

Anthocyanin, phenolic composition, colour measurement and sensory analysis of BC commercial red wines

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Abstract

This research established a database of analytical values associated with 173 commercial red wines from 7 vintages (1995–2001), 4 varieties (Pinot noir, Merlot, Cabernet Franc, Cabernet Sauvignon) and 13 vineyard locations within BC. Wines were analyzed for sulfur dioxide, pH, titratable acidity, phenolics, tartaric esters, flavonols, as well as copigmented, monomeric, polymeric, and total anthocyanins. Colour was evaluated using colour density, hue, and L , a^* , b^* and chroma measurements. The sensory astringent qualities were characterized on a subset of 78 wines, using a panel of 12 judges. The panel evaluated the magnitude of the astringency, astringent after-taste, oakiness and bitterness, as well as 3 astringent sub-qualities (surface roughness, drying, puckering). Data were analyzed by analysis of variance, principle component analyses, and canonical discriminant analyses to track the influence of variety, vintage and vineyard location. Trends were observable despite large variation in winemaking techniques. Red colour, colour density, copigmented, monomeric, polymeric and total anthocyanins were lowest in Pinot noir and highest in Cabernet Sauvignon wines. Younger wines had higher concentrations of copigmented, monomeric, and total anthocyanins than did older wines. Canonical discriminant analysis of the analytical and sensory determinations were successful in distinguishing the wines according to where the grapes were grown. Crown Copyright © 2006 Published by Elsevier Ltd. All rights reserved.

Keywords: Phenols; Anthocyanins; Colour measurement; Sensory analysis; Wine analysis

1. Introduction

Phenol composition is an important aspect in high quality red wines. Phenols are responsible for astringency and bitterness (Fischer & Noble, 1994), and play a role in colour stability (Robinson, Weirs, Bertino, & Mattick, 1966). The phenolic profile of a wine has been shown to be influenced by different viticultural practices (Price, Breen, Valladao, & Watson, 1995; Reynolds, Price, Wardle, & Watson, 1994; Yokotsuka, Nagao, Nakazawa, & Sato, 1999; Zoecklein, Gugelsang, Gump, & Nury, 1995), and different enological techniques (Sims & Bates, 1994; Wightman, Price, Watson, & Wrolstad, 1997; Zoecklein

et al., 1995). The variety (Goldberg, Karumanchiri, Tsang, & Soleas, 1998), vintage (Brossaud, Cheynier, Asselin, & Moutounet, 1999; Yokotsuka et al., 1999), and region where the grapes are grown (Brossaud et al., 1999; Goldberg et al., 1998) all affect the phenolic composition of the wine.

In British Columbia (BC) there has been a concentrated effort since the mid-1980s to produce internationally competitive high quality red wines. The Okanagan Valley appellation of BC contains the highest percentage of *Vitis vinifera* plants and is considered the most ideal location within the province for the production of wine from red varieties. The topography within this valley is complex, resulting in vineyards with different slope aspects, altitudes, soil compositions and textures (Bowen et al., 2005). Climatic conditions vary from the north to the south of the valley while several vineyards are moderated by their proximity to large bodies of water. As a result of this

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geographical variation, as well as variation due to different winemaking styles, wines of a given variety within the Okanagan Valley can exhibit very different sensory characteristics. With this in mind, the objectives of this research were: (1) to contribute to an already existing database of anthocyanin, phenolic and colour measurements on BC commercial red wines, (2) to document the perceived astringency and bitterness from wine from vineyards located throughout the Okanagan Valley and (3) to investigate patterns of wine compositional and sensory analyses for vintages, varieties, and vineyard locations from within the Okanagan Valley, BC.

2. Materials and methods

2.1. Wines and wine sampling procedure

Commercial Cabernet Sauvignon, Cabernet Franc, Merlot, and Pinot noir wines were selected from wineries throughout the Okanagan Valley, BC, Canada. Vintages of these wines ranged from 1995 to 2001. In an attempt to avoid wine oxidation that could affect later sensory results, each bottle of wine was sampled for chemical analysis by partially removing the cork and inserting two gas chromatography needles. Two syringes, one full of nitrogen and the other empty, were attached to these needles, the bottle was inverted putting the needles in contact with the wine, and the nitrogen was subsequently pushed into the bottle causing a 40 ml sample of wine to be forced into the empty syringe.

2.2. Analytical determinations

2.2.1. pH and tartaric acid measurements

The titratable acidity (TA) and pH of each sample were determined through the use of a Metrohm 686 Titroprocessor (Metrohm Ltd., Switzerland) and a symphony SB21 pH meter (Thermo Orion, USA). Titratable acidity determinations, expressed in equivalent of tartaric acid content (g/L), were carried out by diluting a 10 ml aliquot of each wine with 90 ml of distilled water and subsequently titrating the sample with 0.1 N NaOH to a pH endpoint of 8.1.

