Flavour Development in the Vineyard: Impact of Viticultural Practices on Grape Monoterpenes and their Relationship to Wine Sensory Response

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Monoterpenes are responsible for the distinctive flavour of grape cultivars such as Gewürztraminer, Riesling and several muscat cultivars. These components are present as odour-active free volatile terpenes (FVT) and as potentially volatile terpenes (PVT), *i.e.* glycosides and polyols capable of releasing FVT by temperature-, pH-, or enzyme induced hydrolysis. Our first work focused on the impact of fruit exposure on terpene concentrations in Gewürztraminer. Fully-exposed fruit consistently displayed higher FVT and PVT than partially-exposed and fully-shaded fruit. This knowledge was utilised to investigate effects of cultural practices. Hedging and basal leaf removal (BLR) increased FVT and PVT levels, while multi-site experiments also indicated that hedging and BLR could increase FVT and PVT in berries and musts of early-season cultivars such as Bacchus, Pearl of Csaba, Gewürztraminer, Schönburger and Siegerrebe. Canopy division, BLR and increased vine spacing also increased FVT and PVT concentrations in Riesling fruit. Low-heat unit sites appear to promote accumulation of monoterpenes in *Vitis vinifera* more than warmer sites, when compared at equal growing degree days. Prefermentation practices such as delayed harvest, prolonged pressing and skin contact were also shown to increase must terpene content. In many cases, these differences in terpene concentrations in the berries and musts were organoleptically detectable in wines. Our conclusions to date are: *(1)* PVT are more responsive to viticultural and enological practices than FVT; *(2)* FVT and PVT are rarely correlated with soluble solids, titratable acidity or pH, and thus cannot be predicted by standard harvest indices; *(3)* Losses in FVT and PVT can occur between the berry and juice stages, hence the desirability of skin contact; *(4)* FVT and PVT concentrations can, in some cases, be related to wine-tasting results.

Researchers, grape growers and wine makers have long sought, and continue to seek, objective measurements of optimum grape composition. Traditional measurements such as soluble solids, titratable acidity and pH can provide useful guidelines for assessing grape maturity, but provide no guarantee of superior wine grape quality, nor can they satisfactorily predict quality with any assurance. The abundance of chemical and physical changes that occur in the grape berry at, and subsequent to, véraison (Coombe, 1992) provides us with a plethora of objective indicators of grape composition. Some of these measurements have included texture (Lee & Bourne, 1980), lipid composition (Barron & Santa Maria, 1990), anthocyanins (Gonzalez-San Jose, Barron & Diez, 1990), amino acids (Miguel, Mesias & Maynar, 1985) and flavour compounds such as monoterpenes (Reynolds & Wardle, 1989b) and methoxypyrazines (Allen *et al.,* 1989). Among these and other objective measurements, it is the quantitation of flavour and aroma compounds that should, theoretically, be the most definitive.

Publication of a rapid distillation method for the extraction and quantitation of free and bound monoterpenes in grape berries and juices (Dimitriadis & Williams, 1984) added a new and useful tool to the existing arsenal of objective measurements. Their work showed that the spectrophotometric determination of free volatile terpenes (FVT) and potentially volatile terpenes (PVT) correlated very closely to gas chromatographic results, providing some needed confidence in the method.

McCarthy & Coombe (1985), McCarthy (1986), McCarthy, Coombe & Iland (1987) and Cirami & Furkaliev (1987) showed that PVT in Riesling berries were responsive to cluster thinning and reduced irrigation in Australia. It was apparent that these treatment differences were closely related to yield. Eschenbruch *et al.* (1987) demonstrated increases in PVT of Müller-Thurgau berries resulting from cluster thinning and shoot thinning. They concluded that PVT development in that cultivar closely paralleled soluble solids accumulation, and hence afforded no better indication of ultimate grape and wine quality. They were also unable to demonstrate a clear relationship between PVT concentration and wine quality. Smith *et al.* (1988) demonstrated the effectiveness of basal leaf removal on increasing both terpene concentration and wine sensory scores of Sauvignon blanc.

We began using the Dimitriadis & Williams method in 1985 after some necessary modifications, such as a different distillation apparatus and some adjustments to the volume and concentration of some of the reagents (Reynolds & Wardle, 1989a, 1989b). Respective standard errors on *1.* duplicate distillations of a berry homogenate or must, and *2.* duplicate spectrophotometric determinations on an individual distillate, were very small. Furthermore, percentage recovery of linalool added to distilled water in the distillation flask at 1 to 10 mg/L concentrations was very high and usually approached 95%. It appeared that this method was both reliable and efficient, and the relationship between intensity of muscat flavour *vs* berry FVT and PVT concentrations was very strong (Table 1).

It was our initial hypothesis that monoterpene concentration could be used as an accurate maturity index for wine grapes. We also hypothesised that fruit exposure and canopy management practices that impacted favourably on cluster microclimate would also enhance the concentration of monoterpenes in maturing grape berries. In order to test these hypotheses, a strategy was devised to initially examine the effect of fruit exposure on monoterpene levels of a single cultivar, Gewürztraminer. This work was a co-requi-

TABLE 1

Mean berry free volatile terpenes (FVT) and potentially volatile terpenes (PVT) concentrations in several *Vitis vinifera* cultivars. Means are those from several experiments between 1985 and 1989.

Cultivar	Flavour type	Monoterpenes (mg/L)	
		FVT	PVT
Bacchus	mild muscat	1,34	3,62
Gewürztraminer	spicy	1,64	2,63
Kerner	floral	1,00	3,24
Müller-Thurgau	mild muscat	0,77	2,23
Muscat Ottonel	muscat	2,78	7,85
Okanagan Riesling	labrusca	0,88	1,06
Optima	floral	0,92	3,32
Pearl of Csaba	muscat	3,16	6,58
Riesling	floral	0,98	2,63
Schönburger	muscat	1,02	3,59
Siegerrebe	muscat	3,12	7,57

site for research which examined the impact of viticultural practices such as hedging, growth retardants and basal leaf removal, and a prerequisite for further work which tested the influence of vineyard site, cultural practices such as divided canopies, and prefermentation cellar practices that could take advantage of high berry monoterpene concentrations, such as pressing and skin contact. Overall, this work has encompassed 11 cultivars and 10 vineyard sites in eight separate experiments. In all cases attempts were made to correlate terpene levels with sensory results. This paper provides a brief overview of some of the highlights of this work.

MATERIALS AND METHODS

General remarks: Due to the large number of studies described in this paper, full details of experimental design, materials and methods cannot be reported fully. However, there are many aspects common to all of the studies. Unless otherwise specified, all experiments were designed as randomised complete blocks. Those testing two or more experimental factors contained factorialised treatment arrangements. A minimum of four blocks was used in each trial, each of which contained three- to five-vine treatment replicates. Experiments involving several sites were analysed as completely randomised designs (for site). Trials in which treatments were imposed randomly on one-half of each vine were analysed as split plots. Viticultural practices were carried out according to local recommendations (BCMAFF, 1994).

In all field trials, mass of cane prunings (vine size), shoots per vine, yield components (yield per vine; clusters per vine; mean berry mass), berry composition [soluble solids (°Brix); titratable acidity (TA; pH], must composition (°Brix; TA; pH), wine composition (ethanol; TA; pH), and berry and must monoterpenes (FVT and PVT) were routinely measured. Cluster mass and berries per cluster were calculated from the appropriate measured yield variables. Mean cane mass was calculated from vine size and shoots per vine data, while crop loads were calculated as yield: vine size ratios. Wines were always made as replicate fermentations from fruit harvested from each treatment replicate. Particulars about winemaking, instrumentation or other details may be found in cited papers.

