Characterizing the Chemical and Sensory Profiles of United States Cabernet Sauvignon Wines and Blends

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Abstract: Cabernet Sauvignon is one of the most reputable red grape varieties grown in the United States; however, limited information is available on the chemical and sensory composition of the resulting wines. The purpose of this study was to develop a rapid, targeted profiling method for measuring volatile compounds with sensory impact in U.S. Cabernet Sauvignon wines and blends. We developed a semiquantitative, automated headspace solid-phase microextraction (HS-SPME) gas chromatography–mass spectrometry (GC-MS) method combined with synchronous selected ion monitoring (SIM)/scan detection to measure 61 volatile compounds. The compounds monitored included grape-derived norisoprenoids and terpenes; fermentation-derived esters, higher alcohols, and aldehydes; *Brettanomyces*-related compounds; and oak-derived compounds. Methoxypyrazine was also measured using HS-SPME-GC-MS/MS. Twenty-four commercial U.S. Cabernet Sauvignon varietal and blended wines from several regions in California and Washington State were selected to encompass a broad range of wine styles and were analyzed using the GC methods developed. The results were compared to a descriptive sensory analysis of the wines using 11 trained assessors to determine the extent to which the chemical analyses could predict sensory profiles. The rapid, targeted profiling method was able to predict a number of aroma sensory descriptors. The Cabernet Sauvignon wines and blends differed in their chemical and sensory profiles and were differentiated, in part, as a result of the direct and indirect influences of varying alcohol levels. This work provides the wine industry with the ability to rapidly assess wine volatile composition in order to further elucidate the relationships between the chemical compounds and sensory profiles of wines.

Key words: Cabernet Sauvignon, chemical composition, gas chromatography, sensory profile, volatile, wine

Cabernet Sauvignon is the most widely planted red grape variety in the United States, with the majority grown in California and Washington State (NASS 2011, NASS/CDFA 2011). Cabernet Sauvignon wines can vary greatly in style, depending on region and price point. A number of studies have associated the chemical and sensory profiles of Cabernet Sauvignon varietal and blended wines from California (Dooley et al. 2012, Hopfer et al. 2012, Preston et al. 2008), Australia (Costello et al. 2012, Forde et al. 2011, Robinson et al. 2011), France (Chira et al. 2011), Chile (Sivertsen et al. 2001), Brazil (Falcao et al. 2007), and China (Tao and Zhang 2010). All of these studies used headspace solid-phase microextraction (HS-SPME) to sample the volatile composition. SPME is a common extraction technique, as it requires minimal sample preparation, does not use solvents, and is low cost (Canuti et al. 2009). In combination with headspace sampling, SPME has been shown to provide a representative analysis of food and beverage chemical composition during aroma sensory assessment (Johnson et al. 2012, Poinot et al. 2007).

There has been recent increased interest in the use of profiling methods to investigate wine sensory profiles. With the use of time of flight (TOF) detection coupled to comprehensive gas chromatography, thousands of compounds can be resolved. While this is a very powerful tool, not all compounds will necessarily have a sensory impact in wine. In addition, powerful and complex multivariate statistics are required to relate the compositional data. One study used this method to analyze 350 volatile compounds and relate these compounds to 15 sensory attributes (Robinson et al. 2011). Another approach is targeted profiling, where specific compounds can be identified and quantified (Forde et al. 2011, Tao and Zhang 2010). The use of synchronous scan and selected ion monitoring (SIM) acquisition provides full-scan spectra for analyte confirmation, as well as sensitive and selective quantitation and detection of the targeted compounds. Two studies used this approach to analyze volatile compounds in wine (Cai et al. 2009, Del Carlo et al. 2008); however, neither study related the chemical composition to wine sensory profiles. Given that the chemical composition and sensory profiles of wines are now

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widely studied, it is possible to target compounds that occur in wines and are known to impact wine aroma and flavor. Known volatile compounds and their sensory impacts are listed in Francis and Newton (2005) and Polášková et al. (2008).

The purpose of the study was to develop a rapid, analytical method for measuring volatile compounds with sensory impact in red wines, using a targeted profiling approach in synchronous scan and SIM mode, allowing for higher sensitivity and selectivity. To date, the studies that have analyzed both the chemical and sensory composition of U.S. Cabernet Sauvignon wines were investigating the "green" characters in wines (Preston et al. 2008), the effects of blending (Dooley et al. 2012, Hopfer et al. 2012), and the influence of tannin concentrations on taste and mouthfeel attributes (Kennedy et al. 2006, Villamor et al. 2009). No studies have characterized the aroma and flavor profiles of U.S. Cabernet Sauvignon varietal or blended wines and the associated volatile compounds. The results of the targeted profiling method developed in this study were used in combination with descriptive sensory analyses and multivariate statistical methods to model the relationships between the chemical and sensory profiles of U.S. Cabernet Sauvignon wines and blends.

Materials and Methods

Wines. All wines included in the study were produced in the United States and were commercially available. Fourteen wines were 100% Cabernet Sauvignon and 10 were Bordeaux blends with Cabernet Sauvignon as the major variety (at least 56%). Wine selection was based on interest from wine companies and encompassed a broad range of sensory characteristics representative of the styles produced in the United States, including ripe, fruit-forward wines, wines with green characters or *Brettanomyces* taint, oak-driven styles, and wines with different levels of sweetness, bitterness, and tannin characteristics. Twenty-four wines in total were included in the study, 19 from California, from six different American Viticultural Areas (AVAs), and five wines from Washington State, from two different AVAs. The wines ranged in vintage from 2000 to 2009, in price from US $3.29 to $125.00, and in alcohol concentration from 12.4 to 15.9% v/v (Table 1). Wines were coded W1–W24 according to increasing measured alcohol concentration. All wines were bottled under natural or synthetic cork closures. Wines were stored flat, in a dark space at room temperature during the time of experimentation.

HS-SPME-GC-MS. *Materials.* Sixty-one compounds were measured using the HS-SPME-GC-MS method (Table 2). These compounds were chosen based on previous reports in red wine and Cabernet Sauvignon (Francis and Newton 2005, Polášková et al. 2008) with the inclusion of some common taint compounds. All 61 compounds were verified by analyzing reference compounds, except vitispirane I and II, and α-cedrene, due to unavailability. Most of the reference compounds were purchased from Sigma-Aldrich (St. Louis, MO) with a purity of >80%. The exceptions were ethyl 2-methylbutyrate (SAFISIS, Soustons, France), linalool (Alfa Aesar, Ward Hill, MA), acetic acid (EMD, Merck, Darmstadt, Germany), 2-methyl butanoic acid (TCI America, Portland, OR), hexanoic acid (Acros Organics, Geel, Belgium), and propionic acid (MP Biomedicals, Solon, OH), all with a purity of >80%. All standards were diluted using 100% ethanol (Gold Shield Chemical, Hayward, CA). The retention times of the authentic standards were matched to the compounds measured. The compounds were also verified using quantifier/qualifier ion ratios and published retention indices reported for DB-Wax column. Alkanes C8 to C20 were purchased from Sigma-Aldrich. The reported retention indices and references, the calculated retention indices, and retention times for the method developed are shown in Table 2.

