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Influence of Oak Maturation Regimen on Composition, Sensory Properties, Quality, and Consumer Acceptability of Cabernet Sauvignon Wines

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ABSTRACT: Oak barrels have long been the preferred method for oak maturation of wine, but barrels contribute significantly to production costs, so alternate oak maturation regimens have been introduced, particularly for wines at lower price points. To date, few studies have investigated consumers' acceptance of wines made using non-traditional oak treatments. In this study, two Cabernet Sauvignon wines were aged using traditional (i.e., barrel) and/or alternative (i.e., stainless steel or plastic tanks and vats, with oak wood added) maturation regimens. Chemical and sensory analyses were subsequently performed to determine the influence on wine composition and sensory properties, that is, the presence of key oak-derived volatile compounds and perceptible oak aromas and flavor. The quality of a subset of wines was rated by a panel of 10 wine experts using a 20-point scoring system, with all wines considered technically sound. Consumer acceptance of wines was also determined. Hedonic ratings ranged from 5.7 to 5.9 (on a 9-point scale), indicating there was no significant difference in consumers' overall liking of each wine. However, segmentation based on individual liking scores identified three distinct clusters comprising consumers with considerably different wine preferences. These results justify wine producers' use of alternative oak maturation regimens to achieve wine styles that appeal to different segments of their target market.

KEYWORDS: *oak, wine, descriptive analysis, preference, wine consumers*

INTRODUCTION

Consumer research is often used to gain insight into the market acceptance, preference, and perception of different foods and beverages, in particular, to establish the relative influence of extrinsic (e.g., packaging, labeling, and branding) and/or intrinsic (e.g., sensory attributes) characteristics on consumer liking and purchase intent.[1] For example, consumer studies have been undertaken to determine the influence of different bottle closures (i.e., natural cork, synthetic cork, and screw cap) on consumers' perceptions of wine quality and price.[2] Consumers were unable to differentiate wines bottled under different closures during blind tastings, but consumer liking and quality ratings of wines bottled under screw cap decreased significantly when the closure type was disclosed.[2] This study demonstrates the importance of understanding the implications of production decisions, in this case packaging, on consumer acceptability.

Market segmentation can also be used to differentiate consumer groups within a given population. For example, previous studies have segmented wine consumers according to their lifestyles or their wine experience, knowledge, or involvement.[3−7] This enables the inherent heterogeneity of a population to be taken into account, and in some cases, for product development and/or marketing strategies to be targeted toward specific groups within a market. The use of oak in winemaking provides another good example of the potential application of consumer research.

Oak barrels have long been the preferred method for oak maturation of wine. During barrel maturation, volatile compounds are extracted into the wine and impart desirable oak aromas and flavors,[8,9] whereas the controlled oxidation and modification of tannins and anthocyanins are considered to improve the intensity, stability, and structure of wines.[10,11] As a consequence, barrel-aged wines are generally considered to be of higher quality and therefore attract higher prices.[12] However, because the use of barrels also contributes to significantly higher production costs, wine producers have increased their use of alternative oak maturation regimens. Several studies have reported the evolution of oak-derived volatiles and sensory attributes in wine following treatment with oak chips,[13,14] in some cases with micro-oxygenation,[15,16] so as to achieve maturation conditions that more closely replicate traditional barrel aging.

To date, few studies have investigated consumers' acceptance of wines made using non-traditional oak treatments. A recent study compared consumer preferences for wines aged either in oak barrels or with oak chips and reported considerable disparity in consumers' wine preferences.[17] Because consumers did not significantly reject wines made with oak chips, the authors concluded that markets exist for wines made using both oak maturation regimens. The role of oak in winemaking is not well understood by most wine consumers, but knowledgeable consumers do appreciate traditional barrel maturation and are willing to pay a premium for barrel-aged wines, whereas less knowledgeable consumers are accepting of the use of oak chips.[18] A greater understanding of consumer liking for wines made using oak alternatives would enable the wine industry to better ascertain their acceptability in the market. This study therefore aimed to investigate the influence of a range of

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Table 1. Regimens Used for Oak Maturation of 2009 and 2011 Cabernet Sauvignon Wines

wine sample	code	maturation vessel	volume (L)	oak maturation regimen
trial 1 2009 Padthaway Cabernet Sauvignon	SSVAT	stainless steel vat	900	2 g/L toasted French oak chips
	P1VAT	stainless steel vat with two 4.5 mm HDPE panels	900	2 g/L toasted French oak chips
	P2VAT[a]	stainless steel vat with two 1.5 mm HDPE panels	900	2 g/L toasted French oak chips
	FOVAT	stainless steel vat with two French oak panels	900	1.6 m^2 French oak panels
trial 2 2011 Eden Valley Cabernet Sauvignon	barrel[a]	barrel	225−300[b]	French oak (22% new, 16% 1-year-old, and 62% 2-year-old), medium toast
	SS + OAK[a]	stainless steel	4550	French oak staves (1.4 m^2/kL), medium toast
	SS − OAK	stainless steel	4550	no oak treatment
	P1 + OAK[a]	plastic tank (with 12 g/L/year O_2 ingress)	1000	French oak staves (1.4 m^2/kL), medium toast
	P1 − OAK[a]	plastic tank (with 12 g/L/year O_2 ingress)	1000	no oak treatment
	P2 + OAK	plastic tank (with 4 g/L/year O_2 ingress)	1000	French oak staves (1.4 m^2/kL), medium toast
	P2 − OAK	plastic tank (with 4 g/L/year O_2 ingress)	1000	no oak treatment