Gewürztraminer cluster exposure (1985-86): This first experiment examined the impact of cluster exposure to the sun on Gewürztraminer berry monoterpenes (Reynolds & Wardle, 1989b). Four rows (blocks) in the Brodersen vineyard, Kaleden, B.C. (vertical canopy) were sampled weekly (4 x 500 berries + 4 x 100 berries) from each of three cluster exposure categories (fully exposed; partially shaded; fully shaded). The 100-berry samples were analysed for °Brix, TA, and pH, while the 500-berry samples were subjected to a modification of the Dimitriadis & Williams method (1984) for distillation and subsequent colorimetric quantitation of FVT and PVT.

Gewürztraminer canopy manipulation (1985-87): A randomised block experiment (seven treatments, four blocks, and three-vine treatment replicates) at the aforementioned site compared viticultural practices that might impact on cluster exposure (hedging (H); basal leaf removal (BLR); flower cluster thinning (FCT); H + paclobutrazol (HP); H + lateral shoot removal; HP + FCT + BLR; untreated control). Berry samples were taken prior to harvest for determination of °Brix, TA, and pH (100-berry samples) and FVT and PVT (500-berry samples). Wines were made in replicate batches from c. 15 kg samples harvested from each treatment replicate (Reynolds & Wardle, 1989a.).

Effect of site and canopy manipulation:
Gewürztraminer site x *canopy manipulation (1988-92):* Information gained from the aforementioned trials was used to design three multi-site trials, in order to examine site x canopy manipulation interactions. The first experiment utilised three commercial Gewürztraminer vineyards (all vertical canopies) in the north (Cedar Creek Estate Winery, Kelowna, B.C.; mean annual °C growing degree days (GDD): 1045), central (Brodersen vineyard; 1134 GDD) and south (Tokios vineyard, Oliver, B.C.; 1443 GDD) Okanagan Valley. Randomised block experiments (4 blocks and 4-vine treatment replicates) with three treatments (H; H + BLR; untreated control) were established at each site. Yield and fruit composition variables were measured as previously described. Wines were made from each site x treatment combination in 3 of 5 years, and the 1988 and 1991 wines were evaluated using sensory descriptive analysis several times during their storage (Reynolds, Wardle & Dever, 1996a).

Early muscat site x *BLR (1987-88):* A multiple-site trial was established incorporating four muscat flavoured cultivars (Bacchus, Pearl of Csaba, Schönburger, Siegerrebe), each at a southern (>1390 GDD) and northern (945-1164 GDD) commercial vineyard (Reynolds *et al.*, 1995a). Within each cultivar x site combination, BLR was imposed randomly (split plot) on half of each vine to examine the magnitude of impact of each factor on berry and must monoterpene concentration. Samples (both 100-berry and 250-berry) were taken from each site x BLR combination on a weekly basis in 1987 and every 10 days in 1988 between véraison and commercial harvest, and standard fruit composition (100-berry samples) and monoterpenes (250-berry samples) were measured. Wines were made from all the treatment combinations in 1988 and musts were analysed for standard harvest indices as well as FVT and PVT. Difference tests were performed to ascertain differences between sites and BLR treatments within each cultivar.

Okanagan Riesling site x *BLR (1987-88):* Both monoterpenes and total volatile esters (TVE) were followed throughout Okanagan Riesling berry maturation to understand the basis for flavour changes during fruit maturation, from neutral to mild muscat to, ultimately, *labrusca* (Reynolds *et al.,* 1995b). Experimental design and procedures were identical to those in the early muscat trial. Wines were made from the treatment combinations in 1988 and difference testing was performed to ascertain differences between sites and between BLR treatments.

Riesling cultural practices
Shoot density x *crop level (1987-90):* Experiments which examined cultural practices for improvement of Riesling varietal character began with a trial in the Dulik vineyard, Kelowna, B.C., which tested three shoot densities (16, 26, 36 shoots/m row) in combination with three crop levels imposed by cluster thinning (1; 1,5; 2 clus-ters/shoot). Wines were made from the treatment combinations in 1989 and sensory descriptive analysis was performed after 18 months of bottle storage (Reynolds *et al.,* 1994b, 1994c). In addition to berry and must FVT and PVT, individual wine monoterpenes were quantified (Webster *et al.,* 1993) on wine samples collected at bottling and after 18 months of storage at 10°C.

Shoot density x *cordon age (1987-89):* A second shoot-density trial was established at Similkameen vineyards, Cawston, B.C. in the Similkameen Valley, which tested three shoot-density levels (20, 30, 40 shoots/m row) in combination with three cordon ages (ostensibly volume of "old" wood; cordons 1, 2, and 4 yr old). Both standard maturity indices and monoterpenes were measured on berries and musts. Wines were produced in 1989 and sensory descriptive analysis performed on these wines after 18 months of bottle storage (Reynolds, Wardle & Dever, 1994).

Riesling trellising x *vine spacing* x *BLR (1988-present):* At the Research Centre, Summerland, a trellising system x vine spacing (1,2; 1,8; 2,4m) x BLR trial was set up in 1985, with data collection beginning in 1988. Trellising systems were three non-divided canopy systems [0,5 m-high bilateral cordon ("low cordon"; LC); 1,2 m-high bilateral cordon (Lenz Moser); arched cane *(pendelbogen)*] and two divided systems [alternate double crossarm (ADC); V-trellis]. Standard maturity indices and monoterpenes were measured on berry samples ar harvest (Reynolds, Wardle & Naylor, 1996). Wines were made in 1993 from the trellising treatments within the 1,8 m spacing.

Prefermentation decisions and practices
Pressing (1987): Approximately 100 kg each of Gewürztraminer, Kerner, Müller-Thurgau and Muscat Ottonel grapes were harvested from the Research Centre's cultivar collection. The grapes were crushed and destemmed, and their free run fractions were thereafter allowed to drain on the press. After free run fractions were collected, grapes were pressed, and the press fractions were collected into separate fermenters. Replicate "free run" and "press" fermentations were allowed to proceed and the wines were subjected to sensory difference testing after 30 months of bottle storage.

Harvest date (1988): Kerner, Müller-Thurgau, Muscat Ottonel, Optima, Pearl of Csaba and Siegerrebe grapes were harvested from the Research Centre's cultivar collection at harvest dates 10-20 days apart. Replicate fermentations were made from the "early" and "late" harvested fruit, and the wines were subjected to sensory difference testing after 18 months of bottle storage.

Skin contact (1989): Kerner, Müller-Thurgau, Optima and Siegerrebe grapes were harvested from the Research Centre's cultivar collection. Fruit of each cultivar was either crushed followed by immediate pressing, or was given 48-72 hours skin contact. Replicate fermentations were made from the "crush/press" and "skin contact" must, and the resulting wines were subjected to sensory difference testing after 20 months of bottle storage.

Standard harvest indices and monoterpene concentrations were determined in both berries and musts in all the above experiments (Reynolds, Wardle & Dever, 1993).

RESULTS AND DISCUSSION

Effect of fruit exposure on monoterpene accumulation in grape berries: Results indicated that PVT concentrations in Gewürztraminer berries were highest in fully-exposed clusters throughout the course of fruit maturation, but peaked at about 20 days after véraison (Reynolds & Wardle, 1989b). Partially-exposed clusters (those shaded by one layer of leaves) contained a lower concentration of PVT than exposed clusters, but much more than shaded clusters. FVT were not as responsive to fruit exposure as PVT, but followed the same trends. By the final sampling date, °Brix, TA and pH were equalised among the three exposure treatments, but exposure-related differences in FVT and PVT remained until after commercial maturity (Reynolds & Wardle, 1989b). This led us to conclude that: fruit exposure may definitely enhance monoterpene concentrations in grape berries, and FVT and PVT concentrations may not necessarily be correlated to °Brix, TA or pH.