Sample preparation and sampling. Wine samples (10 mL, undiluted) were pipetted into 20 mL round-bottomed, amber glass vials (Agilent Technologies, Santa Clara, CA) with 3 g (±0.02) NaCl (Fisher Scientific, Fair Lawn, NJ). An internal standard, 2-undecanone, was used with an in-vial concentration of 50 µg/L. Vials were sealed with magnetic crimp caps with 3 mm thickness, PTFE-lined silicone septa (Supelco, Bellefonte, PA). Vials were immediately placed on the instrument for analysis. All samples were analyzed in triplicate in a randomized order within 18 hr of loading on the instrument. A 2 cm divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) (Supelco), 23 gauge SPME fiber was used for sampling. Samples were warmed at 40°C and agitated at 500 rpm for 5 min before exposing the fiber for 30 min at 40°C with agitation at 250 rpm.

Instrumental analysis. The samples were analyzed using a 6890 gas chromatograph coupled to a 5975 mass selective detector (MSD) (Agilent) equipped with an MPS2 autosampler (Gerstel, Linthicum, MD). A DB-Wax capillary column (30 m, 0.25 mm i.d., 0.25 µm film thickness) (J&W Scientific, Folsom, CA) and SPME inlet liner (0.7 mm i.d.; Supelco) were used. The instrument was controlled by Maestro (ver. 1.2.3.1; Gerstel) and the data was analyzed using ChemStation software (ver. E.01.01.335; Agilent). Helium was used as the carrier gas at a constant flow of 1 mL/min. The method was retention time locked to the internal standard, 2-undecanone, at constant flow to prevent retention time drifting.

During analysis, the oven was kept at 40°C for 5 min, then increased 3°C/min up to 180°C, and then 30°C/min up to 240°C, before holding for 10 min. The MSD interface was held at 240°C. The inlet temperature was 240°C and the SPME fiber was desorbed in split mode with a 20:1 split ratio. The solvent delay was 2.5 min, and the detector was turned off from 3.80 min to 4.30 min during ethanol elution. The fiber was held in the inlet for 10 min to prevent carryover effects. Electron ionization source was used, with a source temperature of 230°C and electron energy of -70 eV.

The wines were measured using synchronous scan and selected ion monitoring (SIM mode). The scan parameters ran from 40 *m/z* to 300 *m/z*, and both scan and SIM acquisitions were optimized such that there was a minimum of 15 scans over each peak. Sixty compounds were detected in SIM mode (not the volatile acids) using between two and four selected ions and 44 individual timed events, and data were acquired with 5.8 scans/sec. The ions used in the SIM parameters for each compound and retention times are shown in Table 2.

MIBP analysis with HS-SPME-GC-MS/MS. 2-Isobutyl-3-methoxyprazine (MIBP), which can be an important compound in Cabernet Sauvignon varietal aroma (Allen and Lacey 1999), was not detected using the HS-SPME-GC-MS targeted profiling method, and so was quantified separately using a method adapted from Chapman et al. (2004). To achieve the needed selectivity and sensitivity for detecting MIBP at parts per trillion levels and to avoid any coelution issues, a tandem MS/MS triple quadrupole instrument was used. Samples were analyzed with an Agilent 7890A gas chromatograph, paired with an Agilent 7000B triple quadrupole mass spectrometer, equipped with a Gerstel MPS2 autosampler and a DB-Wax capillary column (30 m, 0.25 mm i.d., 0.25 µm film thickness) (J&W Scientific). MassHunter qualitative analysis software was used for data analysis (ver. B.03.01; Agilent).

The MIBP standard and internal standard [$^2H_3$]MIBP used were the same as Chapman et al. (2004). The internal standard concentration in the vial was 50 ng/L, with 10 mL sample and 3 g (±0.02) NaCl (Fisher Scientific). Vials were allowed to equilibrate overnight at room temperature. A 1 cm DVB/PDMS (Supelco) 23 gauge SPME fiber was used. Samples were warmed at 40°C and agitated at 500 rpm for 5 min before extracting for 30 min at 40°C, with agitation at 250 rpm.

The GC inlet temperature was set to 250°C. The injection method was splitless with a SPME injection liner (0.7 mm i.d.; Supelco) and with purge on at 1.2 min at a flow of 50 mL/min; at 3 min the split flow decreased to 20 mL/min (gas saver mode). The SPME fiber remained in the inlet for a total desorption time of 10 min. Helium carrier gas was maintained at constant flow at 1 mL/min. The oven was kept at 40°C for 5 min, then increased 3°C/min to 109°C, and 30°C/min to 240°C before holding for 10 min. The MSD interface was held at 250°C. The solvent delay was 15 min and the gain was set to 15 for multiple-reaction monitoring (MRM) acquisition. The electron ionization source temperature was set to 230°C

Table 1 Details of the 24 wines included in the study and standard chemical parameters ± standard deviation (n = 3).