[a]Wines retained for consumer acceptability and expert panel testing. [b]Blend of wines aged in 4 × 300 L hogsheads and 26 × 225 L barriques.

traditional and alternative oak maturation regimens on the composition, sensory properties, quality, and consumer acceptability of wine. The knowledge gained from this study can be used by wine producers to both inform and justify their use of oak alternatives, in particular for the production of wines at certain price points and/or targeted toward specific segments of the wine market.

MATERIALS AND METHODS

Oak Maturation Trials. Two South Australian Cabernet Sauvignon wines were sourced from industry-based trials, involving a range of different oak maturation regimens (Table 1). Trial 1 involved a 12 month maturation of a 2009 Padthaway Cabernet Sauvignon in four types of 900 L Stakvats (Ausvat Pty. Ltd., Willunga, Australia), being (i) stainless steel, hereafter referred to as "SSVAT"; (ii) stainless steel with two 4.5 mm high-density polyethylene (HDPE) panels, hereafter referred to as "P1VAT"; (iii) stainless steel with two 1.5 mm HDPE panels, hereafter referred to as "P2VAT"; and (iv) stainless steel with two French oak wood panels, hereafter referred to as "FOVAT". French oak chips (medium toast) sourced from the same batch of oak wood were inserted in each of the stainless steel and plastic Stakvats (SSVAT, P1VAT, P2VAT), but not the oak-sided Stakvat (FOVAT), at a rate of 2 g/L. Trial 2 involved a 4 month maturation of a 2011 Eden Valley Cabernet Sauvignon in four different vessels, being (i) 1000 L plastic tanks with oxygen ingress of 17 mg O_2/L/year, hereafter referred to as "P1"; (ii) 1000 L plastic tanks with oxygen ingress of 12.6 mg O_2/L/year, hereafter referred to as "P2"; (iii) 4550 L stainless steel tanks, hereafter referred to as "SS"; and (iv) a combination of new, 1- and 2-year-old French oak barrels (medium plus toast), which were blended after maturation, hereafter referred to as "barrel". Maturation in plastic and stainless steel tanks comprised treatments with and without the addition of French oak staves (medium toast), sourced from the same batch of oak wood (hereafter designated "+ OAK" and "− OAK", respectively). Staves were added to achieve an area-to-volume ratio of 1.4 m^2/kL.

Following completion of each maturation trial, wines were bottled (using 750 mL bottles fitted with metal screw-cap closures for trial 1 and 375 mL bottles fitted with plastic screw-cap closures for trial 2) and stored at 15 °C prior to sensory and chemical analysis. Trial 1 wines were bottle aged for 3 years prior to analysis, whereas trial 2 wines were analyzed approximately 4 months after bottling.

Chemical Analysis of Wine. Wines were analyzed (in duplicate) to determine pH, titratable acidity (TA, as tartaric acid equivalents to an end point of pH 8.2), volatile acidity (VA, as acetic acid equivalents to an end point of pH 8.2), free and total SO_2 content (by the aspiration method), wine color density, and total phenolics, according to methods described previously.[19] Glucose and fructose concentrations were determined enzymatically (Boehringer-Mannheim/R-BioPharm, Darmstadt, Germany). Ethanol content (as % alcohol by volume) was measured with an alcolyzer (Anton Paar, Graz, Austria). Oak volatiles were quantified by gas chromatography−mass spectrometry (GC-MS) using stable isotope dilution analysis (SIDA) methods reported previously.[20−22] These publications describe the preparation of deuterated internal standards, method validation, and instrumental operating conditions. Analysis of oak volatiles was performed by the Australian Wine Research Institute (AWRI) Commercial Services Laboratory using an Agilent 6890 gas chromatograph coupled to a 5973 mass selective detector.

Sensory Analysis of Wine. Wines were equilibrated at 21 °C for 24 h prior to each sensory experiment. Wines were assigned a random three-digit code for descriptive analysis (DA), expert and consumer sensory assessments. Wine aliquots (30 mL) were presented in covered Viticole XL5 (ISO standard) 215 mL stemmed wine tasting glasses, using a randomized presentation order.