Effect of canopy manipulation

Gewürztraminer (1985-87): Many of the vineyards in B.C. and elsewhere in the Pacific Northwest region of North America are over-vigorous, and often produce fruit with low varietal character. Narrow row spacing (<2,4 m) precludes the effective implementation of horizontal canopy division, thus practices such as hedging and BLR are common solutions to these dense canopies. This initial work on Gewürztraminer indicated that FVT and PVT were responsive to cultural practices, BLR especially, and could also be increased by cluster thinning and hedging (Reynolds & Wardle, 1989a). Unfortunately, increases in FVT and PVT of 0,12-0,39 and 0,35-0,44 mg/L, repsectively, in hedged and BLR treatments over an unhedged control were insufficient to produce sensory differences in the wines. The data did indicate, however, as in our fruit exposure study, that FVT and PVT were not dependent upon °Brix, TA or pH.

Gewürztraminer multi-site trial: Regardless of site, BLR consistently increasesd berry PVT, and in one year, FVT as well (Fig. 1). Must FVT and PVT were also highest in the BLR treatment. These modifications in motorterpene concentration were in some cases associated with lower TA, pH and K^+, but slightly lower °Brix as well. Tasters found more muscat aroma and flavour in both the H and BLR wines than in the control (Fig. 2). Principal component analysis (PCA) also reinforced this pattern (Fig. 3) by characterising wines at the southernmost site as vegetative (control), floral (hedge) and muscat (BLR). Wines tasted after 48 months bottle storage were also strongly influenced by viticultural practices; control and hedge wines were identified as having considerable buttery and oxidised flavours, whereas the BLR wines did not (Reynolds, Wardle & Dever, 1996).

Early muscats: Many early-maturing cultivars such as Pearl of Csaba, Bacchus, Schönburger and Siegerrebe have become popular in British Columbia for the production of dessert wines and speciality products. Maturing in the warmest part of the season, they frequently present fruit composition problems such as low °Brix and TA along with high pH. FVT and PVT in the berries were responsive to BLR during the véraison to harvest period (Fig. 4). Musts displayed greater treatment differences, and BLR musts usually contained higher FVT and PVT (Table 1). °Brix and TA were largely unresponsive to BLR in the berries and must, but must pH was in many cases lower in BLR treatments (Reynolds *et al.,* 1995a).

At the warmer Oliver, B.C. sites, aroma differences were observed between control and BLR wines for two out of four cultivars (Reynolds *et al.,* 1995a) and flavour differences were apparent for three of four (Table 2). Tasters almost overwhelmingly indicated that the BLR treatments contained the most muscat and/or floral flavour. These distinctions could be made based on differences in PVT of 1,45; 0,10 and 0,87 mg/L for Pearl of Csaba, Schönburger and Siegerrebe, respectively. Similar trends were apparent for the related Okanagan Riesling experiment (Reynolds *et al.,* 1995b). These results suggest that berry or must monoterpene concentrations may be used as indicators of potential wine varietal character.

Riesling canopy management

Riesling shoot density x *crop level:* Despite large yield and shade increases, increases in shoot density actually increased Riesling berry and must PVT in two years (Reynolds *et al.,* 1994a). Reducing crop level had a minor effect on PVT concentration. Tasters found 26 shoots/m row wines equal to wines of lesser shoot densities in terms of sensory quality, despite higher yields. This may have been due to higher PVT concentration in the original berries and musts (Reynolds *et al.,* 1994a, 1994b). Some monoterpenes, including linalool, linalool oxides, terpineol and citronellol were associated with lower crop levels and low to moderate (16 or 26 shoots/m row) shoot densities, and also increased in concentration during ageing (Reynolds *et al.,* 1994b).

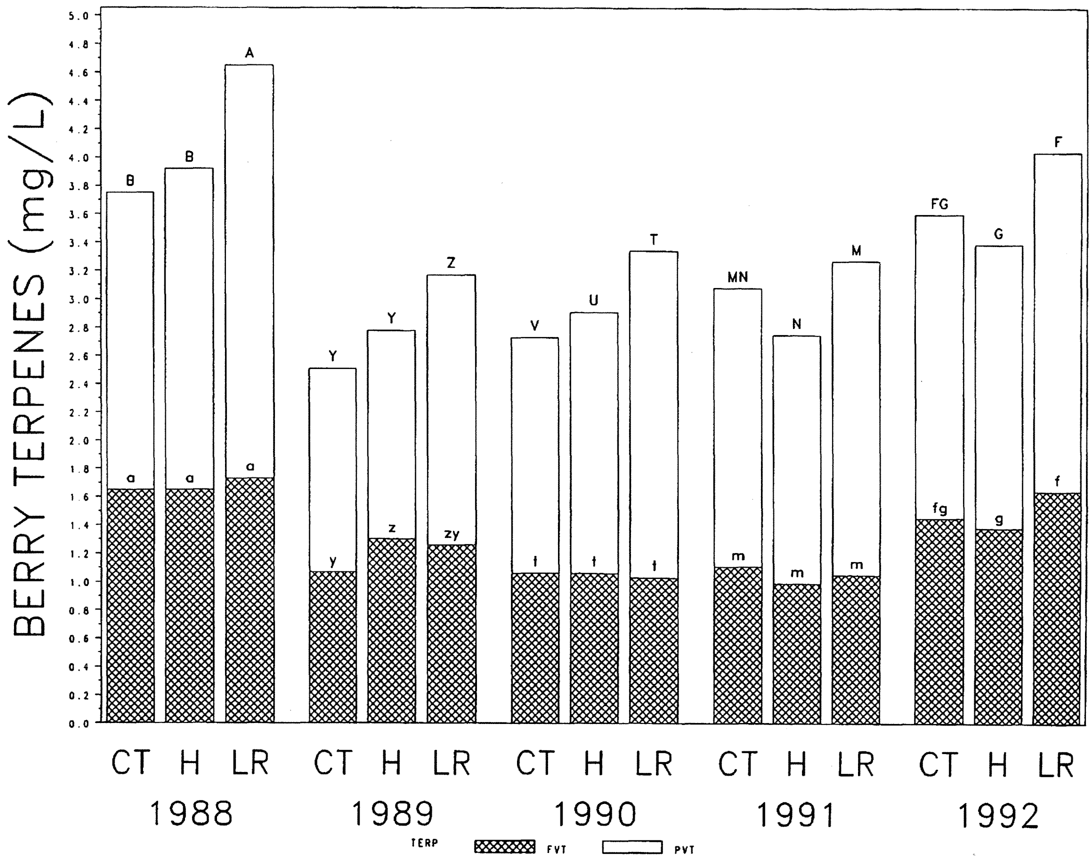

FIGURE 1
Impact of three canopy manipulation treatments on FVT and PVT concentrations in Gewürztraminer berries at harvest, 1988-92. Means are those of three vineyard sites. Bars of like pattern and different letters are significantly different at p ≤ 0,05, Duncan's multiple range test. Legend: CT, H, LR: Control, hedge and leaf removal, respectively.