Wine code	Vintage	Variety[a]	Region[b]	Retail price (US$)	Alcohol % (v/v)	Free SO_2 (mg/L)	Total SO_2 (mg/L)	Titratable acidity (g/L)	pH	Glucose + fructose (g/L)
W1	2008	100% CS	Lodi, CA	$5.99	12.4 ± 0.3	22 ± 6.0	92 ± 2.8	5.6 ± 0.0	3.61 ± 0.0	3.5 ± 0.2
W2		100% CS	California	$3.29	12.5 ± 0.2	16 ± 0.3	61 ± 0.5	5.1 ± 0.0	3.76 ± 0.0	5.7 ± 0.2
W3	2000	100% CS	Napa Valley, CA	$125.00	13.0 ± 0.0	nd[c] ± 2.6	41 ± 2.5	5.7 ± 0.0	3.73 ± 0.0	1.1 ± 0.1
W4	2005	100% CS	Napa Valley, CA	$49.00	13.1 ± 0.1	nd ± 0.7	34 ± 4.4	5.7 ± 0.0	3.91 ± 0.1	0.8 ± 0.1
W5	2009	100% CS	Paso Robles, CA	$5.99	13.2 ± 0.1	24 ± 3.6	105 ± 1.0	5.6 ± 0.0	3.90 ± 0.0	4.8 ± 0.1
W6	2007	100% CS	Napa Valley, CA	$75.00	13.6 ± 0.0	nd ± 1.2	27 ± 4.8	5.0 ± 0.0	3.89 ± 0.0	1.1 ± 0.1
W7	2009	100% CS	Lodi, CA	$7.97	13.8 ± 0.2	11 ± 4.7	65 ± 2.6	5.7 ± 0.0	3.71 ± 0.0	3.0 ± 0.2
W8	2008	88% CS, 10% CF, 2% MER	Napa Valley, CA	$42.00	14.0 ± 0.0	10 ± 1.5	62 ± 0.3	5.9 ± 0.0	3.69 ± 0.0	0.8 ± 0.1
W9	2009	84% CS, 15% CF, 1% MER	Dry Creek Valley, Sonoma County, CA	$14.99	14.3 ± 0.0	11 ± 5.0	56 ± 1.1	5.9 ± 0.1	3.69 ± 0.1	1.4 ± 0.0
W10	2006	95% CS, 5% MAL	Napa Valley, CA	$75.00	14.7 ± 0.0	nd ± 0.8	17 ± 11	6.3 ± 0.1	3.84 ± 0.0	0.9 ± 0.0
W11	2007	75% CS, 14% S, 11% PV	Alexander Valley, Sonoma County, CA	$30.00	15.0 ± 0.0	nd ± 2.1	47 ± 2.1	5.3 ± 0.0	3.81 ± 0.0	2.3 ± 0.2
W12	2009	56% CS, 31% MER, 10% CF, 3% PV	Napa Valley, CA	$27.00	15.2 ± 0.0	13 ± 0.7	61 ± 1.9	5.8 ± 0.0	3.86 ± 0.0	1.5 ± 0.1
W13	2008	100% CS	Napa Valley, CA	$60.00	15.2 ± 0.0	11 ± 2.9	89 ± 1.5	6.0 ± 0.0	3.75 ± 0.0	1.7 ± 0.2
W14	2006	100% CS	Napa Valley, CA	$68.00	15.2 ± 0.0	nd ± 1.3	33 ± 1.5	5.8 ± 0.0	3.62 ± 0.0	1.6 ± 0.1
W15	2006	100% CS	Napa Valley, CA	$60.00	15.2 ± 0.0	nd ± 0.5	30 ± 0.3	5.7 ± 0.0	3.84 ± 0.0	1.4 ± 0.1
W16	2006	100% CS	Columbia Valley, WA	$75.00	15.3 ± 0.0	18 ± 0.9	92 ± 1.3	5.5 ± 0.1	3.83 ± 0.1	1.3 ± 0.1
W17	2008	85% CS, 7% MER, 5% CF, 2% S, 1% PV	Napa Valley, CA	$28.00	15.3 ± 0.0	nd ± 3.6	67 ± 0.6	6.1 ± 0.0	3.67 ± 0.0	1.7 ± 0.1
W18	2007	60% CS, 15% S, 11% MER, 10% PV, 4% CF	Columbia Valley, WA	$26.00	15.5 ± 0.0	nd ± 1.0	60 ± 8.5	5.9 ± 0.0	3.74 ± 0.0	1.2 ± 0.1
W19	2008	75% CS, 13% MER, 8% CF, 3% PV, 1% MAL	Napa Valley, CA	$60.00	15.5 ± 0.1	nd ± 3.8	64 ± 0.9	5.5 ± 0.0	3.87 ± 0.1	1.9 ± 0.4
W20	2008	100% CS	Columbia Valley, WA	$33.00	15.7 ± 0.0	16 ± 1.9	67 ± 4.2	5.9 ± 0.0	3.81 ± 0.1	1.0 ± 0.1
W21	2007	56% CS, 25% MER, 11% CF, 6% PV, 2% MAL	Columbia Valley, WA	$53.00	15.7 ± 0.0	nd ± 3.0	43 ± 5.0	5.6 ± 0.0	3.78 ± 0.0	0.9 ± 0.1
W22	2008	100% CS	Washington State	$50.00	15.9 ± 0.0	10 ± 4.4	76 ± 4.0	5.7 ± 0.0	3.80 ± 0.0	1.3 ± 0.1
W23	2006	100% CS	Napa Valley, CA	$75.00	15.9 ± 0.0	nd ± 0.9	40 ± 6.6	5.1 ± 0.0	3.93 ± 0.0	1.4 ± 0.1
W24	2007	71% CS; 29% CF	Napa Valley, CA	$100.00	15.9 ± 0.0	12 ± 2.1	104 ± 1.7	6.1 ± 0.0	3.81 ± 0.0	1.6 ± 0.0

[a]CS: Cabernet Sauvignon; CF: Cabernet franc; MER: Merlot; MAL: Malbec; S: Syrah; PV: Petit Verdot.
[b]CA: California; WA: Washington State.
[c]nd: not detected (below quantifiable limit of detection of 10 mg/L).

and an electron energy of -70 eV. Scan rates were 3.6 scan/sec and dwell times were optimized to provide ~15 scans over the entire peak. Helium quench gas and nitrogen collision gas flow rates to the collision cell were set to 2.25 mL/min and 1.5 mL/min, respectively. The transitions, collision energies, and retention times of MIBP and the internal standard are in Table 3. All wines were measured in triplicate in a randomized order.

A standard curve was created using model wine, adjusted to within the chemical parameters of the wines included in the study (14% v/v ethanol and 4 g/L potassium bitartrate [Fisher Scientific] in Millipore water, pH 3.79) with concentrations of 0, 1, 2, 5, 10, 20, 30, 40, and 50 ng/L MIBP in triplicate, in addition to the deuterated internal standard. The peak areas of MIBP and deuterated internal standard were linearly correlated with the concentration of MIBP in the standards (r = 0.9959). The limit of quantification (2 ng/L) was determined by a signal to noise ratio of 10:1. The limit of detection (1 ng/L) was determined by a signal to noise ratio of 3:1.

Analysis of standard chemical parameters. The wines were analyzed for standard chemical parameters within two months of the end of the sensory analysis. Alcohol concentration was measured with a NIR-based method using an Alcolyzer Wine M/ME (Anton Parr, Graz, Austria). Free and total sulfur dioxide (SO_2), pH, and titratable acidity (TA) were measured using the DL50 autotitrator (Mettler Toledo, Columbus, OH). Free and total SO_2 was measured using a modified version of the Ripper iodine redox titration, with a limit of detection of 10 mg/L for free SO_2. Acetic acid was measured using an Acetic Acid Flex-Reagent enzymatic kit (Unitech Scientific, Hawaiian Gardens, CA) and UV spectrophotometry. Residual sugar was measured with an enzymatic reaction and UV spectrophotometry, using Infinity Glucose Reagent and D-Fructose (Reagent Grade) (Thermo Fisher Scientific, Waltham, MA), and phosphoglucoisomerase (Fluka, Sigma-Aldrich). All wines were analyzed in triplicate.

Sensory analysis. A descriptive sensory analysis was conducted in October and November 2011. Eleven assessors

Table 2 The compounds measured in the HS-SPME-GC-MS method, their CAS number, retention indices (RI) and source for DB-Wax, retention time, calculated retention indices (CRI), and selected ion monitoring (SIM) qualifying ions.

