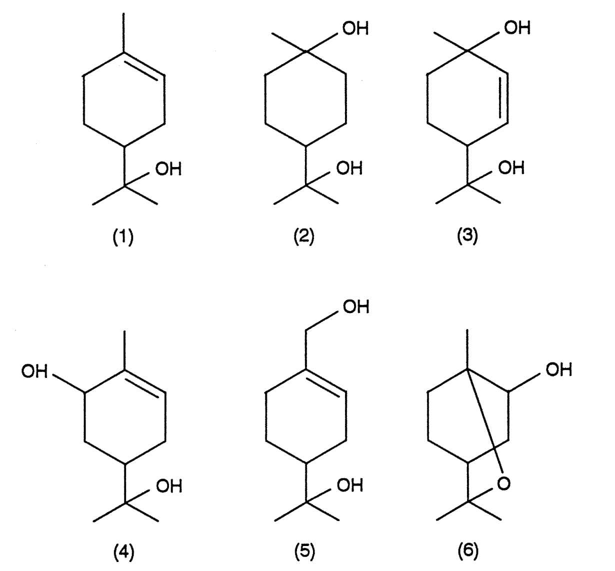
In Sauvignon blanc wines from Australia, New Zealand and France, ibMP concentrations were on average seven times higher than those of ipMP, while those of sbMP were even lower (Lacey *et al.,* 1991). From this it could be deduced that in most cases the latter two methoxypyrazines do not contribute to the overall aroma of grapes and wine of this cultivar. This was confirmed by the use of a sniffing technique ("Charm Analysis"), showing ibMP to be the main contributor to the vegetative/green pepper aroma of a typical wine (Lavin & Acree, 1992). The contribution of ipMP was marginal, while sbMP made no contribution.

Maga (1989) also studied the contribution of these components to the typical Sauvignon blanc aroma. Results indicated that addition of ibMP at ≥ 2 ng/ℓ caused musty and green pepper-like aromas in a model and natural wine, respectively. These results indicated that a threshold value of 2 ng/ℓ also applies to wine. Addition of ipMP at 2 ng/ℓ to the same wines again produced musty aromas in the model wine and earthy and leafy nuances in the natural wine. Aroma expression was also related to the concentration of the compound added. Therefore, other volatiles and individual compound concentration affect the perceived aroma. Aroma threshold values are only guidelines for aroma intensity and could change through synergistic actions with other components in the medium (Ribéreau-Gayon, Boidron & Terrier, 1975). The low threshold values of ibMP and ipMP were also confirmed by Allen *et al.* (1991). Addition of 1 ng/ℓ ibMP and 2 ng/ℓ ipMP to a neutral wine significantly affected the aroma, and 70% of the judges in the first case and 80% in the second could elicit the herbaceous/vegetative aromas.

The presence of another pyrazine, namely 3-methoxy-2-ethylpyrazine, was also reported in Sauvignon blanc grapes (Augustyn *et al.,* 1982). The threshold value of this pyrazine is 425 ng/ℓ (Seifert *et al.,* 1970), and as it is probably present at extremely low concentrations, it is unlikely to make any contribution to Sauvignon blanc aroma (Lacey *et al.,* 1991). The same reasoning applies to 2-methoxy-3-methylpyrazine (Harris *et al.,* 1987), having a threshold value of 4000 ng/ℓ (Seifert *et al.,* 1970).