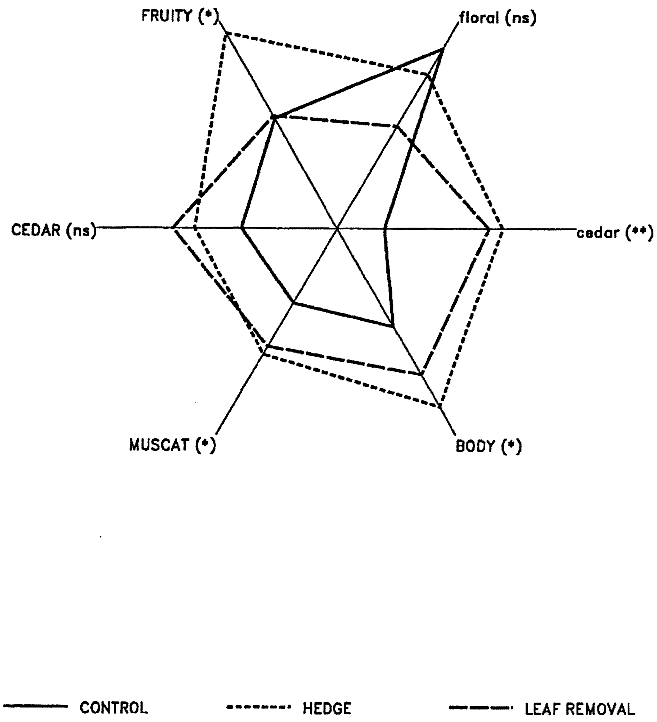

FIGURE 2
Sensory profile of descriptive analysis (n=24) of non-aged 1991 Gewürztraminer wines from three canopy manipulation treatments, Kaleden, B.C. Legend: *, **, ns: significant at p ≤0,05, p ≤0,01, or not significant, respectively. Aroma descriptors are donated by lower case letters and flavour tactile descriptors by upper case script. Axis length=45.

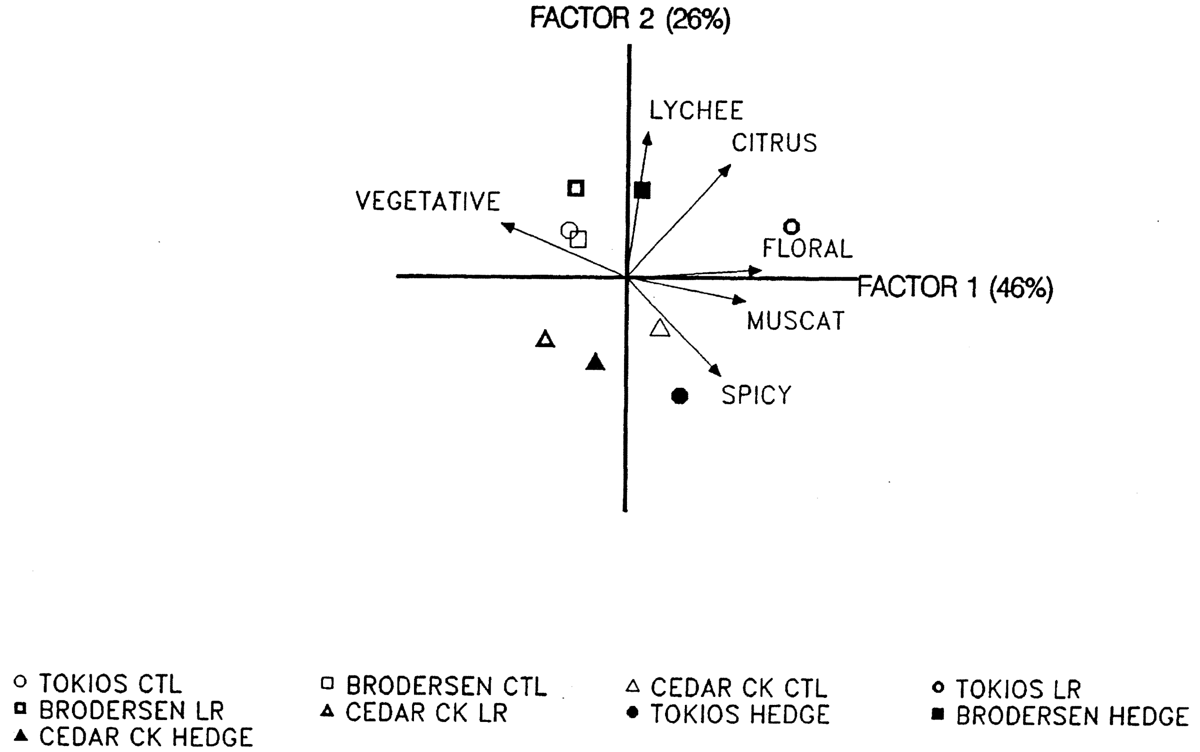

FIGURE 3
Projection of descriptive analysis retronasal aroma data (n=16) of non-aged 1988 Gewürztraminer wines on PCA factors 1 (46% of variability) and 2 (26% of variabilty). Vineyard sites are indicated by octagons (Tokios vineyard, Oliver), squares (Broderson vineyard, Kaleden), and triangles (Cedar Creek Estate Winery, Kelowna). Canopy manipulation treatments are denoted by open characters (control), solid hedged and boldface (BLR).

Riesling shoot density x *cordon age:* Increasing volume of "old" wood increased berry and must PVT (Reynolds, Wardle & Dever, 1994). Wines produced from vines containing more "old" wood were higher in floral aroma and flavour, with less vegetal character. Shoot density had less of an effect than volume of old wood.

Trellising x *vine spacing* x *BLR:* The ADC system produced yields as high as 33t/ha, along with lower TA, and higher FVT and PVT than standard *pendelbogen* and bilateral cordon systems (Fig. 5). Increasing vine spacing increased FVT and PVT levels linearly in one season, and a training x spacing interaction for FVT indicated that the trend was largely confined to the double crossarm system (Reynolds, 1993; Reynolds, Wardle & Naylor, 1996). As expected, mass of cane prunings/m canopy was lowest for the ADC and decreased linearly as vine spacing was increased. Fruit exposure and berry temperatures were considerably higher than in bilateral cordon vines (Reynolds, Wardle & Naylor, 1996). However, despite significant increases in cluster exposure resulting from canopy division, BLR still reduced TA and increased PVT, even in the ADC system (Reynolds, Wardle & Naylor, 1996). This suggests that natural fruit exposure can be augmented by cultural practices to increase potential wine quality.

Wine quality was very similar across all trellising treatments. The ADC wines could be separated from others only by slightly higher vegetal aroma and lesser intensity of aftertaste (Fig. 6). The V-trellis, however, was not different from treatments producing crop sizes several t/ha less. This strongly suggests that crop size is not a strong determinant of Riesling varietal character. However, the increase in vegetal aroma nonetheless suggests that further canopy manipulation or crop control was needed to take full advantage of the ADC trellis.

Impact of vineyard site: The influence of site on fruit composition is difficult to define objectively, when site-based differences in canopy density, phenology, soil type and cultural practices are involved. The work we began in 1987-88 attempted to distinguish between sites on the basis of monoterpene levels by locating vineyards of similar soil type and vine vigour, and by maintaining the vines using identical cultural practices.