Compound	CAS	RI (DB-Wax)	Source[a] (DB-Wax)	Retention time (min)	CRI	SIM ions
Ethyl acetate	141-78-6	907	Flavornet	3.105	915	43, 61, 88
Ethyl isobutyrate	97-62-1	955	Flavornet	4.559	960	43, 71, 116
Diacetyl	431-03-8	970	Flavornet	4.794	967	43, 86
α-Pinene	80-56-8	1032	Flavornet	5.939	1003	93, 121, 136
Ethyl butyrate	105-54-4	1028	Flavornet	6.599	1022	116, 88, 71
Ethyl 2-methylbutyrate	7452-79-1	1050	Flavornet	7.168	1038	57, 102, 130
Ethyl isovalerate	108-64-5	1069	Pherobase	7.769	1055	85, 88, 130
Hexanal	66-25-1	1084	Flavornet	8.150	1066	56, 72, 100
Isobutanol	78-83-1	1099	Flavornet	8.825	1101	43, 74, 55
Isoamyl acetate	123-92-2	1132	Pherobase	9.926	1126	55, 87, 130
α-Terpinene	99-86-5	1178	Flavornet	12.212	1178	93, 121, 136
Limonene	138-86-3	1178	Flavornet	13.060	1197	68, 93, 136
Eucalyptol	470-82-6	1213	Flavornet	13.480	1206	93, 108, 154
Isoamyl alcohol	123-51-3	1205	Flavornet	13.910	1216	57, 70, 88
Ethyl hexanoate	123-66-0	1220	Flavornet	14.890	1238	88, 99, 144
p-Cymene	99-87-6	1261	Flavornet	16.260	1269	119, 134, 91
Hexyl acetate	142-92-7	1270	Flavornet	16.654	1278	43, 84, 144
Acetoin	513-86-0	1287	Flavornet	16.898	1284	43, 45, 88
Octanal	124-13-0	1280	Flavornet	17.236	1292	56, 84, 128
Hexanol	111-27-3	1360	Flavornet	20.503	1366	56, 69, 102
(*Z*)-3-Hexenol	928-96-1	1391	Flavornet	21.761	1395	67, 82, 100
Ethyl octanoate	106-32-1	1436	Flavornet	23.797	1443	88, 101, 172
cis-Linalool oxide	5989-33-3	1420	Flavornet	24.083	1450	59, 68, 170
Acetic acid	64-19-7	1450	Flavornet	24.568	1461	[e]
Furfural	98-01-1	1455	Flavornet	24.730	1465	95, 96, 67
trans-Linalool oxide	23007-29-6	1453	Pherobase	25.279	1478	59, 68, 170
Camphor	76-22-2	1491	Flavornet	26.626	1510	95, 108, 152
Vitispirane I[b]		1515	Humpf and Schreier (1991)	27.273	1526	177, 192, 93
Vitispirane II[b]		1515	Humpf and Schreier (1991)	27.396	1529	177, 192, 93
Linalool	78-70-6	1537	Flavornet	28.629	1560	71, 93, 154
α-Cedrene[b]	469-61-4	1570	Pherobase	28.747	1562	119, 161, 204
5-Methylfurfural	620-02-0	1560	Flavornet	29.157	1573	109, 110, 53
2-Undecanone[c]	112-12-9	1598	Ott et al. (1997)	30.350	1604	58, 71, 170
Phenylacetaldehyde	122-78-1	1625	Flavornet	31.701	1637	91, 92, 120

(9 females, 2 males) were recruited through the University of California, Davis (UCD), ages 21 to 64 years, with varying levels of experience in descriptive sensory analyses. Assessors were selected based on being of legal drinking age, regularly drinking red wine (defined as drinking one glass of red wine per week), having no medical reason for not consuming wine, and available at the necessary times. This project was approved by the Institutional Review Board, UCD.

The assessors participated in five 90-min training sessions, where they generated and discussed sensory attributes and reference standards. The assessors rated 20 aroma attributes and 14 taste and mouthfeel attributes (Table 4). The intensity of each attribute was rated using an unstructured 15-cm line scale anchored by wordings of "low" and "high," except for a few attributes (Table 4) where other opposite adjectives were used.

The wines were presented in a randomized and balanced order across all assessors. Wines were assessed under white lighting in isolated, ventilated tasting booths. Each wine was presented at a constant volume (30 mL) at room temperature, in clear, covered ISO tasting glasses with random three-digit codes that differed for each assessor. All wines were assessed in triplicate. FIZZ software (ver. 2.1; Biosystèmes, Couternon, France) was used for the collection of all data. Assessors were required to assess all aroma reference standards prior to each session. Assessors were also required to wait 30 seconds between samples and cleanse their palates with water and

Table 3 The transition, collision energy, and retention time of the precursor ions for 2-isobutyl-3-methoxyprazine (MIBP) and the internal standard [$^2H_3$]MIBP measured using HS-SPME-GC-MS/MS.

	Transition	Collision energy (volts)	Retention (min)
[$^2H_3$]MIBP	127 to 95[a]	10	26.802
	154 to 126	10	
MIBP	124 to 94[a]	10	26.854
	124 to 95	10	

[a]Quantifier transition.

Table 2 *(cont.)* The compounds measured in the HS-SPME-GC-MS method, their CAS number, retention indices (RI) and source for DB-Wax, retention time, calculated retention indices (CRI), and selected ion monitoring (SIM) qualifying ions.