Other aroma components: The possibility that other components also contribute to the typical Sauvignon blanc aroma should be considered. Francis, Sefton & Williams (1992) demonstrated that extracts of components, liberated from glycosidic precursors in Sauvignon blanc under acidic conditions, showed no grass-like or asparagus-like aromas, suggesting that pyrazine-like aromas do not derive from glycosides. This, however, does not mean that other components of glycosidic origin do not play a role. Williams, Francis & Sefton (1992) added hydrolysates, released acidically and enzymatically from their precursors in Sauvignon blanc grapes, to a neutral wine. The wines were judged and eleven descriptive terms were selected. Enzyme-released hydrolysates enhanced wine aroma with respect to three nuances, namely floral, lime and indeed also grassy. The first two aromas were probably caused by monoterpenes, but the origin of the grass-like aroma was not discussed. To what extent aroma compounds are naturally released by enzymes and contribute to wine aroma remains an unanswered question. Acid-released hydrolysates enhanced eight nuances of wine aroma, namely floral, talc, lime, pineapple, honey, toasty, oak and tea. Honey and tea-like aromas may have been caused by C_{13}-norisoprenoids and the oaky aroma by phenolic compounds. Addition of acid-released hydrolysates from Semillon and Chardonnay to a neutral wine gave similar results, therefore indicating that these aroma nuances are not unique to Sauvignon blanc. Although differences between Sauvignon blanc and, for example, Chardonnay appeared to be minimal, monoterpene concentration constituted a greater percentage of the total aroma concentration of Sauvignon blanc (Williams *et al.,* 1992). In an investigation of the composition of the free and bound aroma components of this cultivar, Sefton, Francis & Williams (1994) suggested that monoterpenes may play a role in its aroma. Volatile components were released from their bound forms by acid and enzymatic hydrolysis. Monoterpenes and C_{13}-norisoprenoids constituted 18% and 27% of the total aroma concentration, respectively. Blumenol C was the enzyme-released C_{13}-norisoprenoid occurring in the highest concentration. p-Menthane derivatives constituted an important part (40-50%) of the enzyme-released monoterpenes with alpha-terpineol and p-menth-1-ene-7,8-diol being the most abundant. In a comparative study between Gewürztraminer, Weisser Riesling and Sauvignon blanc, the latter had relatively high concentrations of free trans-pyran linalool oxide, diendiol-1, cis-8-hydroxy-linalool, 2-hydroxy-1,8-cineole and bound alpha-terpineol, cis-8-hydroxy-linalool and particularly menthenediol-2 (p-menth-ene-7,8-diol) (Versini, Rapp & Dalla Serra, 1992).

Monoterpenes with a p-menthene structure, occurring in relatively high concentrations in bound forms in Sauvignon blanc grapes and wine, are menthenediol-1 (trans- and cis-p-menth-1-ene-6,8-diol), also known as trans- and cis-sobrerol, and menthenediol-2 (Sefton *et al.,* 1994; Versini *et al.,* 1991; Versini *et al.,* 1992). These components (Fig. 2) are oxidized derivatives of alpha-terpineol and increase in concentration during ageing of wine (Versini *et al.,* 1992). Other alpha-terpineol derivatives of importance are 2-exo-hydroxy-1,8-cineole (Bitteur *et al.,* 1990) and p-menth-2-ene-1,8-diol, tentatively identified by Sefton *et al.* (1994). Experiments showed that alpha-terpineol was virtually completely transformed to trans- and cis-p-menthane-1,8-diol at wine pH. However, according to Sefton *et al.* (1994) the abovementioned monocyclic monoterpenes have limited sensory impact and chemical processes, transforming flavourful monoterpenes to p-menthane derivatives, will therefore diminish the sensory contribution of monoterpenes to grapes and wine.



1) alpha-Terpineol
2) p-Menthane-1,8-diol
3) p-Menth-2-ene-1,8-diol
4) p-Menth-1-ene-6,8-diol (Menthenediol-1)
5) p-Menth-1-ene-7,8-diol (Menthenediol-2)
6) 2-exo-Hydroxy-1,8-cineole

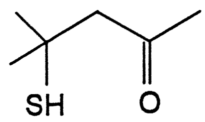
FIGURE 2

p-Menthane and p-menthene derivatives (2-6) of alpha-terpineol.

According to Dubourdieu, Darriet & Lavigne (1993), a sulphur component, 4-methyl-4-mercapto-pentan-2-one (Fig. 3), is important in the typical cultivar aroma of Sauvignon blanc. The threshold value of this component is 0,1 ng/ℓ in water. A component with a similar structure is probably responsible for the typical guava aroma of some South African Chenin blanc and Colombar wines (Du Plessis & Augustyn, 1981). Depending on its concentration level and the composition of wine, it also presents a cat urine aroma. The component mentioned by Dubourdieu *et al.* (1993) does not occur in grapes and juice, but is formed from a precursor during fermentation. The yeast strain therefore probably plays a role in the formation of this sulphur compound.

The importance of C_6-aldehydes and C_6-alcohols in the typical grassy, leafy and herbaceous-like character of unripe grapes is well known. Threshold values of n-hexanal, n-hexanol, cis-3-hexenal, trans-2-hexenal, cis-3-hexenol and trans-2-hexenol in beer are 0,35, 4, 0,02, 0,6, 13 and 15 mg/ℓ, respectively (Meilgaard, 1975). During crushing of grapes when grape cells are broken in the presence of oxygen, high concentrations of hexanal and hexanol are formed from linoleic acid, and trans-2-hexenal, trans-2-hexenol, trans- and cis-3-hexenols from linolenic acid (Drawert *et al.,* 1966; Cordonnier & Bayonove, 1981; Aerny & Humbert, 1993). Since these components occur in all grape juices, it appears that they are not impact components in the typical Sauvignon blanc aroma, and that their possible contribution is probably masked by the effect of other components. In addition, aldehydes are generally present in wine as bisulphite compounds due to the effect of added SO_2. Aldehydes are also reduced to the corresponding alcohols during primary fermentation.

