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Characterization of taste-active compounds of various cherry wines and their correlation with sensory attributes

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ABSTRACT

Five cherry wines exhibiting marked differences in taste and mouthfeel were selected for the study. The taste and mouthfeel of cherry wines were described by four sensory terms as sour, sweet, bitter and astringent. Eight organic acids, seventeen amino acids, three sugars and tannic acid were determined by high performance liquid chromatography (HPLC). Five phenolic acids were determined by ultra performance liquid chromatography coupled with mass spectrometry (UPLC–MS). The relationship between these taste-active compounds, wine samples and sensory attributes was modeled by partial least squares regression (PLSR). The regression analysis indicated tartaric acid, methionine, proline, sucrose, glucose, fructose, asparagines, serine, glycine, threonine, phenylalanine, leucine, gallic acid, chlorogenic acid, vanillic acid, arginine and tannic acid made a great contribution to the characteristic taste or mouthfeel of cherry wines.

1. Introduction

Taste and mouthfeel are the major determinants of consumer preference and acceptance for wines. The perception of taste and mouthfeel are produced by two sets of chemoreceptors in the mouth. Specialized receptors neurons, grouped in cavities within taste buds, generate taste perceptions, especially sour, sweet, salt and bitter. Free nerve endings scattered throughout the oral cavity generate the mouthfeel perception such as astringency [1]. Astringency is not a taste, but a tactile sensation [2] and is the feeling of dryness or roughness that results from increased friction between the tongue and the surfaces inside the mouth [3]. It is widely acknowledged that high quality wines have a balanced level of taste and mouthfeel.

Most traditional studies on sensory analysis of wines have focused on the contribution of aroma [4–7], by direct nasal or retronasal perception, to flavor profiling. Gradually, some researchers began to realize the importance of taste and mouthfeel attributes in the overall wine quality and some works aiming at characterizing wine taste-active compounds have been developed. Through HPLC, Kelebek et al. [8] identified organic acids, sugars and phenolic compositions in orange wine made from a Turkish cv. Kozan; Barrado et al. [9] characterized primary amino acids in Spanish red and white wines; Jiří Gruz et al. [10] analyzed phenolic acids in white wines by ultra performance liquid chromatography coupled with tandem mass spectrometry; Cosme et al. [11] characterized the tannin profiles of red wines using reversed-phase HPLC analysis. The combination profile of these taste-active compounds forms the characteristic of wine and distinguishes one from others. However, no studies have been done so far on taste-active compounds of cherry wines.

In the latest years, different statistical and chemometric tools have been employed to explore the relationships between sensory profiles and flavor compounds of wines. For example, PCA in conjunction with discriminant analysis was applied to anthocyanins, flavonoids determined in Spanish red wines, and aided distinction of origin [12]. Nonetheless, PCA does not take account into the initial grouping of the variables [13]. Therefore, multiway techniques have been developed in order to cope with these difficulties. Generalized procrustes analysis was used to correlate sensory attributes to gas chromatography-olfactometry data for French Chardonnay Wines [14]. Besides, partial least squares regression (PLSR) analysis has been used to correlate sensory properties to volatile compositions in Spanish Albariño wines [15]. Few studies have been done to gather taste-active compounds information such as organic acids, amino acids, phenolic acids, sugars and tannic acid at the same time and correlated to sensory data. There is still a lack of systematic

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study on the relationship between cherry wine samples, sensory attributes and taste-active compounds.

The main objective of this work was to (a) evaluate sensory attributes of cherry wines; (b) study taste-active compounds including organic acids, amino acids, phenolic acids, tannic acid and sugars; (c) distinguish which taste-active compounds have essential effect on sensory attributes of cherry wine through PLSR analysis. Further apprehension of this knowledge will be very meaningful to perfect characteristic taste or mouthfeel of cherry wine by modifying fermentation parameters or making up for taste-active compounds after alcoholic fermentation.

2. Materials and methods

2.1. Materials

Five cherry wines were obtained as follows, W1 (Yantai Hualong wine co., Ltd. pH 3.37, total acidity 5.52, ethyl alcohol 12%); W2 (Shan Dong Linqu sanxin food co., Ltd. pH 3.49, total acidity 5.67, ethyl alcohol 8%); W3 (Shan Dong Zunhuang cherry wine co., Ltd. pH 3.73, total acidity 7.59, ethyl alcohol 12%); W4 (Laizhou Yinghong wine co., Ltd. pH 3.37, total acidity 5.52, ethyl alcohol 12%); W5 (Si Chuan Hanyuan fruit wine company. pH 3.68, total acidity 7.90, ethyl alcohol 11%). The cherry wines were stored in fridge at −2 °C. Storage time was one week. Five bottles of different cherry wines were used for analysis.