Compound	CAS	RI (DB-Wax)	Source[a] (DB-Wax)	Retention time (min)	CRI	SIM ions
Ethyl decanoate	110-38-3	1636	Flavornet	32.003	1645	88, 101, 200
Methionol	505-10-2	1723	Flavornet	34.929	1722	61, 106, 73
β-Citronellol	106-22-9	1762	Flavornet	36.938	1778	69, 82, 156
2-Phenethyl acetate	103-45-7	1829	Flavornet	38.235	1814	91, 104, 121
β-Damascenone	23726-93-4	1813	Flavornet	38.454	1820	69, 121, 190
α-Ionone	127-41-3	1809	Interpolated Flavornet	39.471	1850	121, 93, 192
Guaiacol	90-05-1	1859	Flavornet	39.828	1860	81, 109, 124
Geraniol[d]	106-24-1	1834	Pherobase	39.866	1861	69, 93, 154
Benzyl alcohol	100-51-6	1865	Flavornet	40.477	1879	79, 107, 108
cis-Oak lactone	55013-32-6	1886	Flavornet	40.609	1883	99, 156, 87
Ethyl dihydrocinnamate[d]	2021-28-5	1906	Flavornet	40.624	1884	91, 104, 178
2-Phenethyl alcohol	60-12-8	1925	Flavornet	41.678	1916	65, 103, 122
β-Ionone	79-77-6	1912	Flavornet	42.475	1940	135, 177, 192
trans-Oak lactone	39212-23-2	1933	Flavornet	42.918	1954	99, 156, 87
4-Methylguaiacol/cresol	93-51-6	2067	Flavornet	43.060	1958	95, 123, 138
γ-Nonalactone	104-61-0	2042	Flavornet	45.236	2027	85, 99, 156
4-Ethylguaiacol	2785-89-9	2031	Flavornet	45.485	2035	122, 137, 152
2-Ethylphenol	90-00-6	2054	Pherobase	46.971	2085	77, 107, 122
trans-Ethyl cinnamate[d]	103-36-6	2139	Flavornet	48.522	2138	131, 103, 176
γ-Decalactone[d]	706-14-9	2103	Flavornet	48.881	2150	85, 170, 128
Eugenol	97-53-0	2141	Flavornet	49.772	2182	103, 149, 164
4-Ethylphenol	123-07-9	2200	Pherobase	50.080	2193	77, 107, 122
4-Vinylguaiacol[d]	7786-61-0	2198	Flavornet	50.566	2210	107, 135, 150
Syringol	91-10-1	2296	Flavornet	52.419	2279	111, 139, 154
Isoeugenol	97-54-1	2250	Flavornet	53.438	2340	103, 149, 164
Farnesol	106-28-5	2350	Flavornet	53.606	2363	69, 81, 222
γ-Dodecalactone	2305-05-7	2384	Flavornet	53.679	2373	85, 100, 198, 128
Vanillin	121-33-5	2569	Flavornet	55.417	2584	151, 152, 109

[a]For Flavornet: Acree and Arn, www.flavornet.org; for interpolated Flavornet: value was interpolated from Flavornet. For Pherobase: mean values of El-Sayed, www.pherobase.com.
[b]Compound not verified using an authentic reference.
[c]Internal standard.
[d]Compound not detected in any of the Cabernet Sauvignon varietal and blended wines tested.
[e]Acetic acid analyzed in scan mode only.

unsalted crackers. At the end of each session, assessors were given food; upon completion of the sensory analysis study, each assessor was given a moderately priced gift card.

Data analysis. For the semiquantitative targeted profiling method, peaks were quantified relative to the internal standard (2-undecanone) using peak area of an extracted ion. For MIBP, measured using GC-MS/MS, the absolute concentration was determined by relative response of MIBP to the deuterated internal standard using a standard curve.

During the descriptive sensory analysis, one assessor missed one session of six wines. The missing values were imputed using the assessor's mean replicate values. The chemical data were analyzed using an analysis of variance (ANOVA) measuring for the effects of wine and replicate using a

Table 4 Attributes, descriptions, and reference standards used in the sensory descriptive analysis.

Attribute	Description[a]	Reference standard
Aroma		
Overall aroma intensity		–
Fresh fruit	Red apple, banana, orange, peach, pear, pomegranate, grape, mango, citrus	2 pieces red and yellow papaya from canned tropical fruit (Dole), ½ cm^2 piece fresh banana, ½ cm^2 fresh apple, ½ cm fresh lemon rind
Dark fruit	Plum, cherry, dark fruit, black fruit, black currant, cassis, jam	1 cm^2 piece fresh red plum, 1 cm^2 fresh pluot, ½ tsp red plum jam (Smuckers), ½ tsp canned plum juice (Dole)
Berry	Blackberry, blueberry, raspberry, strawberry, tart berry, forest fruit	1 fresh strawberry, 1 fresh raspberry, 1 fresh blackberry, all halved
Dried fruit	Fig, prune, cooked cherry	2 dried raisins, halved, ½ dried Mission fig, 1 dried prune, halved, 1 dried apricot, halved (all Sun Maid)
Floral	Flowery, perfume, jasmine, honeysuckle	½ tsp orange blossom (Sadaf) in 10 mL water
Butterscotch	Vanilla, creamy, caramel, sweet aromas, buttery, chocolate, mocha, honey	½ tsp butterscotch caramel (Mrs Richardson) and ½ tsp honey (Fresh to Market)
Wood	Oak, pencil shavings, red wood, forest, nutty, smoky, roasted, toasted	1 ball cedar (Cedar Fresh), ½ tsp shaved medium toast American oak (Evoak), ½ tsp shaved medium toast French oak (Evoak)
Spice	Cinnamon, baking spices	1 tsp apple pie spice (McNess)
Pepper	Black pepper, licorice	3 whole black peppercorns (McCormick), ½ tsp coarse ground black pepper (Safeway) in 10 mL water
Vegetal	Bell pepper, vegetables, cooked vegetables	1 fresh green bean, halved, 1 strip of fresh green bell pepper
Herbal	Grassy, leafy	1 tsp fresh, cut grass, 1 tsp green leaves
Mint	Menthol	1 fresh mint leaf in 10 mL water
Sulfur	Rubbery, reduced, camphor	1 hard-boiled egg, halved
Earthy	Soil, dirt, overripe fruit, rotting fruit, compost, musty, dusty, dry	½ cup fresh, dry soil
Barnyard	Brett, bandaid	1 grain 4-ethylphenol
Alcohol		1 tsp vodka (Sobieski)
Vinegar	Acetic, sour	1 tsp white vinegar (Best Yet) in 10 mL water
Chemical	Nail polish remover, acetone, solvent, plastic	1 drop ethyl acetate, ½ tsp bleach (Clorox)
Burning	Physical prickling sensation in nose	–
Taste/mouthfeel		
Overall flavor intensity		–
Sourness	Acidity, tart	2 g/L tartaric acid (Fisher Scientific) dissolved in water
Sweetness		15 g/L (D)-fructose (Sigma) dissolved in water
Bitterness		800 mg/L anhydrous caffeine (Sigma) dissolved in water
Alcohol	Warm to hot	150 mL/L vodka (Sobieski) in water
Viscosity	Thickness of mouthfeel, body of wine, oiliness Low anchor (thin) High anchor (thick)	7 g/L pectin ex-citrus (Sigma) dissolved in water
Complexity	Subtle, simple to complex	–
Astringency	Dry, tannic, puckering	800 mg/L alum (McCormick) dissolved in water
Smooth	Texture of mouthfeel	–
Silky	Texture of mouthfeel	–
Sharp	Texture of mouthfeel	–
Gritty	Texture of mouthfeel	–
Length of flavor	Low anchor (short) High anchor (long)	–
Burning	Physical sensation of tingling or numbing of tongue	–

[a]All attributes without specified anchors are low anchor (low) and high anchor (high).

pseudo-mixed model test, with mean square (wine*replicate) as the error. For the descriptive sensory analysis, an ANOVA measured the effects of wine, replicate and assessor, using a pseudo-mixed model test, with mean square (wine*assessor) as the error. The chemical and sensory data were related to one another using multiple pairwise correlations and partial least squares regression (PLSR), where the chemical data as x-variables (predictor variables), were related to the sensory descriptive data, as y-variables by PLS2 (Noble and Ebeler 2002). A further series of PLS1 models were generated using individual sensory attributes (y-variable) related to the chemical data (x-variables). For all PLS models, the variables were standardized by variance before analysis. The PLS model was cross-validated using an uncertainty test. The optimal number of components for the models was determined by inspection of residual variance explained by each principal component (PC). JMP (ver. 9.0; SAS Institute, Cary, NC), SAS (ver. 9.2; SAS Institute), XLSTAT (ver. 2009.3.01; Addinsoft, New York, NY), and UnScrambler (ver. 9.8; CAMO Software AS, Oslo, Norway) software were used for all data analyses.