Di Stefano & Corino (1984; 1986) found only minor differences in terpene levels between Moscato bianco and Moscato giallo grapes grown on several sites in the Piemonte and Val d'Aosta regions in Northern Italy. Subsequent work (Corino & Di Stefano, 1988) showed that higher terpene concentrations were associated with warm sites. Likewise, Noble (1979) found few differences between Chardonnay wines whose origins included Monterey (region I), Oakville (Napa County; region III), and Livermore (Alameda County; region III). Larrechi & Ruiz (1987) and Larrechi, Guash & Ruiz (1988) used multivariate analysis to distinguish between wine-growing regions in Catalonia, Spain. Ewart (1987) found that a cool, high-elevation site (High. Eden, South Australia) produced

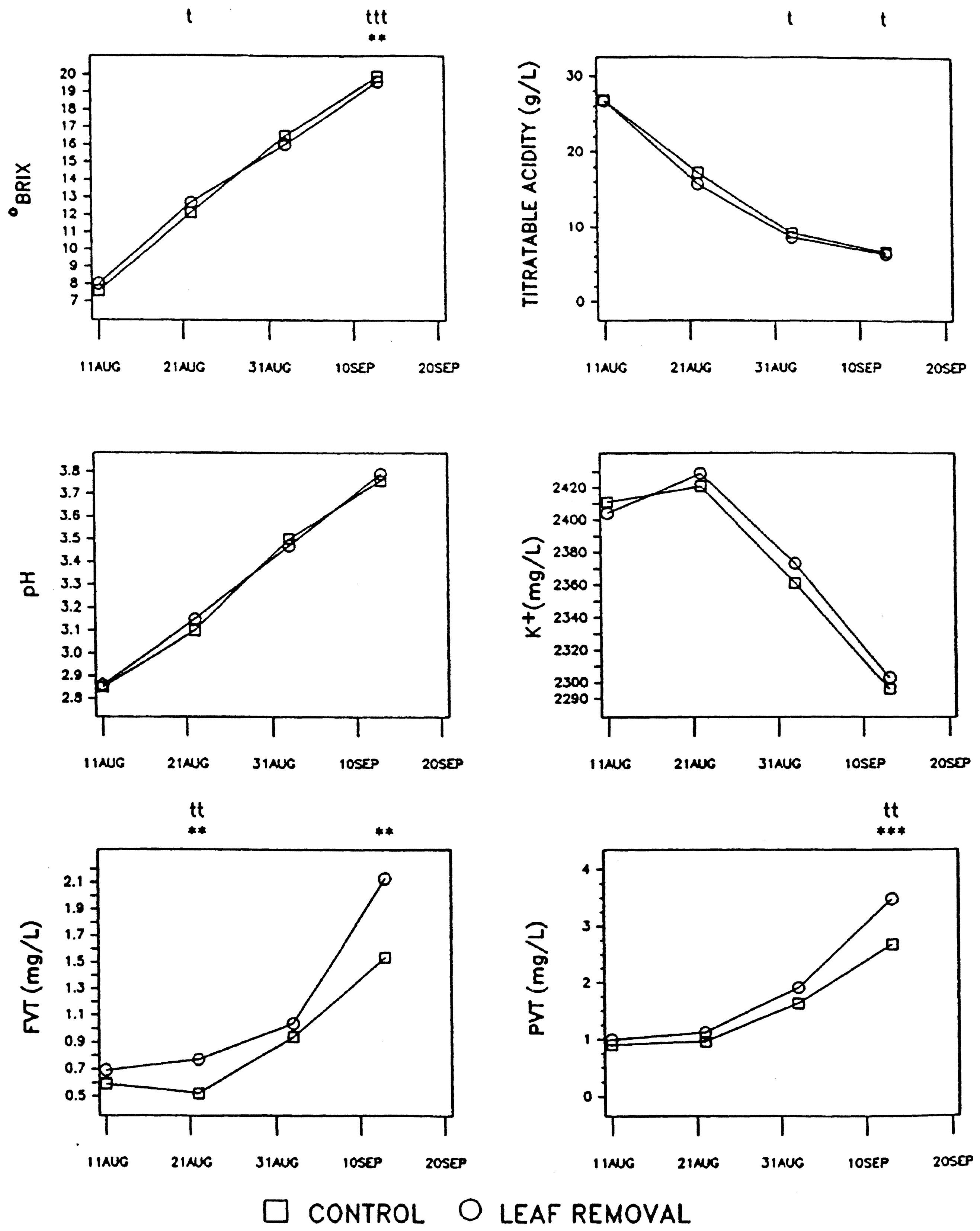

FIGURE 4

Changes in °Brix, TA pH, K^+, FVT, and PVT of 1988 Schönburger berries during maturation, subjected to two canopy manipulation treatments. Legend: **, ***: Significant at $p \leq 0{,}01$ or 0,001, respectively; otherwise not significant. ^{t,tt,ttt}: Site x canopy manipulation interaction, $p \leq 0{,}05$, 0,01, or 0,001, respectively.

TABLE 2
FVT and PVT concentrations and triangle test results comparing flavour of wines from grapes grown under two canopy manipulation treatments, Oliver, B.C., 1988.

Cultivar and canopy manipulation	Must monoterpenes (mg/L)		Number of panellists/correct responses		
	FVT	PVT	More muscat	n and significance[z]	More floral
Pearl of Csaba					
Control	1,59	3,99	1/9		1/9
BLR	1,77	5,44	8/9*		6/9
Significance	***	**		* (n=15)	
Schönburger					
Control	1,52	2,48	2/13		3/13
BLR	1,76	2,58	9/13		5/13
Significance	*	***		*** (n=15)	
Siegerrebe					
Control	1,42	3,35	1/9		0/9
BLR	1,51	4,22	8/9*		8/9*
Significance	***	***		** (n=12)	

[z] Overall significance of triangle test. Minimum number of correct responses is 8 if n=12.
*, **, ***, ns: Significant at $p \leq 0,05$, 0,01, 0,001, or not significant, respectively.