2.2.2. Analysis of phenolics

In the determination of total phenolic, flavonol, tartaric ester, and anthocyanin content, a sample 0.5 ml in volume was taken from each wine and diluted to a volume of 5 ml with 10% ethanol. A 0.25 ml aliquot of each diluted sample was subsequently added to 0.25 ml of 0.1% HCl in 95% ethanol, and 4.55 ml of 2% HCl. Each sample was vortexed and allowed to stand for 15 min. The absorbance of each sample was measured in a 1 cm quartz cuvette at 280, 320, 360, and 520 nm using a Beckmann DU 640 spectrophotometer (Beckman, USA). Absorbance readings at each wavelength corresponded to total phenolic (A_{280}), tartaric ester (A_{320}), flavonol (A_{360}), and anthocyanin (A_{520}) content, which was determined from standard curves con-

structed using dilutions of gallic acid (in 10% ethanol), quercetin (in 95% ethanol), caffeic acid (in 10% ethanol), and malvidin-3-glucoside (in 10% ethanol) at 280, 320, 360, and 520 nm, respectively.

2.2.3. Tannin determination

The procedure for tannin determination was based on that originally developed by Hagerman and Butler (1978) and revised by Harbertson et al. Microlitres of resuspension buffer (5% triethanolamine, 5% SDS, and pH adjusted to 9.4 with HCl) was added, and the sample was vortexed for 10 min to redissolve the tannin–protein pellet. Each sample was put in a 1.5 ml cuvette, and the background absorbance was measured at 510 nm using a Beckman DU 640 spectrophotometer (Beckman, USA). One hundred and twenty five microlitre of ferric chloride reagent (0.01 N HCl and 10 mM FeCl_3) was added to each sample and allowed to stand for 10 min. After the 10 min incubation period, the absorbance of each sample was again measured at 510 nm. The tannin concentration in each sample was finally determined by subtracting the background and final absorbancies, and comparing the value obtained to a standard curve derived using catechin.

2.2.4. Colour determinations

Two methods were used to determine the colour of each wine sample. In the first, the spectrophotometric absorbance of the wine at 420, 520, and 700 nm was determined using a 1 mm cuvette. Colour density and hue were calculated using the following equations which incorporated corrected values for a 1 cm cuvette;

$$\text{Colour density} = [(A_{520} - A_{700}) + (A_{420} - A_{700})]$$

$$\text{Colour hue/tint} = [(A_{420} - A_{700}) / (A_{520} - A_{700})]$$

The second method for colour determination utilized a CIELAB program for the spectrophotometer that determined L , a^* , b^* coordinate values for each wine sample in a 1 mm cuvette. The values of which correspond to the degree of wine lightness and the degree of red (when $a^* > 0$), green (when $a^* < 0$), yellow (when $b^* > 0$), and blue (when $b^* < 0$) colour (Ayala, Echavarri, & Negueruela, 1997).

2.2.5. Copigmented, monomeric, polymeric, and total anthocyanin determination

The copigmented, monomeric, polymeric and total anthocyanin content of each wine was determined using the colorimetric effects that SO_2 and acetaldehyde have on the forms of anthocyanins. In this procedure, 20 μl of 20% acetaldehyde was added to 2 ml of wine and the sample was allowed to stand for approximately 45 min. To another 2 ml sample of wine, 160 μl of 5% (w/v) SO_2 was added. The absorbance of each sample was measured at 520 nm in a 1 mm cuvette using a Beckman DU 640 spectrophotometer (Beckman, USA). Finally, the absorbance was determined without the addition of acetaldehyde or SO_2 at 520 nm. The following equations were utilized,

using values corrected for a 1 cm cuvette, to determine copigmented, monomeric, polymeric, and total anthocyanin content, respectively;

$$\text{Copigmented anthocyanins} = (A^{\text{ace}} - A^{\text{wine}}),$$

$$\text{Monomeric anthocyanins} = (A^{\text{wine}} - A^{\text{SO}_2}),$$

$$\text{Polymeric anthocyanins} = (A^{\text{SO}_2}),$$

$$\text{Total anthocyanins} = (A^{\text{ace}}).$$

2.3. Sensory analysis

A panel of 12 judges composed of Agriculture and Agri-Food Canada students and employees (7 males and 5 females between the ages of 22 and 55 years) participated in this research. All of the judges were experienced wine tasters and six of them had previously participated in a similar study that characterized astringency by scoring attributes on an unstructured line scale.