Results and Discussion

Chemical analyses. Out of the 61 volatile compounds measured with the targeted profiling method developed using HS-SPME-GC-MS, 56 compounds were detected in the Cabernet Sauvignon varietal and blended wines included in the study (Table 2). Five targeted compounds were not detected in any of the wines: *trans*-ethyl cinnamate, ethyl dihydrocinnamate, 4-vinylguaiacol, γ-decalactone, and geraniol. The synchronous scan and SIM acquisition provides full scan spectra for analyte confirmation as well as sensitive and selective detection of the targeted compounds. To our knowledge, this is the first report of this approach for profiling volatile compounds that may contribute to aroma in wines. MIBP was detected using the HS-SPME-GC-MS/MS method adapted from Chapman et al. (2004) in some of the Cabernet Sauvignon varietal and blended wines included in the study.

From an ANOVA, all volatile compounds and standard chemical parameters were significantly different ($p < 0.05$) among the wines, except α-pinene and acetic acid (measured enzymatically). Levels of acetic acid ranged from 0.37 g/L in wine W9 to 0.71 g/L in wine W13 (data not shown). There were significant replicate differences ($p < 0.05$) for the following components: titratable acidity, limonene, *p*-cymene, ethyl octanoate, and vitispirane I and II. The results of the standard chemical analyses are shown in Table 1.

Descriptive sensory analysis. From an ANOVA of the descriptive analysis results, seven aroma attributes and 12 taste and mouthfeel attributes were significantly different ($p < 0.05$) among the wines: overall aroma intensity, fresh fruit aroma, berry aroma, butterscotch aroma, wood aroma, pepper aroma, barnyard aroma, overall flavor intensity, alcohol flavor, sweet taste, bitter taste, viscosity, complexity, astringency, smooth mouthfeel, silky mouthfeel, sharp mouthfeel, gritty mouthfeel, and in-mouth burning sensation. One other aroma attribute, vegetal, was significant at $p = 0.07$ and was included in all further analyses, given its importance as a varietal character of Cabernet Sauvignon wines. There were also some replicate differences ($p < 0.05$) among the wines for berry aroma, bitter taste, complexity, sharp mouthfeel, and burning sensation.

Relating chemical and sensory data. A partial least squares regression (PLSR) was performed on standardized significant chemical and sensory data for the 24 Cabernet Sauvignon varietal and blended wines included in the study (Figure 1). The first two principal components (PCs) explained 38% of the variance for the chemical data (x-variables), and 46% of the variance for the sensory data (y-variables). The third principal component explained an additional 7% and 10% of variance for the chemical and sensory data, respectively (data not shown).

The spread of wines in the score plot suggests that the wines were largely separated by alcohol level (Figure 1B). Wines with lower alcohol concentrations (denoted by lower code numbers) are positioned on the left side of the plot, while wines with higher alcohol concentrations are positioned on the right. PC1 displays the separation of samples primarily on the basis of fruity attributes and sweet taste on the left side of the PC, compared with alcohol flavor, bitter taste, and astringency on the right (Figure 1A). Lower alcohol wines, W1 to W7 (12.4 to 13.8% v/v), were generally sweeter and higher in fruity and butterscotch aromas and smooth and silky mouthfeel. The higher alcohol wines on the right side of the plot (Figure 1B) were generally more bitter and astringent, higher in wood aromas, overall flavor intensity, alcohol flavor, and complexity, with sharp and gritty mouthfeel and burning sensation. In the lower right quadrant, wines W9, W12, W13, W16 to W22, and W24 were tightly clustered together, indicating that they had similar chemical and sensory profiles, despite alcohol concentrations ranging from 14.3 to 15.9% v/v. For a more in-depth analysis of the influence of alcohol on the wines included in the study, see King et al. (2012). There was some separation of the samples vertically by PC2 in Figure 1A, primarily based on the barnyard and vegetal aroma attributes in the upper section and butterscotch and berry aroma attributes in the lower section. Wines W3 and W10 were rated highest in barnyard aroma, while wines W4 and W8 were rated highest in vegetal aroma.

The wines were analyzed for differences in price, region, vintage, and varietal composition (data not shown). There were slight differences among wines by price from the significant chemical data. Lower priced wines (<US $30) were higher in those volatile compounds present in the lower left quadrant of the PLSR plot (Figure 1A), as the majority of these wines were also lower in alcohol concentrations. The wines could not be differentiated by varietal composition (that is, the amount of Cabernet Sauvignon in the blend or the presence of other grape varieties) based on the chemical or sensory profiles, similar to the results of Dooley et al. (2012) and Hopfer et al. (2012).

In the overall model, 36 of the 56 compounds measured in the Cabernet Sauvignon wines and blends using the developed GC methods contributed significantly ($p < 0.05$) to

the prediction of the sensory attributes (PLS2), as indicated by their positions toward the exterior edges of the plot (Figure 1A). These compounds were ethyl acetate, hexyl acetate, ethyl isobutyrate, ethyl isovalerate, ethyl octanoate, isobutanol, isoamyl alcohol, isobutanol, 2-phenethyl alcohol, benzyl alcohol, β-ionone, α-terpinene, *cis*-linalool oxide, vitispirane I and II, *p*-cymene, furfural, 5-methylfurfural, *cis*-oak lactone, *trans*-oak lactone, camphor, acetic acid, phenylacetaldehyde, octanal, farnesol, eugenol, isoeugenol, syringol, vanillin, linalool, acetoin, and diacetyl as well as free SO_2, total SO_2, residual sugar, and alcohol. In order to further explore the chemical compounds responsible for the sensory attributes in more depth, PLS1 regression analyses were performed for each sensory attribute. The chemical data was found to predict a number of sensory descriptors.