Methanol and formic acid of chromatography grade were purchased from Sinopharm Chemical Reagent Co. Ltd. Gallic acid (≥99%), p-hydroxybenzoic acid (≥99%), chlorogenic acid (≥95%), vanillic acid (≥97.0%), caffeic acid (≥99.0%), asparagines (99%), glutamic acid (≥99.5%), serine (≥99.5%), histidine (≥99%), glycine (≥99%), threonine (≥99.5%), arginine (≥99.0%), alanine (≥99.5%), tyrosine (≥99%), cysteine (≥99%), valine (≥99.5%), methionine (≥99.5%), phenylalanine (≥99%), isoleucine (99%), leucine (≥99.5%), lysine (≥98%), praline (≥99.5%),oxalic acid (99.999%), tartaric acid (≥99.9995%), malic acid (≥99.5%), lactic acid (≥98%), acetic acid (≥99.7%), citric acid (≥99.5%), succinic acid (≥99.5%), tannic acid (≥99.5%),sucrose (≥99.5%), glucose (≥99.5%), fructose (≥99%)were chromatography grade and obtained from Sigma–Aldrich Chemical Co. (St. Louis, MO). Pure water was obtained from a Milli-Q purification system (Millipore, Bedford, MA). Other reagents were all purchased from Shanghai Chemical Plant (Shanghai, China).

2.2. Sensory evaluation

Quantitative descriptive sensory analysis was applied for evaluation of the wine samples, using a ten-point interval scale (0 = none, 9 = extremely strong). The sensory evaluation was done by a well-trained panel made of 4 females and 4 males, 23–30 years old. The panel has previously been trained according to ISO 4121, ASTM-MNL 13 and DIN 10964 [16]. Sensory sessions took place in a sensory laboratory, which complied with international standards for test room [17]. Three specific training sessions were carried out. In the first session, panelists generated descriptive terms for the cherry wines; in the second session, different reference standards were presented and discussed by panelists. From these discussions, the four sensory terms (sour, sweet, bitter and astringent) as shown in Fig. 1 were selected for further descriptive analysis. In the third sessions, the cherry wines were evaluated in duplicate using the ten-point interval scale mentioned above. Then, the reference materials of taste and mouthfeel were as follows: sour (4 g L^{-1} tartaric acid), sweet (30 g L^{-1} sucrose), bitter (0.15 g L^{-1} quinine sulphate), astringent (1.0 g L^{-1} aluminium sulphate). Sensory evaluation was performed in coded, tulip glass containing 20 mL of cherry wines. Samples were presented in a random order.

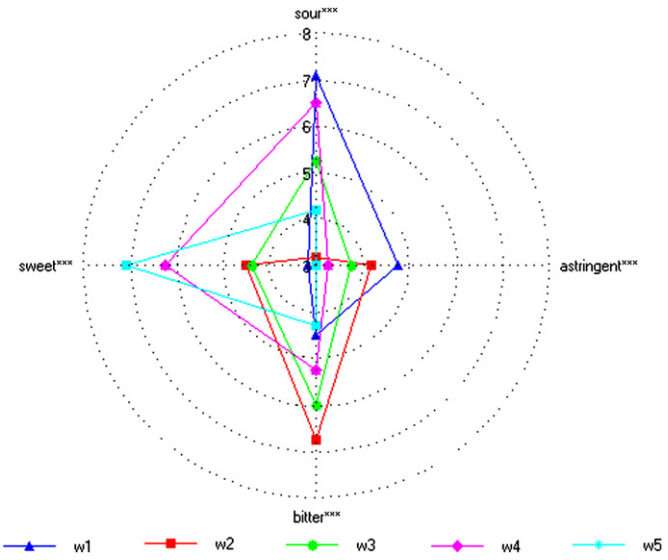

Fig. 1. Graph of the mean sensory score of the five cherry wines studied. Notations *** indicate significance at $p < 0.001$.

Between samples, the panellists were asked to rinse their mouth with distilled water, to eat some plain crackers for 30 s and finally to rinse again with distilled water for another 45 s in order to minimize fatigue and standardize the assessment process.

2.3. Analysis of taste-active compounds

2.3.1. HPLC analysis of organic acids

A HPLC system (Agilent 1100, Agilent Company, Palo Alto, CA, America) equipped with a UV/Vis detector (SPD-20A) monitored at 210 nm was used for the analysis of organic acids. The column was Waters Atlantis C18, (Waters, Britain), 250 mm × 4.5 mm, 5 μm. The column temperature was 30 °C. The mobile phase was a mixture of 0.05 mol L^{-1} H_3PO_4 and methanol (95:5, v/v) at the flow rate of 0.8 mL min^{-1}. Before injection, samples were filtered through 0.45 μm pore size membrane filter. A volume of 10 μL was injected into the instrument for analysis. Percentage recovery values of the standards ranged from 93.2% to 100.5%. The R^2 values of the standards ranged from 0.9998 to 0.9999.