Other components probably playing a role in the typical cultivar aroma of Sauvignon blanc are the potato-like methional and the so-called cucumber aldehyde, trans-2, cis-6-nonadienal (Augustyn *et al.,* 1982).



4-Methyl-4-mercapto-pentan-2-one

FIGURE 3

Flavourful sulphur component of Sauvignon blanc wines.

FACTORS AFFECTING THE DEVELOPMENT OF THE TYPICAL SAUVIGNON BLANC AROMA

The intensity of the typical Sauvignon blanc aroma and therefore the concentrations of the components responsible for this aroma are affected by origin/climate (Allen *et al.,* 1988; Allen & Lacey, 1993). The intensity is lower in hot areas, while in cool areas such as New Zealand it can be very prominent. Lacey *et al.* (1988) showed ibMP to occur in much higher concentrations in New Zealand Sauvignon blanc wines (12,6-34,5 ng/ℓ) than in Australian wines (0,6-14,6 ng/ℓ).

Heymann, Noble & Boulton (1986) found methoxypyrazines to be light sensitive and easily degradable to other components. This was confirmed by Maga (1989), showing that methoxypyrazine concentrations decreased more rapidly in the presence of light over 12 months' storage in clear glass bottles (up to 60%), when compared to green and amber coloured bottles (up to 40%). When bottles were stored for 12 months in the dark, concentration decreases were drastically smaller (≤4%), irrespective of glass colour. Allen (1993) demonstrated that methoxypyrazine concentrations decreased with an increase in sunlight exposure, obtained by a decrease in the number of leaf layers. In the same context Allen & Lacey (1993) proved that different pruning techniques caused significant differences in ibMP levels.

Regarding the localization of methoxypyrazines in grapes, Allen *et al.* (1989) suggested that these components probably occur in the solid parts of the grape berry, because Cabernet Sauvignon wines showed higher methoxypyrazine concentrations than those recorded in the corresponding juice before fermentation. This may possibly be ascribed to the extraction of methoxypyrazines from the solid parts by ethanol during fermentation or by the liberation thereof from precursors by specific yeast strains (Allen, 1994).

Methoxypyrazine concentrations decrease with grape ripening (Versini *et al.,* 1990; Lacey *et al.,* 1991; Allen, 1993). When compared to sugar accumulation, it was found that the ibMP concentration decrease mainly occurred before sugar accumulation reached 50% of the final concentration (Lacey *et al.,* 1991). They also found that a warmer year had a more pronounced effect on ibMP concentration decrease than a cooler year. The ibMP concentration decreased to a level lower than its threshold value in the warmer year, probably yielding wines without the desired, typical Sauvignon blanc aroma. On the contrary, the cooler year yielded more cultivar-typical wines.

Apart from methoxypyrazine concentration decreases during grape ripening and/or increased sunlight exposure, monoterpene and C_{13}-norisoprenoid concentrations generally increase under the same conditions. Therefore, to obtain a balance between the abovementioned component levels would be difficult, though Allen (1993) suggested that cool climatic conditions would benefit the development of methoxypyrazines, as well as monoterpenes and C_{13}-norisoprenoids.

CONCLUSIONS AND RECOMMENDATIONS

Research results indicate that the typical vegetative, grassy and green pepper-like aroma of Sauvignon blanc can mainly be ascribed to the occurrence of methoxypyrazines, and more specifically ibMP, which normally occurs above its threshold value and in concentrations higher than those of other methoxypyrazines. Results also suggest that components other than methoxypyrazines may contribute to the complexity of Sauvignon blanc aroma.

Application of existing knowledge to produce cultivar-typical Sauvignon blanc wines can best be made by following certain guidelines. To accommodate the effect of macro- and mesoclimate on methoxypyrazine concentrations, Sauvignon blanc should preferably be cultivated in cool areas or against cooler slopes in warm areas. Microclimate within the canopy can be manipulated by viticultural practices to obtain favourable conditions, that is relatively low temperature and reduced sunlight exposure, which will theoretically benefit methoxypyrazine precursor metabolism and methoxypyrazine retention during grape ripening. However, the negative effects of low temperature and lack of sunlight exposure on various viticultural aspects as well as on grape and wine quality in general should be borne in mind. Furthermore, to retain the typical Sauvignon blanc aroma, wines should be bottled in dark-coloured bottles and stored in dark rooms.