For those sensory attributes on the left side of the plot (Figure 1A), berry and butterscotch aromas, which were positively correlated with each other (r = 0.56, $p < 0.05$), were positively

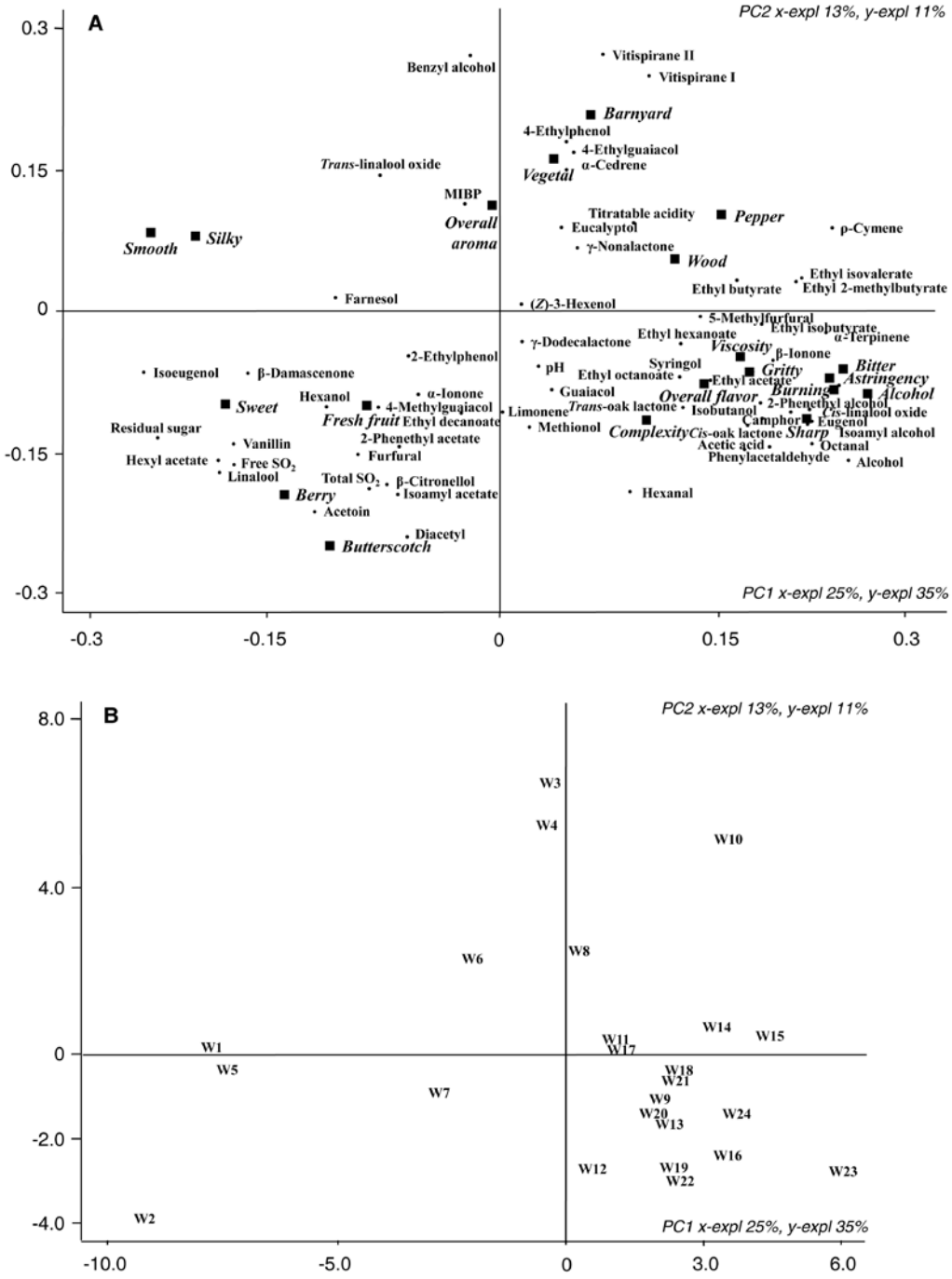

Figure 1 Partial least squares regression (PLSR) plot of (**A**) standardized significant volatile aroma compounds, and standard chemical parameters as x-variables (predictor variables) (small black circles) and standardized significant sensory attributes ($p < 0.07$) as y-variables (black squares); for (**B**) 24 U.S. Cabernet Sauvignon varietal and blended wines. In **B**, numbers indicate increasing alcohol concentration from 12.4% v/v (W1) to 15.9% v/v (W24); see Table 1 for details.

associated with acetoin, linalool, free SO_2, and residual sugar and negatively associated with ethyl 2-methylbutyrate, ethyl isovalerate, and *p*-cymene. Berry aroma was also positively associated with hexyl acetate, which has been shown in Australian Cabernet Sauvignon wines to both positively (Forde et al. 2011) and negatively (Robinson et al. 2011) influence berry aroma. Butterscotch aroma was also positively associated with diacetyl, vanillin, and farnesol. Diacetyl, in particular, is a byproduct of malolactic fermentation, which occurs in the majority of red wines, and contributes buttery or butterscotch aromas to wine (Bartowsky et al. 2002). Fresh fruit aroma was moderately positively correlated with berry and butterscotch aroma ($r > 0.42$, $p < 0.05$), and was positively associated with residual sugar and hexyl acetate, and negatively associated with α-terpinene.

Sweet taste was associated with residual sugar, as expected. Similarly, smooth and silky mouthfeel, which were strongly positively correlated with one another ($r = 0.91$, $p < 0.05$) and also to sweet taste ($r > 0.59$, $p < 0.05$), were also associated with residual sugar, as well as free SO_2 and isoeugenol, and negatively associated with those compounds on the right side of the plot, in particular, alcohol, ethyl acetate, ethyl isobutyrate, ethyl isovalerate, ethyl 2-methylbutyrate, isobutanol, isoamyl alcohol, 2-phenethyl alcohol, α-terpinene, β-ionone, *cis*-linalool oxide, *p*-cymene, octanal, acetic acid, camphor, phenylacetaldehyde, *trans*-oak lactone, eugenol, and syringol.

For those sensory attributes on the upper right side of the plot (Figure 1A), barnyard aroma was associated with vitispirane I and II and negatively associated with linalool. Barnyard aroma was also strongly positively correlated with α-cedrene, 4-ethylphenol, and 4-ethylguaiacol ($r > 0.88$, $p < 0.05$), although these compounds were not significant x-variables for this attribute. 4-Ethylphenol and 4-ethylguaiacol are produced by the spoilage yeast *Brettanomyces* and are known to impart aromas of horse saddle and leather to wine (Chatonnet et al. 1997). Vegetal aroma was negatively associated with residual sugar, ethyl isobutyrate, isobutanol, 2-phenethyl alcohol, isoeugenol, and vanillin. Vegetal aroma was positively correlated with 2-isobutyl-3-methoxypyrazine (MIBP) ($r = 0.45$, $p < 0.05$) and to a lesser extent eucalyptol, although these compounds were not significant x-variables for vegetal aroma. MIBP is the main compound responsible for green vegetable or bell pepper aromas in wine and is considered a varietal character of Cabernet Sauvignon (Sala et al. 2005). Eucalyptol or 1,8-cineole is responsible for the eucalyptus or menthol-like aromas in wine (Saliba et al. 2009) and is often considered more of a regional character of Australian Cabernet Sauvignon wines (Robinson et al. 2011).