Over the course of this study, one training session and 19 evaluation sessions were conducted. During the training session, judges were provided with a draft scorecard that had been adapted from King, Cliff, and Hall (2003) along with references and practice samples. The scorecard used 10 cm unstructured line scales to rate the magnitude of the attributes that have been used to describe the sub-qualities of astringency (Gawel, Oberholster, & Francis, 2000; Lawless & Corrigan, 1993). These included astringency, astringent aftertaste, oak, bitterness, surface smoothness, drying, puckering/drawing and roughing. At the opening of the training, the definition of all the terms related to astringency were reviewed and the tasting protocol for evaluating astringency was outlined. In this training session, 'drying' was defined as the lack of lubrication between the surfaces of the mouth and 'puckering' was the tightening and drawing sensation that can be felt in the cheeks and muscles of the face (Lawless & Corrigan, 1993). Astringency was described as 'roughing' when the entire mouth surfaces were affected with a sensation that was difficult to clear.

During the training session, consensus was used to locate a reference sample along the line scale for each of the attributes. Hereafter, all scorecards were marked with the position of the reference sample and the wines were evaluated in comparison to the reference. The reference sample was a composite made from 22 bottles of commercially made Merlot wines from different producers and vintages. This reference sample was included in all tasting sessions along with the other samples being evaluated. Also during the training, fabric samples were selected to anchor the surface smoothness line scale. Silk, felt and burlap were located along the scale at 1, 5, and 9 cm, respectively. All other scales were anchored at 1 and 9 cm with low and high as well as the reference wine sample.

Wines were evaluated using a completely randomized design. Judges evaluated 4 wines per session for a total of 17 sessions and 5 wines per session for the last two. Each

wine was coded with a three digit random code. In order not to bias the perception of astringency the judges were not told the variety or the vintage of the wine. Each session was conducted in individual booths under red light. Just prior to assessment, a 30 ml wine sample was poured into 210 ml ISO wine glasses. Glasses were coded with three digit random numbers and placed in a random order. In each evaluation session, the reference wine sample and fabric samples were provided to help standardize the use of the scale.

To minimize fatigue and standardize the assessment process, a rigorous tasting and rinsing procedure was established. The judges were asked to: (1) sip and swirl the wine in their mouth for 4–5 s, (2) expectorate and (3) wait 10 s. The judges were then asked to take a second sip, using the same procedure, and fill out the scorecard. The judges were asked to rinse their mouth with water, have a piece of bread or melba toast, rinse again with water, and wait 1 min before going on the next sample. To ensure the timing protocol was rigidly adhered to, a stop-watch was provided.

2.4. Statistical analysis

Data were analyzed using the SAS statistical package (SAS Institute, Cary, NC). Analysis of variance was conducted on the analytical and sensory variables to determine the main effects of variety, vintage and location, as well as all the 2-way interactions: variety * location, vintage * location and variety * vintage. Analyses were performed using the GLM procedure. Duncan's multiple range test was used to separate the means ($p \leq 0.05$) for the chemical and sensory data. Varietal wines which were produced from grapes from multiple regions were dropped from the analyses.

Principal components analysis (PCA) was conducted in order to show groupings of the wines and the interrelationship of the variables. It was performed on the mean sensory scores and analytical values for the 78 tasted wines. Analyses were performed on the correlation matrix, without rotation, using the SAS factor procedure (SAS Institute, Cary, NC).

An initial evaluation of the inter-correlation of the sensory variables showed that several attributes (astringency, astringent aftertaste, surface smoothness, drying, puckering, and roughness) were all highly correlated ($p \leq 0.001$). This suggested that many of the sensory attributes may be redundant or be tracking the same underlying variable. Therefore, a new sensory variable called 'astringence' was created by averaging the scores of all six attributes. Many of the analytical variables measuring anthocyanins (copigmented, monomeric, polymeric and total anthocyanin and anthocyanin) were also highly correlated. Again a new variable was created, called 'anthocyanin' which was an average of the five individual determinations. These new variables were then utilized for the principal component analysis.

Canonical discriminant analyses (CDA) were performed to examine regional differences using: (1) the chemical determinations, (2) the sensory evaluations and (3) both the chemical and sensory analyses. CDA created new variables, called canonical discriminant functions in order to separate the classes (regions). Analyses were performed using the SAS candisc procedure (SAS Institute, Cary, NC). The Mahalanobis distance, a measure of the significance squared distances between classes, was utilized as an index of separation between the regions.