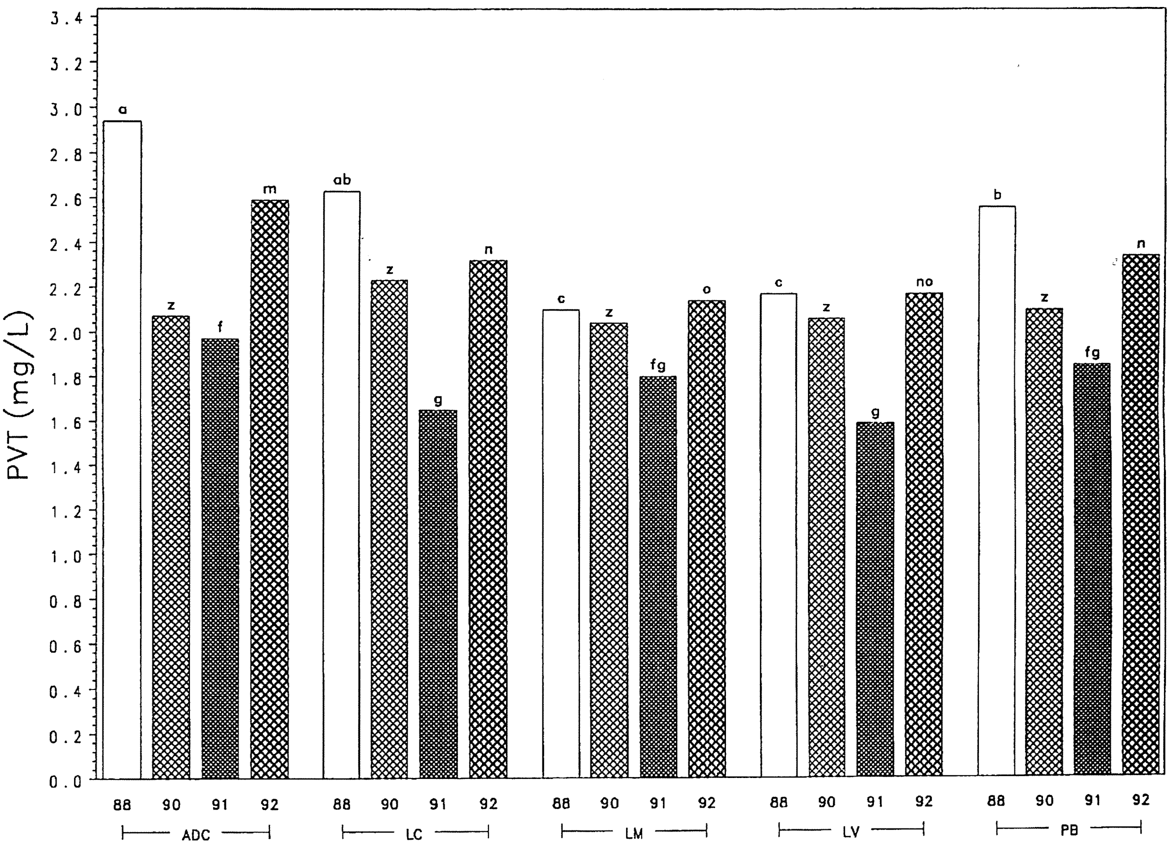

FIGURE 5
PVT concentration of Riesling berries subjected to five trellising treatments, 1988-92. Bars of like pattern and different letters are significantly different letters are significantly different at p ≤0,05, Duncan's multiple range test. Legend: ADC: alternate double crossarm; LC: low cordon; LM: Lenz Moser; LV: low "V"; PB: pendelbogen.

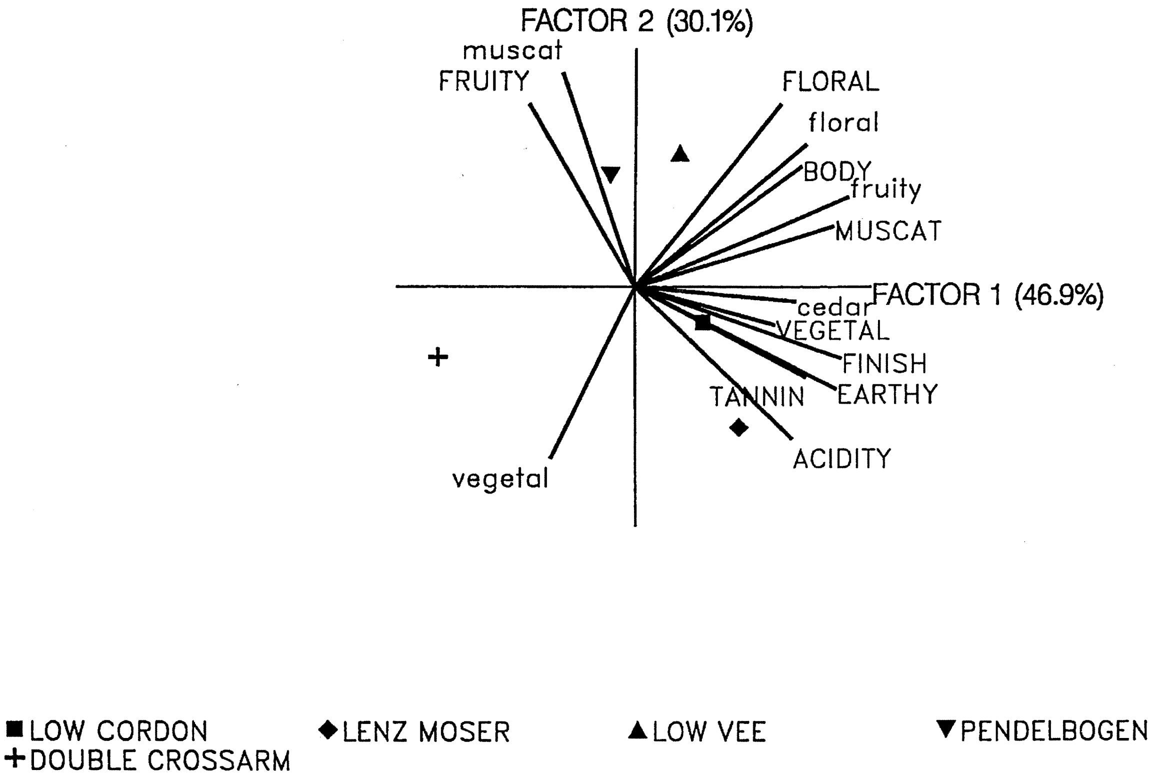

FIGURE 6
Projection of descriptive analysis data (n-24) of aged 1993 Riesling wines from different trellis systems on PCA factors 1 (46,9% of variability) and 2 (30,1% of variability). Aroma descriptors are denoted by lower case letters and flavour and tactile descriptors by upper case script.

TABLE 3

Must FVT and PVT, and results of triangle tests comparing flavour of wines produced from grapes grown at two vineyard sites, 1988.

Cultivar and site	Must monoterpenes (mg/L)		Number of panellists/correct responses		
	FVT	PVT	More muscat	n and significance[z]	More floral
Bacchus					
Oliver	1,28	2,31	7/8		1/8
Kelowna	1,41	2,53	1/8		5/8
Significance	**	ns		** (n=11)	
Pearl of CSaba					
Oliver	1,68	4,71			
Kelowna	1,59	3,84			
Significance	ns	**		ns (n=15)	
Schönburger					
Oliver	1,64	2,53	9/14		2/14
Kelowna	1,95	1,99	1/14		6/14
Significance	*	***		*** (n=15)	
Siegerrebe					
Oliver	1,49	3,79	3/8		2/8
Kelowna	1,87	3,17	4/8		3/8
Significance	***	***		** (n=12)	

[z] Overall significance of triangle test. Minimum number of correct responses is 8 if n=11.
*, **, ***, ns: Significant at $p \leq 0{,}05$, 0,01, 0,001, or not significant, respectively.

Riesling fruit with highest terpene concentration, but terpene concentrations could not be linked to wine scores. Thus, although great volumes of anecdotal evidence exist for differentiating sites, very few objective studies have been carried out to quantitate these differences.

Early muscat site x *BLR:* Fruit maturation proceeded faster at the Oliver sites on a daily basis, and FVT and PVT were therfore usually higher in Oliver berries on any given sampling day (Reynolds et al., 1995a). Therefore, due to these phenological differences between sites, data were adjusted for statistical comparison using GDD as a covariate. This data transformation showed, in most cases, that the cooler Kelowna sites matured their fruit more quickly when expressed on a per GDD basis. Oliver musts tended to be higher in FVT and PVT, although harvested at similar TA and pH (Table 3).

Tasters distinguish between wines from the Oliver and Kelowna sites on the basis of aroma for only one of the four cultivars (Reynolds *et al.,* 1995a), but the sites could be distinguished on the basis of flavour for three of the four cultivars (Table 3). For Bacchus and Schönburger, the Oliver sites were clearly identified as having the more intense muscat flavour.