LITERATURE CITED

AERNY, J. & HUMBERT, B., 1993. Recherche et dosage des composés responsables du caractére herbacé des vins de Chasselas. *Revue suisse Vitic. Arboric. Hortic.* **25,** 347-351.

ALLEN, M.S., 1993. Viticultural effects on methoxypyrazine grape flavour: Current research directions. *Aust. Grapegrower & Winemaker* **354,** 10-12.

ALLEN, M.S., 1994. Commercial support for methoxypyrazine flavour research. *Aust. Grapegrower & Winemaker* **366,** 22-23.

ALLEN, M.S. & LACEY, M.J., 1993. Methoxypyrazine grape flavour: influence of climate, cultivar and viticulture. *Die Wein-wissenschaft* **48,** 211-213.

ALLEN, M.S., LACEY, M.J. & BOYD, S., 1994. Determination of methoxypyrazines in red wines by stable isotope dilution gas chromatography – mass spectrometry. *J. Agric. Food Chem.* **42,** 1734-1738.

ALLEN, M.S., LACEY, M.J., BROWN, W.V. & HARRIS, R.L.N., 1989. Occurrence of methoxypyrazines in grapes of *Vitis vinifera* cv. Cabernet Sauvignon and Sauvignon blanc. In: RIBÉREAU-GAYON, P. & LONVAUD, A. (eds.). Actualités Oenologiques 89. 4e Symposium International d'Oenologie, 15-17 June 1989, Bordeaux, France. pp. 25-30.

ALLEN, M.S., LACEY, M.J., HARRIS, R.L.N. & BROWN, W.V., 1988. Sauvignon blanc varietal aroma. *Aust. Grapegrower & Winemaker* **292,** 51-56.

ALLEN, M.S., LACEY, M.J., HARRIS, R.L.N. & BROWN, W.V., 1991. Contribution of methoxypyrazines to Sauvignon blanc wine aroma. *Am. J. Enol. Vitic.* **42,** 109-112.

ANONYMOUS., 1994. S.A. Wine Industry Statistics no. 18. KWV, Public Relations Department, Suider-Paarl, Republic of South Africa.

AUGUSTYN, O.P.H., RAPP, A. & VAN WYK, C.J., 1982. Some volatile aroma components of *Vitis vinifera* L. cv. Sauvignon blanc. *S. Afr. J. Enol. Vitic.* **3,** 53-60.

BAYONOVE, C., CORDONNIER, R. & DUBOIS, P., 1975. Etude d'une fraction caractéristique de l'arôme du raisin de la variété Cabernet Sauvignon: mise en évidence de la 2-méthoxy-3-isobutylpyrazine. *C.R. Acad. Sci. Ser. D.* **281,** 75-78.

BITTEUR, S.M., BAUMES, R.L., BAYONOVE, C.L., VERSINI, G., MARTIN, C.A. & DALLA SERRA, A., 1990. 2-exo-Hydroxy-1,8-cineole: a new component from grape var. Sauvignon. *J. Agric. Food Chem.* **38,** 1210-1213.

BUTTERY, R.G., SEIFERT, R.M., GUADAGNI, D.G. & LING, L.C., 1969. Characterization of some volatile constituents of bell peppers. *J. Agric. Food Chem.* **17,** 1322-1327.

CHENG, T-B., REINECCIUS, G.A., BJORKLUND, J.A. & LEETE, E., 1991. Biosynthesis of 2-methoxy-3-isopropylpyrazine in *Pseudomonas perolens. J. Agric. Food Chem.* **39,** 1009-1012.

CORDONNIER, R. & BAYONOVE, C., 1981. Etude de la phase préfermentaire de la vinification. Extraction et formation de certains composés de l'arôme; cas des terpénols, des aldéhydes et des alcools en C_6. *Connaiss. Vigne Vin* **15,** 269-286.

DRAWERT, F., HEIMANN, W., EMBERGER, R. & TRESSL, R., 1966. Enzymatische Bildung von Hexen-(2)-al-(1). Hexanal und deren Vorstufen. *Liebg. Ann. Chem.* **694,** 200-208.

DUBOURDIEU, D., DARRIET, P. & LAVIGNE, V., 1993. Recherche sur l'arôme varietal du cepage Sauvignon. In: LEMPERLE, E. (ed.). Proc. 10th. Int. Oenol. Symp., 3-5 May 1993, Montreux, Switzerland. pp. 405-416.

DU PLESSIS, C.S. & AUGUSTYN, O.P.H., 1981. Research note. Initial study on the guava aroma of Chenin blanc and Colombar wines. *S. Afr. J. Enol. Vitic.* **2,** 101-103.