3. Results and discussion

3.1. Analytical determinations

Among the compositional parameters studied, a number of notable varietal differences were observed. In Pinot noir wines, the total anthocyanin composition, as well as copigmented, monomeric, and polymeric anthocyanins were observed to be lower than in wines produced from Merlot, Cabernet Franc, or Cabernet Sauvignon wines (Table 1). The lower anthocyanin content most likely contributed to the lower colour density, degree of redness (a^*), and higher colour hue and L^* (brightness) values associated with Pinot noir wines (Table 1). Across all varieties, total anthocyanins were highly correlated with colour density, degree of redness (a^*), colour hue and L^* (brightness) with correlation coefficients of 0.92, 0.63, -0.74 , -0.83 , respectively. According to Boulton (2001), the lack of colour within Pinot noir wines can be related back to the natural inability of this variety to form copigmented anthocyanins. Not only do copigmented anthocyanins increase individual colour intensity, but they also increase anthocyanin extraction during maceration through increased solubility (Eiro & Heinonen, 2002).

In contrast to Pinot noir, Cabernet Sauvignon wines typically had the highest total anthocyanin content, and highest content in copigmented, monomeric, and polymeric anthocyanins (Table 1). Colour density and a^* values were also typically highest in wines from this variety, while L^* values were typically the lowest (Table 1). Similar reports of increased colour densities with higher amounts of anthocyanin content have also been made by Mayen, Merida, and Madina (1994).

Both tartaric ester and flavonol concentrations differed amongst varieties. The flavonol concentration in Cabernet Sauvignon was substantially higher than the other varieties, while tartaric ester concentrations were highest in Cabernet Sauvignon and Cabernet Franc followed by Merlot and finally Pinot noir. These variations in phenolic composition may simply reflect a natural qualitative difference amongst varieties. However, variation in berry maturation (Ramos et al., 1999), berry size and/or weight at harvest (Kennedy, Matthews, & Waterhouse, 2002), and in climatic conditions encountered by each variety during berry maturation (Bergqvist, Dokoozlian, & Ebisuda, 2001) may also have contributed differences amongst the varieties in phenolic profile. Since different winemaking techniques are used in the production of varietal wines, further differences in the phenolic profile may have resulted from the variation in pressing regime, the extent and temperature of maceration (Merida, Moyano, Millan, & Medina, 1991), the temperature of fermentation (Zoecklein et al., 1995), and the use of enzymes (Revilla & Gonzalez-SanJose, 2003; Wightman et al., 1997). The type of oak used during aging and the extent to which it was carried out will also affect qualitative and quantitative phenolic composition (Aiken & Noble, 1984). In the present study the diversity of enological factors were spread across all varieties; therefore, it is likely that varietal variation

Table 1
Composition and colour of Cabernet Sauvignon, Cabernet Franc, Merlot, and Pinot noir wines from British Columbia, Canada

	Cabernet Sauvignon (<i>n</i> = 22)	Cabernet Franc (<i>n</i> = 29)	Merlot (<i>n</i> = 63)	Pinot noir (<i>n</i> = 59)	Level of significance
pH	3.72a	3.71a	3.66b	3.68ab	*
Titratable acidity (g tartaric acid/L)	6.24a	5.80b	5.81b	5.88b	**
Total phenolics (mg gallic acid/L)	1055	932	1025	1063	ns
Tartaric esters (mg caffeic acid/L)	162.0a	147.1ab	140.4bc	128.3c	**
Flavonols (mg quercetin/L)	64.4a	40.3b	49.7b	39.2b	***
Anthocyanins (mg malvidin-3-glucoside/L)	124.9a	94.1b	109.7ab	61.0c	***
Tannins (mg catechin/L)	414.2	266.2	382	331.1	ns
Copigmented anthocyanins	0.57a	0.47a	0.47a	0.28b	***
Monomeric anthocyanins	1.68a	1.09b	1.26b	0.72c	***
Polymeric anthocyanins	2.50a	1.94b	2.28a	1.42c	***
Total anthocyanins	4.76a	3.50c	4.01b	2.42c	***
<i>L</i>	76.63c	81.10b	79.91b	87.10a	***
a^*	20.92a	16.08b	18.62ab	12.18c	***
b^*	7.83a	6.01b	8.18a	6.47b	***
Colour density	3.76a	2.68c	3.20b	2.21d	***
Colour hue	0.85b	0.86b	0.88b	1.02a	***

ns, *, **, and *** indicate non-significance and significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, respectively. Values with different letters denote significant ($p \leq 0.05$) differences among varieties.

may be, at least in part, due to the inherent differences as well as climatic factors found during berry maturation.