Descriptive Analysis. DA was undertaken using a panel comprising 10 University of Adelaide staff and students (seven females, three males). Panelists were recruited on the basis of their availability and previous participation on DA panels involving analysis of red wine. Prior to formal assessment, panelists underwent 9 h of training (comprising 6 × 1.5 h sessions held over 6 weeks) involving detection, identification, evaluation, and intensity rating of red wine aroma and palate (i.e., flavor, taste and mouthfeel) attributes. During the training sessions, the panel evaluated each wine at least twice, to generate appropriate aroma and palate terms and to gain familiarity in recognizing and scoring their intensity, according to previously published protocols.[23] The training sessions also included three practice evaluation sessions conducted in sensory booths, under the conditions used during formal assessment. Data were evaluated after each practice evaluation to assess panelist-by-sample interactions, to determine when formal assessment should commence. The panel agreed upon 15 aroma attributes and 16 palate attributes; when reference standards were used, their preparation is shown in Table 2. Because panelists were unable to perceive any differences in wine color, appearance was not evaluated. Three formal assessment sessions were held, with all 11 wines presented in each session, such that all wines were assessed in triplicate. Panelists assessed each wine in an isolated tasting booth at 22−23 °C under red lights, with a light temperature of 6500 K, and rated the intensity of each sensory

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Table 2. Reference Standards Used in Descriptive Analysis of Cabernet Sauvignon Wines after Oak Maturation

descriptor[a]	reference standard
red fruit	two McCain frozen raspberries and one fresh strawberry
confectionary	$^1/_2$ Allens strawberries and cream lolly + 0.5 cm piece Coles banana lolly
dark fruit	two McCain frozen blackberries and two McCain frozen blueberries
herbaceous	0.5 cm cube of green capsicum, two small tomato plant leaves
mint/menthol	$^1/_2$ tsp eucalyptus solution (1 drop of eucalyptus oil (Bosisto's, Australia) in 2 L of water)
dusty[b]	3 cm square of Hessian, 3 sticks of white chalk crushed
earthy	1 tsp wet earth with moss
charry	1 tsp 4-ethylguaiacol solution (1 drop of 4-ethylguaiacol in 50 mL of water) and 2 tsp of oak solution (medium-toasted American oak wood (Oak Chips Inc., Waverly, OH, USA) prepared in 10% ethanol)
leather[b]	3 cm × 10 cm piece of leather
mocha	1 tsp of mocha solution (100 g of 70% Lindt chocolate + 20 coffee beans in 250 mL of water)
licorice	0.5 cm piece of Darrell Lea licorice
sweet oak	$^1/_8$ tsp of vanillin powder (Sigma-Aldrich) + $^1/_2$ tsp of oak solution
spice	$^1/_4$ tsp of McKenzie's mixed spice + $^1/_4$ tsp of freshly ground black pepper + 3 cloves
woody[b]	1 cm × 9 cm × 0.5 cm untoasted French oak wood (Oak Chips Inc.) + $^1/_2$ tsp of pencil shavings

[a]Samples prepared in 30 mL of Cabernet Sauvignon cask wine, unless otherwise stated. [b]Denotes samples that were prepared dry.

descriptor using a 15 cm unstructured line scale with anchor points of "low" and "high" placed at 10 and 90% on the scale, respectively. Sensory reference standards (Table 2) were developed during training sessions and provided to panelists at each formal assessment session in covered, opaque black glasses. Panelists were required to reacquaint themselves with the sensory reference standards and written definitions of attributes several times during each evaluation. Distilled water and crackers were provided as palate cleansers, and panelists were required to have a 1 min break between samples and a 5 min break every three samples. Sensory data were collected using FIZZ software (version 2.47b, Biosystemes, Couternon, France).

Consumer Acceptance and Expert Panel Testing. On the basis of the outcomes of DA, five wines (barrel, SS + OAK, P1 + OAK, P1 − OAK, and P2VAT), with distinct sensory profiles were selected for consumer acceptance and expert panel testing. Consumer acceptability tests were carried out in a sensory laboratory at a central location, with each participant assigned a random "taster" number and allocated to an individual booth. Participants were recruited using a variety of methods, including social networking sites (e.g., Facebook, LinkedIn, Twitter), distribution of a flyer (via a mailbox drop within a 6 km radius of the University of Adelaide's Waite campus, and distribution at local wine retail outlets) and e-mail. Participants were screened against inclusion criteria requiring consumption of red wine at least once a month and being of legal drinking age (i.e., ≥18 years of age); exclusion criteria precluded participation by wine industry professionals and university staff and students. One hundred and sixteen consumers were recruited and acceptability tests were performed in October 2012, approximately 3 months after DA was completed. Consumers were asked to rate their hedonic liking of each wine using a 9-point scale with anchors from 1 (dislike extremely) to 9 (like extremely). Prior to evaluation of wines, consumers were instructed on how to assess the wine and use the hedonic scale. Coded samples were presented monadically with consumers signaling the researchers for their next sample using a switch in the sensory booth. Crackers and distilled water were provided as palate cleansers. After wines were evaluated, consumers answered demographic questions regarding gender, age, education, household income, and wine consumption. Consumers also indicated their average spend per bottle of wine for home consumption.

The expert panel comprised 10 wine industry personnel (9 males and 1 female), who met the criteria of "expert" defined by Parr and co-workers.[24] Each panelist assessed 10 wines, that is, the subset of 5 wines in duplicate. Participants were asked to assess each wine according to the 20-point scoring system used in Australian wine show judging[25] and to provide informal comments describing what they liked or disliked about each wine. Tasting was conducted 4 months after consumer acceptability testing in an open-plan tasting room at a winery in the Barossa Valley.