Pepper aroma was positively associated with ethyl butyrate, ethyl 2-methylbutyrate, ethyl isovalerate, β-ionone, α-terpinene, *cis*-linalool oxide, *p*-cymene, octanal, and eugenol and negatively associated with free SO_2, residual sugar, hexyl acetate, acetoin, linalool, and isoeugenol. Wood aroma was positively associated with α-terpinene, *p*-cymene, camphor, and β-ionone and negatively associated with residual sugar and isoeugenol. Wood aroma was also associated with eugenol, *trans*-oak lactone, guaiacol, vanillin, and 4-methylguaiacol, all known oak-derived compounds (Jarauta et al. 2005), although these compounds were not significant x-variables in the PLS2 model for this attribute.

Overall aroma intensity was not well described by the model, probably because it was verbally defined by assessors as the initial assessment of intensity of all aromas when smelling, giving an impression of the general effusiveness of a wine. No specific compounds were associated with overall aroma intensity; however, this attribute was in close proximity to MIBP and *Brettanomyces*-related compounds in the plot (Figure 1A). These are known impact compounds in wine, with low sensory detection thresholds and the ability to mask other aromas when present in wine (Polášková et al. 2008), indicating that they may have contributed to the rating of overall aroma intensity in the wines. Overall flavor intensity, on the other hand, was positively associated with a number of compounds in the model, in particular alcohol, ethyl acetate, ethyl isobutyrate, ethyl 2-methylbutyrate, ethyl isovalerate, isobutanol, isoamyl alcohol, 2-phenethyl alcohol, α-terpinene, *cis*-linalool oxide, *p*-cymene, octanal, camphor, phenylacetaldehyde, methionol, and eugenol.

Bitter taste, astringency, alcohol flavor, sharp and gritty mouthfeel, and burning sensation were all positively correlated with one another ($r > 0.65$, $p < 0.05$). Viscosity was also moderately positively correlated with these attributes ($r > 0.55$, $p < 0.05$), as indicated by its close proximity on the right side of the PLSR plot (Figure 1A). All these sensory attributes were positively associated with alcohol concentration. Similar results have been shown in other studies, where ethanol, the main constituent of alcohol in wine, enhanced bitterness (Demiglio and Pickering 2008, Jones et al. 2008, Mattes and DiMeglio 2001) and astringency (Sáenz-Navajas et al. 2010) and caused unpleasant textural characters in wines, described as hotness and roughness (Jones et al. 2008), burning (Williams 1972), aggressiveness (Demiglio and Pickering 2008), and irritation (Mattes and DiMeglio 2001).

Bitter taste, alcohol flavor, viscosity, gritty mouthfeel, and burning sensation were associated with ethyl acetate, ethyl isobutyrate, α-terpinene, isobutanol, isoamyl alcohol, 2-phenethyl alcohol, β-ionone, *cis*-linalool oxide, *p*-cymene, octanal, 5-methylfurfural, *cis*-oak lactone, and eugenol and negatively associated with free SO_2, residual sugar, and isoeugenol. Bitter taste, alcohol flavor, and burning sensation were also positively associated with ethyl butyrate, ethyl 2-methylbutyrate, ethyl isovalerate, ethyl octanoate, acetic acid, camphor, phenylacetaldehyde, and syringol. Astringency and sharp mouthfeel were associated with ethyl acetate and syringol and negatively associated with total SO_2. Astringency was also positively associated with pH, α-terpinene, acetic acid, and 2-phenethyl alcohol and negatively associated with diacetyl and acetoin.

The high number of volatile compounds associated with taste and mouthfeel attributes in the model suggest a correlative and not causal relationship, particularly as there were no logical associations between them, such as sweetness and fruitiness, which might have elicited a taste and aroma interaction (Noble 1996). The Cabernet Sauvignon varietal and

blended wines were primarily differentiated in the model by alcohol concentration in the score plot (Figure 1B), indicating that similarly, alcohol is also separating the compounds and sensory attributes in the loadings plot (Figure 1A). A number of the significant compounds driving the taste and mouthfeel attributes in the model, such as the esters, higher alcohols, monoterpenes, norisoprenoids, lactones, and phenols, occur in higher levels in high alcohol wines and are thus correlated to the sensory attributes that are also higher in high alcohol wines, such as bitter taste, astringency, viscosity, sharp and gritty mouthfeel and burning sensation.

A number of sensory attributes were not well modeled by the PLSR, possibly because the compounds responsible were not measured using the GC methods developed. One such class of compounds, the sulfur-containing volatiles, were not measured; due to their high volatility, analysis of these compounds often requires special GC columns and/or selective detectors (Herszage and Ebeler 2011). These compounds have been reported to contribute varietal character in Cabernet Sauvignon wines (Bouchilloux et al. 1998). Future work will involve expanding and adapting the HS-SPME-GC-MS method to include other important volatile compounds known to impact wine sensory profiles.

Conversely, a number of the compounds measured were identified as not important to any of the sensory attributes. This may be because they were below their sensory limit of detection or they might be contributing to the sensory profiles of the wines without clear individual descriptors, as shown by Ferreira et al. (2002). It may also be due to mixture effects, where synergistic or masking interactions of volatile compounds make it difficult to determine individual sensory contributions (Francis and Newton 2005).

All of the sensory attributes that were predicted by the PLS model in this study exhibited both negative and positive associations of multiple compounds. Wine aroma composition is difficult to define by chemical composition, as one compound rarely drives the perception of a single sensory descriptor. The commercial wines used in this study were made from grapes grown in different regions and blended in different ratios with different grape varieties by producers with different winemaking techniques and oak regimes. To determine the actual influence of individual compounds or groups of compounds on the sensory perception of red wines, addition and omission testing or spiking studies need to be performed. However, the results of this study provide further information on some of the relationships that might exist between chemical compounds and sensory profiles of wines.

Conclusions

Wine aroma composition is complex, multifaceted, and dependent upon interactions of hundreds of volatile and nonvolatile compounds in wine. The aim of this study was to understand how differences in sensory properties among Cabernet Sauvignon wines and blends are produced by variations in chemical composition. To do this, we developed a rapid, targeted profiling method for measuring a wide range of volatile compounds in red wine, able to predict a number of important sensory descriptors, without extensive sample preparation or the use of multidimensional GC instrumentation. The method uses HS-SPME combined with GC-MS using synchronous scan and SIM detection to optimize sensitivity and selectivity for the targeted analytes. Using this method, commercial U.S. Cabernet Sauvignon varietal and blended wines were found to differ in their chemical and sensory profiles, in part, as a result of the direct and indirect influences of varying alcohol levels. The results of this study provide further information on the chemical and sensory profiles of the most widely planted grape variety in the United States, which can be used to better define Cabernet Sauvignon varietal and blended wine styles.

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