When the vintages were averaged across all varieties, there were significant vintage differences ($p \leq 0.001$) in copigmented, monomeric, and total anthocyanin content (Table 2). Younger wines had higher concentrations of copigmented, monomeric, and total anthocyanins than did those from older vintages (Table 2). Vintage differences were thought to be due to both variation in climatic conditions (Kliewer, 1977) as well as the increased oxidation, polymerization, and precipitation of anthocyanins that take place during aging (Zoecklein et al., 1995).

Colour hue and a^* values tended to exhibit the lowest and highest values, respectively, within vintages that also exhibited high amounts of copigmented, monomeric, and total anthocyanins. This is in agreement with Boulton (2001) who suggested that up to 30–50% of the red colour of young red wines is dependent on the development and concentration of copigmented anthocyanins. Lowest colour hue and highest a^* values tended to be associated with the vintages with high levels of copigmented, monomeric and total anthocyanins.

Although both total phenol and tannin concentrations differed among vintages, no clear trend was evident. Total phenol concentration was highest in 2001 and lowest in 1999 and 1997. Wines from the 1996 and 2001 vintage contained the greatest concentration of tannins, while those from the 1995 vintage contained the least. The lack of a clear relationship between vintages is most likely the product of the complex nature of phenol composition and how it is affected by varying climatic conditions between seasons, as well as variation amongst the wines in terms of degree of aging.

Figs. 2–4 show the effect of variety, vintage and vineyard location on the sensory attributes used to describe the astringent character of the wines. The Cabernet Sauvignon

wines were the most astringent followed by the Merlot wines. Unlike other areas of the world where Cabernet Franc wines have a reputation for being astringent, these Okanagan Cabernet Franc wines were found to have a lower astringency that was not significantly different from that of the Pinot noir wines. The 2001 vintage had the highest ratings for all the astringency descriptors. As might be expected, the older vintages generally had lower astringency ratings. The exception was 1996 which had the second highest rating for astringency and puckering. Chemical analysis (Table 2) also showed that this vintage was the highest in total phenolics and tannins. Anecdotally, grape growers and winemakers have indicated that of all the vintages in this study (1996) had the poorest weather, with the least ripe grapes and the highest acidity. The southern part of the Okanagan valley produced wine with the highest astringency. This may be in part due to the varieties that are produced in this area. As well, this area accumulates a higher number of growing degree days (Bowen et al., 2005) producing mature grapes that allow a greater extraction of tannin from the skin.

3.2. Principle components analysis

Principle component analysis of the sensory and analytical variables explained 80.1% of the variation in the data in the first two dimensions, with 57.2% and 22.9% explained by factor I and factor II, respectively (Fig. 1). Most of the separation occurred among factor I which was positively loaded with the majority of the sensory and analytical variables and negatively loaded with L^* and colour hue. The positive factor I variables were ‘split’ into those which loaded positively on factor II in the upper right quadrant (astringence, total phenol, tartaric esters, tannin), and those loaded negatively on factor II in the lower right quadrant (anthocyanins, colour density, pH

Table 2
Composition and colour of BC commercial red wines produced from 1995 through 2001

	1995 (n = 4)	1996 (n = 6)	1997 (n = 19)	1998 (n = 51)	1999 (n = 32)	2000 (n = 40)	2001 (n = 21)	Level of significance
pH	3.58b	3.66a	3.64a	3.68a	3.66a	3.71a	3.72a	*
Titrateable acidity (g tartaric acid/L)	5.93	5.85	5.9	5.78	5.88	6.06	5.86	ns
Total phenolics (mg gallic acid/L)	932bcd	1128ab	903cd	1030abcd	888d	1096abc	1194a	***
Tartaric esters (mg caffeic acid/L)	140.6	133.9	133.7	146.1	130.6	140.6	146.8	ns
Flavonols (mg quercetin/L)	76.9a	63.9ab	47.3bc	44.1bc	35.6bc	50.0bc	50.5bc	*
Anthocyanins (mg malvidin-3-glucoside/L)	64.4b	66.2b	76.7b	75.6b	74.7b	107.3b	158.6a	***
Tannins (mg catechin/L)	135.4c	405.0ab	302.2abc	363.7ab	199.4bc	412.5a	490.1a	***
Copigmented anthocyanins	0.09d	0.10d	0.13d	0.23cd	0.37c	0.59b	1.05a	***
Monomeric anthocyanins	0.83c	0.60c	0.98bc	1.00bc	0.93bc	1.25b	1.66a	***
Polymeric anthocyanins	2.1	1.7	1.96	1.95	1.75	2.26	1.77	ns
Total anthocyanins	3.03b	2.39b	3.07b	3.17b	3.04b	4.10a	4.47a	***
L	83.5	86.4	82.8	82.9	83	80.2	80.7	ns
a^*	13.7ab	11.0b	15.1ab	15.0ab	14.1ab	20.5a	17.7ab	**
b^*	7.7ab	8.5a	7.2ab	7.5ab	6.4b	7.6ab	6.6b	**
Colour density	2.82ab	2.47b	2.81ab	2.80ab	2.56b	3.24a	3.08ab	**
Colour hue	0.93b	1.07a	0.92b	0.95b	0.92b	0.88b	0.88b	***