Data Analysis. Data were analyzed using Senpaq v5.01 (Qi Statistics, 2012) and XLSTAT 2013.1.01 (Addinsoft, 2012). Consumer acceptance data were analyzed using a combination of descriptive and multivariate techniques, including analysis of variance (ANOVA) with post hoc Tukey's test, partial least-squares regression (PLSR), internal preference mapping, and principal component analysis (PCA). Hedonic clusters were identified using cluster analysis.

RESULTS AND DISCUSSION

Cabernet Sauvignon wines (a 2009 Padthaway and a 2011 Eden Valley) were matured using a range of traditional and/or alternative oak maturation regimens (Table 1). Various chemical and sensory analyses were subsequently performed to compare the influence of each maturation regimen on the composition, sensory properties, quality and consumer acceptability of wines.

Influence of Oak Maturation Regimen on Chemical Composition of Wine. The wine color density, wine hue, total phenolics, alcohol content, pH, TA and VA of wines are reported in Table 3. Wines from trial 1 (i.e., 2009 Padthaway wines) had slightly lower pH, TA and VA and slightly higher alcohol content than wines from trial 2 (i.e., 2011 Eden Valley wines). There were no meaningful differences between the basic wine parameters of trial 1 wines, but trial 2 wines showed greater variation, in particular for wine color density and phenolic content, which ranged from 9.7 to 10.2 and from 51 to 57 au, respectively. Increased phenolic content can influence the perception of astringency by enhancing the drying sensation,[26] but the relatively small differences observed

Table 3. Wine Color Density, Wine Hue, Phenolics, Alcohol Content, pH, Titratable Acidity (TA), and Volatile Acidity (VA) of Cabernet Sauvignon Wines after Oak Maturation

		wine color density	wine hue	phenolics (au)	alcohol (% v/v)	pH	TA[a] (g/L)	VA[a] (g/L)
trial 1, 2009 Padthaway Cabernet Sauvignon	mean	12.6 ± 0.3	0.84 ± 0.01	61 ± 1	14.6 ± 0.01	3.43 ± 0.01	6.1 ± 0.05	0.42 ± 0.02
	range	12.4−12.8	0.83−0.86	60−62	14.5−14.6	3.43−3.45	6.0−6.2	0.41−0.42
trial 2, 2011 Eden Valley Cabernet Sauvignon	mean	9.9 ± 0.4	0.77 ± 0.01	53 ± 2	14.2 ± 0.05	3.51 ± 0.01	6.4 ± 0.07	0.52 ± 0.15
	range	9.7−10.2	0.76−0.80	51−57	14.1−14.3	3.50−3.53	6.4−6.6	0.54−0.62

[a]TA measured as g/L of tartaric acid; VA measured as g/L of acetic acid.

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Table 4. Oak Volatile Composition of Cabernet Sauvignon Wines after Oak Maturation[a]

		concentration (μg/L)							
treatment		*cis*-oak lactone	*trans*-oak lactone	guaiacol	4-methyl guaiacol	eugenol	vanillin	furfural	5-methyl furfural
trial 1, 2009 Padthaway Cabernet Sauvignon	SSVAT	128 ± 1 a	23 ± 0	7 ± 0 b	4 ± 0 b	12 ± 1	54 ± 1 b	121 ± 0	nd
	P1VAT	121 ± 1 b	27 ± 3	8 ± 0 a	11 ± 0 a	5 ± 7	153 ± 12 a	123 ± 1	nd
	P2VAT	121 ± 1 b	29 ± 0	8 ± 0 a	10 ± 0 a	nd	128 ± 42 ab	119 ± 3	nd
	FOVAT	122 ± 4 b	29 ± 3	8 ± 0 a	11 ± 1 a	10 ± 0	131 ± 19 ab	119 ± 2	nd
	P value	0.048	0.107	<0.001	<0.001	0.096	0.052	0.243	
trial 2, 2011 Eden Valley Cabernet Sauvignon	barrel	99 ± 1 a	79 ± 4 a	4 ± 1 c	1 ± 0 c	6 ± 9	123 ± 3 b	261 ± 24 c	32 ± 1 d
	SS + OAK	39 ± 1 c	30 ± 1 c	28 ± 1 b	15 ± 0 b	nd	242 ± 5 a	1877 ± 2 b	282 ± 1 b
	SS − OAK	nd	nd	4 ± 1 c	nd	nd	18 ± 7 c	173 ± 1 cd	nd
	P1 + OAK	30 ± 1 d	46 ± 2 b	27 ± 1 b	16 ± 0 a	nd	281 ± 64 a	32 ± 1 e	54 ± 1 c
	P1 − OAK	nd	nd	4 ± 1 c	nd	nd	6 ± 8 c	121 ± 4 de	nd
	P2 + OAK	47 ± 1b	24 ± 2 d	33 ± 1 a	16 ± 0 a	6 ± 8	313 ± 98 a	2633 ± 141 a	368 ± 13 a
	P2 − OAK	nd	nd	3 ± 0 c	nd	nd	20 ± 11 c	116 ± 4 de	nd
	P value	<0.001	<0.001	<0.001	<0.001	0.580	<0.001	<0.001	<0.001

[a]Values are the mean of two technical replicates (± standard deviation). Means within a column (per trial) followed by different letters are significantly different (P = 0.05, one-way ANOVA, Tukey's LSD post hoc).