FRANCIS, I.L., SEFTON, M.A. & WILLIAMS, P.J., 1992. Sensory descriptive analysis of the aroma of hydrolysed precursor fractions from Semillon, Chardonnay and Sauvignon blanc grape juices. *J. Sci. Food Agric.* **59,** 511-520.

HARRIS, R.L.N., LACEY, M.J., BROWN, W.V. & ALLEN, M.S., 1987. Determination of 2-methoxy-3-alkylpyrazines in wine by gas chromatography/mass spectrometry. *Vitis* **26,** 201-107.

HEYMANN, H., NOBLE, A.C. & BOULTON, R.B., 1986. Analysis of methoxypyrazines in wines. I. Development of a quantitative procedure. *J. Agric. Food Chem.* **34,** 268-271.

LACEY, M.J., ALLEN, M.S., HARRIS, R.L.N. & BROWN, W.V., 1991. Methoxypyrazines in Sauvignon blanc grapes and wines. *Am. J. Enol. Vitic.* **42,** 103-108.

LACEY, M.J., BROWN, W.V., ALLEN, M.S. & HARRIS, R.L.N., 1988. Alkyl methoxypyrazines and Sauvignon blanc character. Proc. 2nd. Int. Cool Climate Vitic. Oenol. Symp., 11-15 Jan. 1988, Auckland, New Zealand. pp. 344-345.

LAVIN, E.H. & ACREE, T.E., 1992. Gas chromatography-olfactometry of alkyl methoxypyrazines in wine. *Am. J. Enol. Vitic.* **43,** Abstracts. pp. 392. 17th Annual Meeting of the ASEV/Eastern Section, July 1992, Corning, New York, USA.

MAGA, J.A., 1989. Sensory and stability properties of added methoxypyrazines to model and authentic wines. In: CHARALAMBOUS, G. (ed.). Flavors and Off-flavors. Proc. 6th. Int. Flavor Conf., 5-7 July 1989, Rethymnon, Crete, Greece. pp. 61-70.

MEILGAARD, M.C., 1975. Flavor chemistry of beer: Part II: Flavor and threshold of 239 aroma volatiles. *Tech. Q. Master Brew. Assoc. Am.* **12,** 151-168.

MURRAY, K.E. & WHITFIELD, F.B., 1975. The occurrence of 3-alkyl-2-methoxypyrazines in raw vegetables. *J. Sci. Food Agric.* **26,** 973-986.

RIBÉREAU-GAYON, P., BOIDRON, J.N. & TERRIER, A., 1975. Aroma of Muscat grape varieties. *J. Agric. Food Chem.* **23,** 1042-1047.

RIZZI, G.P., 1988. The biogenesis of food-related pyrazines. *Food Rev. Int.* **4,** 375-400.

SEFTON, M.A., FRANCIS, I.L. & WILLIAMS, P.J., 1994. Free and bound volatile secondary metabolites of *Vitis vinifera* grape cv. Sauvignon blanc. *J. Food Sci.* **59,** 142-147.

SEIFERT, R.M., BUTTERY, R.G., GUADAGNI, D.G., BLACK, D.R. & HARRIS, J.G., 1970. Synthesis of some 2-methoxy-3-alkylpyrazines with strong bell pepper-like odors. *J. Agric. Food Chem.* **18,** 246-249.

VERSINI, G., RAPP, A. & DALLA SERRA, A., 1992. Considerations about the presence of free and bound p-menth-1-enediols in grape products. In: SCHREIER, P. & WINTERHALTER, P. (eds.). Flavour Precursors. Analysis-Generation-Biotechnology. Proc. Int. Symp. 30 Sept. – 2 Oct. 1992, Würzburg, Germany. pp. 243-249.

VERSINI, G., DALLA SERRA, A., DELL'EVA, M. & BERTAMINI, M., 1990. Monoterpenic compounds and 2-isobutyl-3-methoxypyrazine during the ripening course of *Vitis vinifera* L. cv. Sauvignon blanc grapes. Presented at Bioflavour '90, Glasgow, Scotland.

VERSINI, G., RAPP, A., RENIERO, F. & MANDERY, H., 1991. Structural identification and presence of some p-menth-1-enediols in grape products. *Vitis* **30,** 143-149.

WILLIAMS, P.J., FRANCIS, I.L. & SEFTON, M.A., 1992. Sensory and chemical analysis of hydrolysed flavour precursors from Sauvignon blanc grapes. In: SCHREIER, P. & WINTERHALTER, P. (eds.). Flavour Precursors. Analysis-Generation-Biotechnology. Proc. Int. Symp. 30 Sept. – 2 Oct. 1992, Würzburg, Germany. pp. 235-242.