ns, *, **, and *** indicate non-significance and significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, respectively. Values with different letters denote significant ($p \leq 0.05$) differences among vintages.

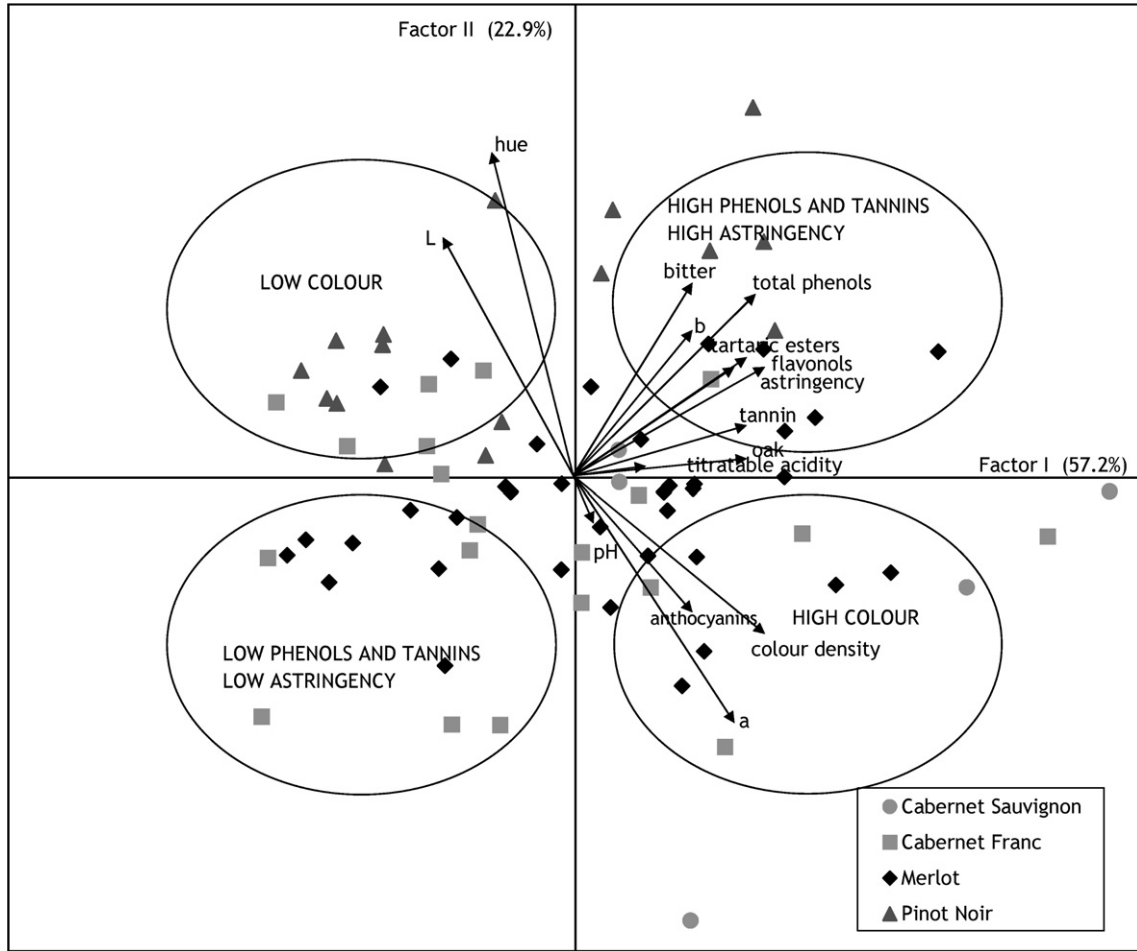


Fig. 1. Principal component analysis of the sensory and analytical determinations for 78 commercial BC red wines.