Table 5. Mean Intensity Ratings for Sensory Attributes of Cabernet Sauvignon Wines after Oak Maturation[a]

	trial 1 2009 Padthaway Cabernet Sauvignon				trial 2 2011 Eden Valley Cabernet Sauvignon						
attribute[b]	SSVAT	P1VAT	P2VAT	FOVAT	barrel	SS + OAK	SS − OAK	P1 + OAK	P1 − OAK	P2 + OAK	P2 − OAK
A-red fruit	4.8	5.2	5.5	5.2	7.1 ab	6.8 ab	8.3 a	6.2 b	7.8 a	5.9 b	7.8 a
A-confectionary	4.5	5.3	5.2	4.2	5.7 ab	6.0 ab	6.9 ab	5.5 b	7.0 ab	5.7 ab	7.1 a
A-dark fruit	6.8	7.6	7.2	6.9	6.8 b	6.7 b	7.1 ab	7.3 ab	7.0 ab	6.9 ab	8.2 a
A-herbaceous	3.5	3.3	3.9	3.5	4.1 ab	3.4 b	4.0 ab	4.3 ab	4.9 a	3.2 b	5.2 a
A-mint/menthol	4.1	4.1	4.0	3.6	4.3 bc	4.1 bc	4.4 bc	4.1 bc	5.4 ab	4.0 c	5.9 a
A-dusty	6.7	6.1	6.2	6.7	4.1 abc	4.3 abc	3.5 c	4.9 a	3.7 bc	4.5 ab	4.2 abc
A-charry	4.1 b	4.8 ab	5.1 ab	5.9 a	3.2 b	4.5 a	2.7 b	5.6 a	3.0 b	4.6 a	3.2 b
A-leather	5.2 b	5.0 b	5.4 ab	6.6 a	3.2 ab	3.3 ab	2.5 b	3.6 ab	3.0 ab	3.7 a	3.1 ab
A-mocha	3.5	4.3	4.0	4.2	3.0 c	3.8 bc	3.6 bc	5.0 a	3.5 bc	4.4 ab	3.5 bc
A-sweet oak	4.4	5.1	4.9	4.7	4.8 ab	5.1 ab	4.6 b	5.8 a	5.1 ab	5.7 ab	4.9 ab
A-woody	5.1	5.9	6.4	5.8	4.0 b	4.9 ab	3.9 b	5.4 a	4.0 b	5.2 ab	4.2 ab
P-red fruit	6.5	6.0	6.2	7.2	8.1 ab	7.0 ab	8.2 ab	6.9 b	7.9 ab	7.0 b	8.3 a
P-earthy	3.3	3.8	3.5	3.6	2.8 b	3.5 a	2.8 ab	3.3 ab	3.0 ab	3.2 ab	3.4 ab
P-charry	3.3 b	5.2 a	4.9 a	5.0 a	3.7 bc	4.4 ab	3.0 c	5.0 a	3.3 c	4.6 ab	3.7 bc
P-mocha	3.5	4.3	4.2	4.3	3.8 ab	4.2 ab	3.7 ab	4.4 a	3.4 b	4.3 a	3.4 b
P-licorice	3.7	3.9	3.2	3.6	3.5 bcd	2.9 d	4.4 a	3.9 abc	4.3 ab	3.5 cd	3.9 abc
P-sweet oak	4.7 ab	5.4 a	4.4 b	4.9 ab	4.7 bc	4.7 bc	4.2 c	5.6 ab	4.4 c	6.5 a	4.9 bc
P-woody	5.6 b	7.4 a	6.6 ab	6.4 ab	4.8 b	6.7 a	5.3 ab	5.9 ab	5.5 ab	5.9 ab	5.1 ab
tannins	7.9 b	8.5 ab	9.4 a	9.0 ab	7.2 ab	7.3 a	6.7 ab	7.2 ab	7.4 a	6.0 b	7.3 ab

[a]Values are mean scores from one wine replicate (per treatment) presented to 10 judges in three replicate sessions. Means within a row (per trial) followed by different letters are significantly different (P = 0.05, one way ANOVA, Tukey's LSD post hoc). [b]A, aroma attribute; P, palate attribute.

between phenolic measurements obtained in the current study (i.e., 5−10%) would not be expected to lead to perceptible sensory differences.

Similar concentrations of oak volatiles were observed in each of the trial 1 wines, albeit SSVAT wines contained significantly lower levels of vanillin than the other wines from trial 1 (Table 4). Of the oak volatiles measured, only *cis*-oak lactone and eugenol occurred at concentrations above their detection thresholds, of 23 and 5 μg/L, respectively.[27,28] More significant differences were observed between trial 2 wines. Wines aged using maturation regimens without the addition of oak wood (i.e., SS − OAK, P1 − OAK, and P2 − OAK) contained low or undetectable (<1 μg/L) levels of oak volatiles, as expected. The barrel-aged wine contained the highest concentrations of *cis*- and *trans*-oak lactones (99 and 79 μg/L respectively), but comparatively lower levels of other oak-derived volatiles. The maturation regimens involving addition of oak staves yielded similar oak volatile concentrations, albeit P1 + OAK wines contained extremely low levels of furfural and 5-methylfurfural (i.e., <100 μg/L) compared to SS + OAK and P2 + OAK wines (which contained >1800 μg/L) and even the unoaked wines. Again, *cis*-oak lactone was detected (in oaked wines) at concentrations above its detection threshold. The guaiacol and vanillin levels of trial 2 wines aged using alternative oak maturation regimens also exceeded threshold concentrations, being 10 and 200 μg/L, respectively.[28]