Gewürztraminer site x *canopy manipulation:* No clear pattern emerged regarding the relationship between site and FVT (Reynolds, Wardle & Dever,1996), but berries from both the Oliver and Kelowna sites were highest in PVT in two of five years (Fig. 7). Must FVT and PVT in 1988 were highest from the Kelowna site (Reynolds, Wardle & Dever, 1996). The wines from the Oliver and Kelowna sites were identified as having the most spicy flavour in a tasting conducted shortly after bottling in 1989. Another descriptive analysis session conducted approximately 48 months after bottling showed that the Oliver and Kelowna sites produced wines characterised by high citrus aroma, those from the Kaleden site were primarily vegetative, acidic and astringent, while wines from the Oliver site were charac-

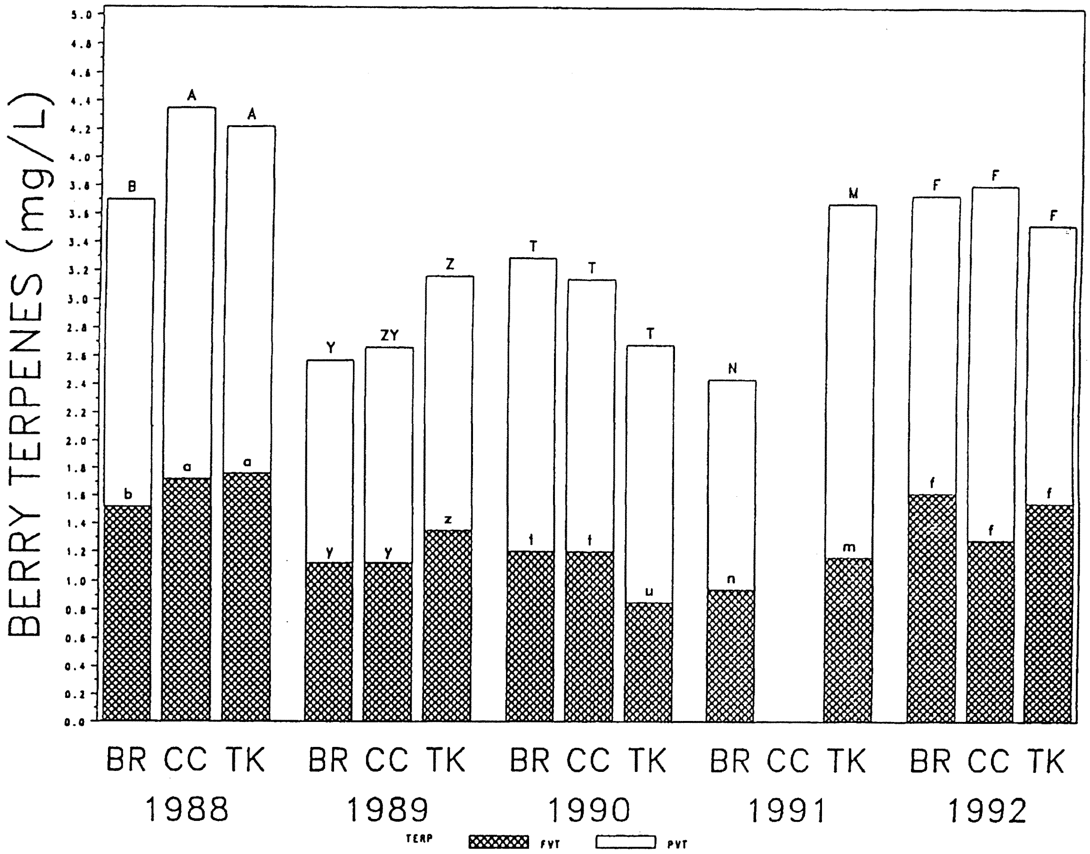

FIGURE 7
Impact of three vineyard sites on FVT and PVT concentrations in Gewürztraminer berries at harvest, 1988-92. Means are pooled across thrre canopy manipulation treatments. Bars of like pattern and different letters are significantly different at p ≤ 0,05, Duncan's multiple range test. Legend: BR, CC, TK: Brodersen (Kaleden), Cedar Creek (Kelowna) and Tokios (Oliver), respectively.

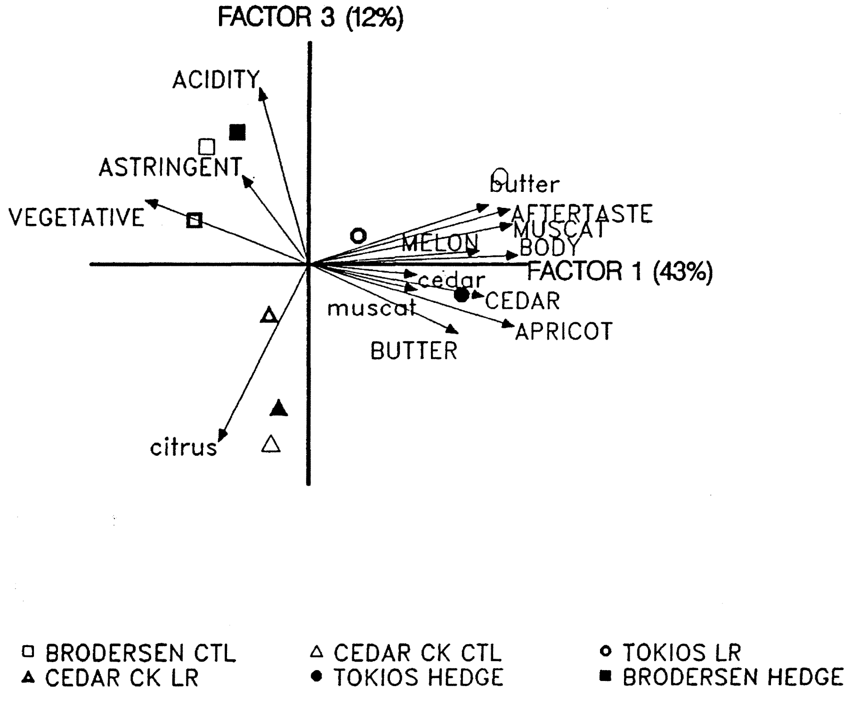

FIGURE 8
Projection of descriptive analysis data (n=24) of aged 1988 Gewürztraminer wines (48 months bottle storage) on PCA factors 1 (43% of variability) and 3 (12% of variability). Vineyard sites are indicated by octagons (Tokios vineyard, Oliver), squares (Brodersen vineyard, Kaleden) and triangles (Decar Creek Estate Winery, Kelowna). Canopy manipulation treatments are denoted by open characters (control), solid (hedged) and boldface (BLR). Aroma descriptors are denoted by lower case letters and flavour and tactile descriptors by upper case script.

TABLE 4
Must FVT and PVT concentrations and results of triangle tests comparing aromas of wines of three cultivars made from free run and press fractions, 1987.

Cultivar and press treatment	Must monoterpenes (mg/L)		Number of panellists/correct responses		
	FVT	PVT	More muscat	n and significance[z]	More floral
Müller-Thurgau					
Free run	0,88	1,93	1/7		6/7
Press	0,86	1,81	3/7		1/7
Significance	ns	ns		* (n=10)	
Muscat Ottonel					
Free run	1,30	3,62	2/7		4/7
Press	1,36	3,91	4/7		2/7
Significance	ns	*		* (n=10)	
Gewürztraminer					
Free run	0,91	1,75			
Press	0,85	1,91			
Significance	ns	*		ns (n=10)	

[z] Overall significance of triangle test. Minimum number of correct responses is 7 if n=10.
*, ns: Significant at $p \leq 0,05$, or not significant, respectively.

TABLE 5

Must FVT and PVT concentrations, and results of triangle tests comparing aromas of wines of five cultivars made from "early" and "late" harvested fruit, 1988.