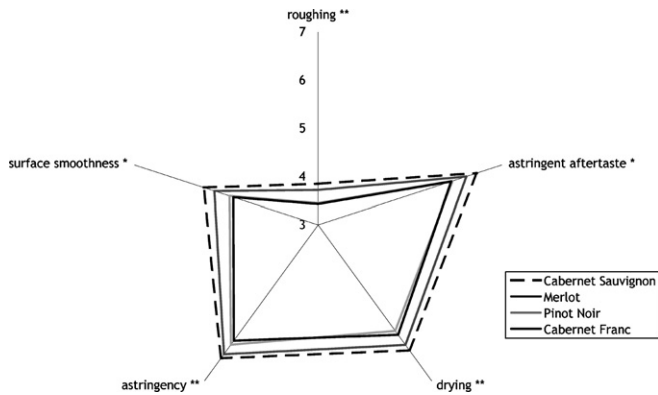


Fig. 2. Cobweb diagram showing the varietal effect on astringent character in 78 commercial BC red wines. Attributes identified with *, **, and *** are statistically significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively.

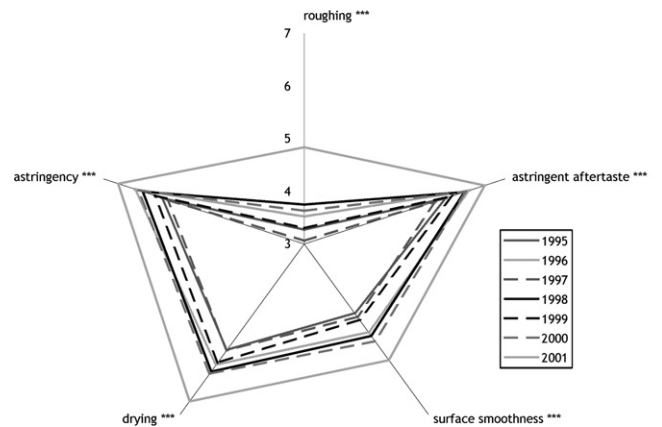


Fig. 3. Cobweb diagram showing the vintage effect on astringent character in 78 commercial BC red wines. Attributes identified with *, **, and *** are statistically significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively.

and a^*). The PCA plot showed both flavonol and tartaric ester concentrations were highly correlated with the combined sensory attribute astringence and therefore may be useful as predictors of the perceived mouthfeel qualities.

The vectors which represented colour (L , hue) were located at approximately 90° to the vectors for mouth-

feel/astringency. The perpendicular orientations reflected that these two ‘groups’ of variables are unrelated to one another. In contrast, the bitterness of the wines is more related to the mouthfeel characteristics than the colour indices. This is consistent with the fact that bitterness is

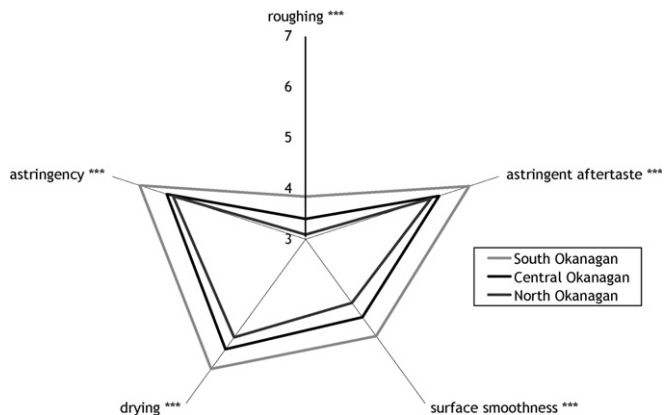


Fig. 4. Cobweb diagram showing the location effect on astringent character in 78 commercial BC red wines. Attributes identified with *, **, and *** are statistically significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively.

associated with compounds which are extracted concomitantly with the phenolics during skin contact or maceration of the skin during fermentation. Those wines with high colour determinations had low L and hue values, as reflected by the 180° angle between these vectors. This is consistent with the fact that deeply coloured red wines transmit less light and have lower L values, whereas lightly coloured wines transmit more light and have higher L values. L and hue are highly correlated as indicated by the small angle between these vectors. Wines were scattered throughout the plot in each of the four quadrants as follows: quadrant I contained wines high in phenol, tannin and astringency; quadrant II contained wines low in colour; quadrant III contained wines low in phenol, tannin and astringency and quadrant IV contained wines high in colour. The sensory attribute astringency was located in quadrant I and was highly correlated with tannin ($r = 0.69$, $n = 78$) and total phenol ($r = 0.67$, $n = 78$) concentrations.