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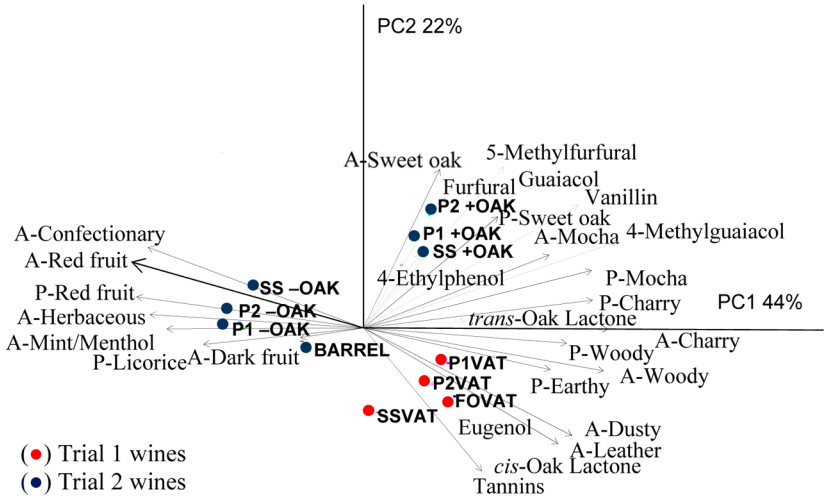

Figure 1. PCA biplot of oak volatile concentrations and sensory attribute ratings for Cabernet Sauvignon wines after oak maturation.

The differences observed between the oak volatile profiles of wines from trial 1 compared to those from trial 2 likely reflect differences in oak composition, in agreement with previous studies.[29−31] Interestingly, the oak wood used in trial 1 yielded a considerably higher proportion of *cis*-oak lactone (i.e., approximately 4-fold higher levels) than *trans*-oak lactone, whereas the oak used in trial 2 gave approximately equal concentrations of each isomer. Compositional differences can also be attributed to differences in the rate of oak addition, the surface area available for extraction, and the duration of oak maturation. Surprisingly, meaningful differences in wine color, phenolic and oak volatile profiles were not observed for the different maturation regimens, even when oxygen ingress varied considerably (Table 1).

Influence of Oak Maturation Regimen on Sensory Properties of Wine. ANOVA was performed on the DA data, and 19 of 31 attributes were found to significantly differentiate ($P < 0.05$) wines within each trial (Table 5).

Wines from trial 1 were generally rated higher in *dusty*, *charry*, *leather*, and *woody* characters than trial 2 wines, with FOVAT receiving the highest ratings for *charry* and *leather* aromas. Similar ratings were given to varietal attributes, that is, *red fruit*, *dark fruit*, and *herbaceous* attributes. That wines from this trial were perceived to be more complex, that is, to exhibit more intense oak- and age-related sensory attributes, reflects the extended period of oak maturation (12 months) and bottle aging (24 months) prior to sensory analysis. The duration of oak maturation directly influences the concentration of volatiles extracted from oak wood into wine,[32] but biochemical reactions continue to occur, for example, the conversion of furanic aldehydes into their corresponding alcohols.[33,34] This likely explains the lower levels of furfural (i.e., approximately 120 μg/L) and the absence of 5-methylfurfural observed in trial 1 wines, compared to trial 2 wines, in particular SS + OAK and P2 + OAK (Table 4).

The unoaked wines from trial 2 received similar ratings for most attributes and tended to exhibit more intense varietal characteristics, for example, *red fruit*, *dark fruit*, *herbaceous*, and *mint/menthol* attributes, than the oaked wines; the prominence of varietal characters is due to the absence of oak influence. Of the oak-treated wines, the barrel-aged wine received the lowest scores for most oak-related attributes, which was not surprising given the low levels of oak volatiles observed in this wine. The ratings for oak attributes in the barrel wine more closely resembled scores given to the unoaked wines, and instead, the barrel wine displayed more intense *red fruit* and *mint/menthol* aromas and *red fruit* on the palate. P1 + OAK exhibited the highest *charry*, *mocha*, *sweet oak*, and *woody* aromas and *charry*, *licorice* flavor, whereas P2 + OAK displayed *leather* and *sweet oak* on the palate. Previous studies have investigated the impact of micro-oxygenation (MOX) on wine sensory attributes, including the development of aged notes in MOX wines. For example, Cejudo-Bastante and colleagues observed an increase in nutty, tobacco, and spice notes in MOX-treated wines compared to wines stored in stainless steel tanks without oxygen addition.[35] Several of the maturation regimens used in trial 2 deliberately enabled oxygen ingress (Table 1), but the resulting wines did not exhibit overly apparent aged notes.