Cultivar and harvest stage (°Brix)	Must monoterpenes (mg/L)		Number of panellists/correct responses		
	FVT	PVT	More muscat	n and significance[z]	More floral
Kerner					
16,6	1,88	2,27	3/13		6/13
18,3	2,21	2,38	5/13		6/13
Significance	***	ns		*** (n=15)	
Müller-Thurgau					
18,0	1,64	1,59	5/9		2/9
18,5	1,96	1,46	2/9		5/9
Significance	*	ns		* (n=15)	
Muscat Ottonel					
16,8	1,56	4,74	3/10		2/10
17,9	1,76	5,65	1/10		5/10
Significance	ns	**		** (n=15)	
Optima					
15,5	1,27	2,24	2/11		4/11
19,4	1,38	2,48	4/11		5/11
Significance	**	*		*** (n=15)	
Siegerrebe					
17,7	1,74	4,11	3/11		4/11
19,7	1,63	5,75	7/11		4/11
Significance	ns	***		*** (n=15)	

[z] Overall significance of triangle test. Minimum number of correct responses is 9 if n=15.
*, **, ***, ns: Significant at $p \leq 0{,}05$, 0,01, 0,001, or not significant, respectively.

terised by butter, cedar and muscat flavours, as well as apricot, butter, cedar and muscat flavour, high astrigency, aftertaste and body (Fig. 8). These results corres-pond with the PVT concentrations measured in the berry samples taken at harvest.

Impact of prefermentation decisions and practices: Effective extraction of free terpenes, as well as liberation of free terpenes from their glycosidic precursors, may be achieved through fermentation practices such as skin contact, pressing and the use of enzymes (Cordonnier & Bayonove, 1981; Strauss *et al.*, 1986). Pressing treatment was shown by Cordonnier & Bayonove (1979) as well as Kinzer & Schreier (1980) to have an impact on terpene concentration in musts. Bayonove *et al.*, (1976), Marais & Van Wyk (1986), Marais (1987), Marais & Rapp (1988) have indicated that use of duration of skin contact can appreciably increase the concentration of specific terpenes in must and wine. Other considerations such as harvest date may also have an impact on terpene concentration in musts and wines. Work by Hardy (1970), Bayonove & Cordonnier (1970) and Gunata *et al.* (1985) showed that terpenes can increase in fruit long after the point of commercial maturity, while Marais & Van Wyk (1986) and Marais (1987) indicated that delayed harvest of Bukettraube, Riesling and Gewürztraminer, led to higher terpene concentrations in musts and wines, respectively. In many cases, these differences could be distinguished by

TABLE 6

Must FVT and PVT concentrations, and results of triangle tests comparing aromas of wines produced by two processing methods, 1989.

Cultivar and Promace treatment	Must momoterpenes (mg/L)		Number of panellists/correct responses		
	FVT	PVT	More muscat	n and significance[z]	More floral
Kerner					
Crush & press	0,79	2,02		wines not tasted	
Skin contact	1,62	2,76			
Significance	***	***			
Müller-Thurgau					
Crush & press	0,93	2,30		wines not tasted	
Skin contact	1,36	2,36			
Significance	**	ns			
Optima					
Crush & press	1,36	4,54			
Skin contact	1,75	5,07			
Significance	***	*		*** (n=24)	
Siegerrebe					
Crush & press	1,88	5,16	5/15		3/15
Skin contact	2,04	6,10	5/15		8,15
Significance	ns	**		*** (n=24)	

[z] Overall significance of triangle test. Minimum number of correct responses is 3 if n=24.
*, **, ***, ns: Significant at $p \leq 0,05$, 0,01, 0,001, or not significant, respectively.

sensory evaluation. Ewart (1987), on the other hand, found that wine quality was reduced in late-harvested Riesling, even though the late-harvested fruit attained the highest total terpene concentration.

Pressing: Pressing had no effect on terpenes of Müller-Thurgau, but PVT in press juice of Muscat Ottonel and Gewürztraminer were higher than in their free run fractions. FVT were not affected (Table 4). Tasters could distinguish between the aromas of Müller-Thurgau and Muscat Ottonel wines made from free run and press juice (Table 4). Despite the lack of difference between treatments in FVT and PVT concentration in Müller-Thurgau, tasters indicated that the press wines had a stronger floral character than the free run wines. This trend was not as strong for the Muscat Ottonel wines, despite higher PVT in the press juice. Concentrations of FVT and PVT decreased substantially from the berry to the juice stage; losses in FVT were 52%, 41% and 22% for Muscat Ottonel, Gewürztraminer, and Kerner, respectively, and losses in PVT were 16%, 52%, 13% and 28% for Müller-Thurgau, Muscat Ottonel, Gewürztraminer, and Kerner, respectively (Reynolds, Wardle & Dever, 1993).

Harvest date: FVT and PVT increased in three of six cultivars with delays in harvest dates between 10 and 20 days (Table 5). Tasters could distinguish between wines from "early" and "late" harvested fruit in five of six cultivars on the basis of aroma, and three of the six on the basis of flavour (Table 5; Pearl of Csaba data not shown). In many cases, these tasters indicated that the late harvested treatments had either the strongest muscat and/or strongest floral character. Pearl of Csaba appeared to be the only unresponsive cultivar (Reynolds, Wardle & Dever, 1993).

Skin contact: Skin contact increased FVT and PVT in three of four cultivars (Table 6). Only Siegerrebe produced large enough aroma and flavour differences to allow tasters to distinguish between the two treatments. There was no clear indication of whether skin contact resulted in more muscat or floral character in the aroma of flavour (Reynolds, Wardle & Dever, 1993).

Interfering substances: Interfering substances may limit the use of the FVT/PVT method. Specific C_6 compounds (Bravdo, 1991, pers. comm.) and *trans*-hex-2-en-1-ol (Dimitriadis & Williams, 1984) are thought to react slightly with the vanillin solution used in the colorimetric procedure. In wines FVT readings are elevated by amyl alcohols (Williams, 1985, pers. comm.), but wine PVT may be quantitated by this method. Benoteau & Reynolds (1994) indicated that 2-hexen-1-al increases the absorbance at 608 nm when added to linalool solutions, but this interference has no significance unless this compound is added in amounts >2,5 mg/L. Most C_6 compounds detected in grapes and wines have been measured at levels <1 mg/L, and the majority of these compounds appear to be unreactive with the vanillin reagent used in the colorimetric method.

CONCLUSIONS

The results of these experiments suggest that fruit exposure, canopy manipulation, prefermentation practices and vineyard site may influence monoterpene content of berries and juices of several *V. vinifera* cultivars. These differences can sometimes be confirmed organoleptically in wines. A failure to find good agreement between analytical and sensory results may be due to variability among judges, but may also be ascribed in part to the confounding taster response to non-floral monoterpenes such as α-terpineol. This underscores the need to follow up work of this nature with gas chromatographic analyses of wines to overcome problems of this nature.

The possibility of interfering substances may limit the use of the FVT/PVT method as well as the scope of interpretation that may be made from the results. However, in spite of these limitations this method can allow an operator, with two distillations apparatus, to process 12-15 berry samples per day. It has applications for wineries, breeding programmes and field-oriented research programmes with limited time and/or personnel availibilty in the laboratory.

Our work has demonstrated that vineyard and cellar practices may affect monoterpene content in berries and juices, that many of these terpenes may be lost during the wine-making process, and that organoleptic evaluation may confirm analytical results. Our specific conclusions to date are: *(1)* PVT are more responsive to viticultural and enological practices than FVT; *(2)* FVT and PVT are rarely correlated with soluble solids, TA or pH and thus cannot be predicted by standard harvest indices; *(3)* Losses in FVT and PVT can occur between the berry and juice stages, hence the desirability of skin contact; *(4)* FVT and PVT concentrations can, in some cases, be related to wine-tasting results.

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