For the most part, Pinot noir wines were located into distinct groups: one to the far left of the plot representing wines which are low in colour and mouthfeel qualities and the other high in the plan representing wines which are intermediate in colour and mouthfeel qualities, but which also have more bitterness than the other wines. Cabernet Sauvignon wines all loaded positively along factor I and for the most part negatively along factor II. The two Cabernet Sauvignon wines in the center of the plot cannot easily be differentiated from the other wines; however, the three wines located in the lower right were both astringent and highly pigmented. Although the Merlot wines were found in all quadrants, they tended to be located closer to the center of the plot. This would indicate that they encompassed a wide range of characteristics without exhibiting high levels of any one attribute. Cabernet Franc wines were located throughout the plot representing wines with a broad range of sensory and colour characteristics. A high level of the colour components and lower astringency located a few of the Cabernet Franc wines in the lower left

of the plot. There were also several wines located in the upper left quadrant indicating both low astringency and low colour similar to the Pinot noir wines located in the same area. The dispersion of the Cabernet Franc wines throughout the plot indicates the diversity of styles that are produced in the Okanagan.

3.3. Canonical discriminant analysis

Canonical discriminant analysis (CDA) measures how well the objects (wine) fit preassigned groups or classes. Bowen et al. (2005) have classified the Okanagan valley into five distinct growing regions based on soil types and climate. The North Okanagan was classified as region 1, the Central Okanagan as region 2 and the South Okanagan as regions 3–5. Regions 3–5 are located close to each other geographically and have similar weather but vary mainly in soil types. In this study, these regions 3–5 were combined.

CDA of the analytical variables, as well as a CDA of the sensory variables, showed only a partial separation among the regions. However, when the analytical and sensory variables were combined for a single analysis (Fig. 5), CDA was very successful in classifying the wines according to vineyard location. The majority of the separation (74.7%) was along discriminant function I and could be attributed to differences in astringency, anthocyanins, colour density, a^* (redness) and tannin, in the positive direction; or differences in L (lightness) and hue, in the negative direction. In contrast, 25.3% of the separation was explained by discriminant function II and was attributed to differences in oak and titratable acidity. The Mahalanobis distances between all regions were all highly significant ($p \leq 0.0001$), indicating a distinct separation among the grape growing regions. Class centroids for the regions were identified with symbols of the same shape as the wine locations, but slightly larger in size (Fig. 5). The centroid for the North Okanagan region was located nega-

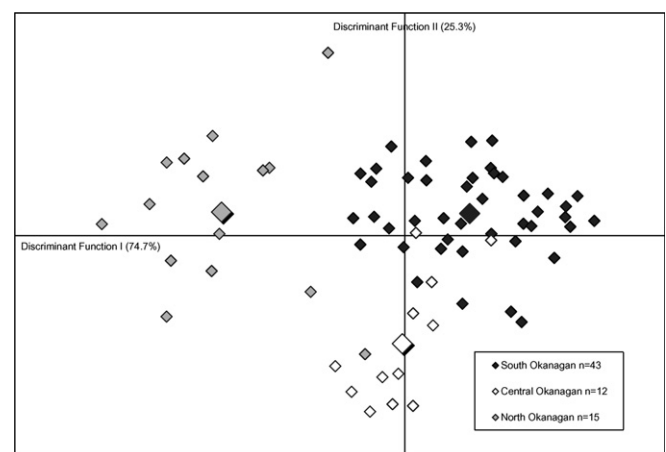


Fig. 5. Canonical discriminant analysis of the sensory and analytical determination for 78 commercial BC red wines, with region as the classification variable. Class centroids are identified with the same symbol, as the wine locations, but of a slightly larger size.

tively along discriminant function I and positively along discriminant function II. In contrast, the centroid for the Central Okanagan was located positively along discriminant function I and negatively along discriminant function II. The centroid for the South Okanagan was located positively on both discriminant functions I and II. Most of the wines from the combined regions 3–5 were located in this area region indicating that they had a higher astringency and darker colour. The separation of the North and South Okanagan wines, along discriminant function I, can be attributed to differences in astringency, anthocyanin, colour density, a^* (redness) and tannin; while the separation of the Central and South Okanagan wines, along discriminant function II, is attributed to differences in oak and titratable acidity.

4. Conclusion

Analysis of the phenolic and colour components of wine combined with the sensory evaluation of the astringent characteristics showed variety, vintage and location differences. Phenolic differences in variety and vintage are to be expected. However, such a distinct separation according to where the grapes were grown lends a strong support for differences in terroir that result in distinctively different wines. These differences were found across all varieties and vintages. Differences in the varieties grown in the three locations as well as winery influences may have contributed to the location differences in the wines. Further work controlling for these factors would provide more support for a distinct regional difference within the Okanagan appellation of British Columbia.

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