PCA was performed on the mean intensity ratings obtained for the sensory attributes that were perceived to be significantly different across the two trials (Figure 1), with PC1 and PC2 accounting for 44 and 22% of variation between wines, respectively. Clear separation was observed between oaked wines, which were predominantly located in the right quadrants, and unoaked wines, which were located in the left quadrants. The barrel-aged wine was located in close proximity to the unoaked wines, which again was not surprising given its relatively low levels of oak volatiles (Table 4). PC1 suggests separation of oaked and unoaked wines is primarily driven by the intensity of varietal (i.e., *fruit/green*) versus oak-related sensory attributes. Discrimination of trial 1 and 2 wines was also observed, with wines aged in vats clustered together in the bottom right quadrant and wines aged in stainless steel or plastic tanks (containing oak) clustered in the top right quadrant. Trial 1 wines were in part differentiated on the basis of *dusty* and *leather* aromas, which reflect the increased age of these wines. SS + OAK, P1 + OAK, and P2 + OAK each contained higher levels of vanillin (being 242−313 μg/L) than trial 1 wines (Table 4). These concentrations exceed the detection threshold reported for vanillin in red wine, that is, 200 μg/L.[28] Vanillin might therefore contribute to the *sweet oak* and *mocha* attributes that helped differentiate these wines. Differentiation of trial 1 and 2 wines may also have been influenced by guaiacol, *cis*-oak lactone, and eugenol, that is, the other volatiles observed in selected wines at concentrations above their threshold levels (Table 4).

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Influence of Oak Maturation Regimen on Quality and Consumer Acceptance of Wines. A subset of five wines was selected for quality and acceptability ratings by wine experts and consumers, respectively. The expert panel used a 20-point scoring system to rate wine quality (Table 6); mean scores ranged from 13.8 (for the barrel-aged wines) to 14.8 (for P1 − OAK), which indicates all wines were technically sound. The experts informally described the unoaked sample as having "*varietal characters, fresh cherry nose, forest fruits, confectionary*" but "*lacking complexity and palate length*". The barrel-aged wine was considered to display "*dull, manufactured oak*" and "*lack fruit intensity*". P2VAT was described as "*savory, chocolate, dusty, earthy, lacking fruit flavor*" with "*softer tannins*" and "*more complex than the other wines*". In general, these comments were in good agreement with DA results.

Table 6. Consumer Liking and Expert Quality Ratings for Selected Cabernet Sauvignon Wines after Oak Maturation[a]

	hedonic ratings[b]				quality ratings[b]
treatment	total sample (n = 116)	cluster 1 (n = 35)	cluster 2 (n = 55)	cluster 3 (n = 26)	wine experts (n = 10)
barrel	5.7	5.11 b	6.35 a	4.85 b	13.75
SS + OAK	5.8	4.49 b	6.45 a	6.12 a	14.42
P1 − OAK	5.9	4.31 b	6.60 a	6.23 a	14.82
P1 + OAK	5.9	3.91 b	6.73 a	6.58 a	13.92
P2VAT	5.9	5.80 b	7.00 a	3.42 c	14.65

[a]Means within a row followed by different letters are significantly different (P = 0.05, one-way ANOVA, Tukey's LSD post hoc). [b]Hedonic ratings were determined using a 9-point scale and quality ratings using a 20-point scoring system.

One hundred and sixteen consumers participated in the acceptance test, and their demographic data are reported in Table 7. A similar proportion of male and female participants and a relatively even distribution of ages were achieved. Most consumers were regular wine drinkers and consumed wine at least once per week (i.e., 86%). There were no significant differences in the hedonic ratings given by the consumer cohort for the five wines (Table 6), with mean scores ranging from 5.7 to 5.9. However, as in previous research,[17] disparity in consumers' wine preferences was observed, and cluster analysis based on individual hedonic scores enabled the identification of three distinct consumer segments (Tables 6 and 7). The first cluster comprised 35 consumers, who were not overly accepting of any wine, but who liked P2VAT most and P1 + OAK least. Cluster 2, the largest cluster (n = 55), gave similar scores to each wine and quite closely resembled the total sample. Cluster 3 comprised 26 consumers, who did not like the barrel-aged or P2VAT wines, but equally liked the other wines. Surprisingly, the wine produced using traditional barrel maturation was not favored by any segment and actually received the lowest overall score, whereas P1 − OAK, the wine made without oak contact, was quite well liked by clusters 2 and 3.

Internal preference mapping was undertaken to investigate the sensory attributes driving consumer liking. PLSR was performed on the DA data and hedonic ratings for each consumer segment and the total sample (Figure 2). Sensory attributes with regression coefficients > ±0.2 are generally considered to influence consumer liking.[6] In the current study, there were neither positive nor negative drivers for either the total consumer sample or cluster 2. In contrast, strong positive drivers were observed for cluster 1, including *leather* aroma (0.34) and flavor (0.33), *licorice* flavor (0.24), and *astringent/dry* mouthfeel (0.26), whereas strong negative drivers included *mocha* (−0.47) and *charry* (−0.30) aromas. This explains cluster 1's preference for P2VAT, which exhibited more apparent aged characters relative to other wines. Positive drivers for cluster 3 included *red fruit* (0.42), *charry* (0.27), and *mocha* (0.56) aromas and *earthy* (0.61) and *woody* (0.31) flavors. The strong negative drivers for cluster 3 were *dusty* (−0.44) and *leather* (−0.64) aromas and *leather* flavor on the palate (−0.57). Consumers within this cluster tended to be younger, from households with higher incomes, who were willing to spend more for wine on average than consumers from clusters 1 and 2 (Table 7). On the basis of demographic data, hedonic scores, and the sensory attributes driving wine preferences, consumers from clusters 2 and 3 would be most likely to be receptive to wines made using alternate oak maturation regimens; indeed, consumers from cluster 2 were generally accepting of all wines (Table 6).

Table 7. Consumer Demographics for Total Sample (n = 116) and Consumer Segments

	total sample[a] (n = 116)	cluster 1[a] (n = 35)	cluster 2[a] (n = 55)	cluster 3[a] (n = 26)
gender				
male	50.9	42.9	63.6	34.6
female	49.1	57.1	36.4	65.4
age (years)				
18−34	27.6	37.1	20.0	30.8
35−54	31.9	28.6	27.3	46.2
55+	40.5	34.3	52.7	23.1
education				
high school	10.3	17.1	7.3	7.7
technical/trade	15.5	5.7	21.8	15.4
bachelor's degree	29.3	28.6	30.9	26.9
postgraduate	44.8	48.6	40.0	50.0
household income ($AUD)				
<$25000	8.6	11.4	7.3	7.7
$25001−50000	11.2	5.7	14.5	11.5
$50001−75000	18.1	25.7	16.4	11.5
$75001−100000	21.6	25.7	18.2	23.1
$100001−150000	28.4	20.0	32.7	30.8
$150001−200000	7.8	5.7	7.3	11.5
>$200000+	4.3	5.7	3.6	3.8
wine consumption				
4+ times/week	22.2	22.9	27.3	11.5
2−3 times/week	35.9	28.6	40.0	38.5
once a week	27.4	28.6	23.6	34.6
once every 2 weeks	11.1	17.1	7.3	11.5
once a month	2.6	2.9	1.8	3.8
average price/bottle for home consumption ($AUD)				
<$10	2.6	2.9	1.8	3.8
$11−15	26.5	25.7	27.3	26.9
$16−20	37.6	40.0	41.8	26.9
$21−30	28.2	28.6	25.5	34.6
$31−50	3.4	2.9	1.8	7.7
$51+	0.9	0	1.8	0

[a]Values expressed as percentages.

This study demonstrates consumer acceptance of wines made using alternative oak maturation regimes. The presence of key oak-derived volatile compounds and perceptible oak aromas and flavor in oak-aged wines was confirmed by chemical

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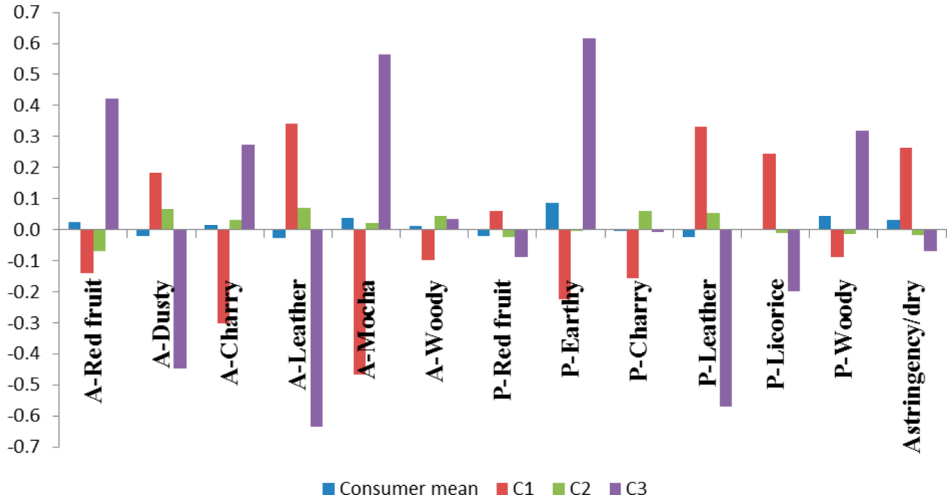

Figure 2. PLSR plot of consumer liking against wine sensory attributes for selected Cabernet Sauvignon wines.

and sensory analysis. Differences observed in the oak volatile concentrations and intensity of varietal versus oak-derived aromas and flavors of wines reflect differences in oak treatment, including the duration of oak maturation and the use of different oak woods. Quality rating scores ranged from 13.8 to 14.8, indicating wines were considered technically sound, but because wines aged using oak alternatives tend not to be premium quality wines, quality scores were always expected to be modest. Segmentation based on consumers' hedonic ratings demonstrated the variation in wine preferences of different consumers, but importantly, also demonstrated the appeal of wines made using alternative maturation regimens to consumers within different segments. These results justify wine producers' use of alternative oak maturation regimens, in particular for the production of wines targeted at certain price points and/or toward specific segments of the wine market. Furthermore, this study highlights the importance of combining compositional and descriptive sensory analyses with consumer research (e.g., hedonic ratings) to achieve a more substantial overview of the drivers of wine quality and acceptability.

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