2.3.2. HPLC analysis of amino acids

The amino acids in the sample were analyzed using an Agilent liquid chromatograph 1100 with a UV detector operated at 338 nm. The column was ODS Hypersil (250 mm × 4.6 mm, 5 μm), whilst the mobile phase, consisting of 20 mM sodium acetate and 1:2 (v/v) methanol–acetonitrile, was delivered at a flow rate of 1 mL min^{-1}. The column temperature was 40 °C. Pre-column derivation with o-phthalaldehyde (OPA) was used. Samples were filtered through 0.45 μm pore size membrane filter before injection. A volume of 10 μL was injected into the instrument for analysis. Percentage recovery values of the standards ranged from 92.2% to 101.1%. The R^2 values of the standards ranged from 0.9972 to 0.9999.

2.3.3. UPLC-MS analysis of phenolic acids

Chromatographic analysis for phenolic acids of the cherry wine was performed on a UPLC system Acquity (Waters, Massachusetts, USA) consisting of a binary solvent manager and a sample manager. A bridged ethylene hybrid (BEH) C_{18} analytical column (100 mm × 2.1 mm, 1.7 μm, Waters, MA, USA) was used at 25 °C. The mobile phase consisted of solvent A (water with 5% formic acid, v/v) and solvent B (methanol with 5% formic acid, v/v) and the flow rate was 0.25 mL min^{-1}. The gradient program was as

follows: 0–20 min: 5–15% B; 20–25 min: 15–10% B; 25–30 min: 10–5% B. At the end of this sequence the column was equilibrated under initial conditions for 5 min.

The mass spectrum analysis was carried out with an LC-diode array detector (DAD) interfaced with an ESI Trap MS under negative mode. The effluent was introduced into an electrospray source (source block temperature 100 °C, desolvation temperature 350 °C, capillary voltage 3.2 kV, cone voltage 40 V). Argon was used as collision gas (collision energy 2 eV) and nitrogen as desolvation gas (540 L h^{-1}).

Cherry wine (50 mL) was extracted twice with 40 mL of ethyl acetate for 20 min in a separating funnel. The organic layer was separated from the aqueous fraction and evaporated to dryness by rotary evaporation. The dried extract was dissolved in 10 mL of methanol. A volume of 10 μL was injected into the instrument for analysis. Percentage recovery values of the standards ranged from 95.2% to 102.3%. The R^2 values of the standards ranged from 0.9962 to 0.9999.

2.3.4. HPLC analysis of tannic acid

A HPLC system (Agilent 1100, America) equipped with a Diode Array Detector (DAD) monitored at 275 nm was used for the analysis of tannic acid. The column was Akasil-C18 (Agela Technology Inc, America) 250 mm × 4.6 mm, 5 μm. The column temperature was 25 °C. The mobile phase was a mixture of methanol and pure water (1:1, v/v) at the flow rate of 0.5 mL min^{-1}. Samples were filtered through 0.45 μm pore size membrane filter before injection. A volume of 10 μL was injected into the instrument for analysis. Percentage recovery value of the standard was 98.8%. The R^2 value of the standard was 0.9999.

2.3.5. HPLC analysis of sugars

Analysis of sugars was performed using a HPLC system (Agilent 1100, Agilent Company, Palo Alto, CA, America) with a refractive index detector (RID-10A). The column was Waters Sugarpak1 (300 mm × 6.5 mm, 5 μm) operated at 85 °C. The analytical conditions used were as follows: flow rate 0.4 mL min^{-1}, eluent pure water. Samples were filtered through 0.45 μm pore size membrane filter before injection. A volume of 10 μL was injected into the instrument for analysis. Percentage recovery values of the standards ranged from 93.6% to 99.7%. The R^2 values of the standards ranged from 0.9998 to 0.9999.

2.4. Statistical analysis

Sensory data from the descriptive analysis was evaluated by analysis of variance (ANOVA) using SPSS v13.0 (SPSS Inc., Chicago, IL, USA). ANOVA with Duncan's multiple comparison tests were performed to determine the difference among individual sample for each sensory attribute.

PLSR analysis was used to explore the relationship between wine samples, sensory data and taste-active compounds of 5 cherry wines through UNSCRAMBLER ver. 9.7 (CAMO ASA, Oslo, Norway). All variables were centered and standardized (1/Sdev) so that each variable has a unit variance and zero mean before applying PLSR analyses. By applying PLSR analysis to standardized data, importance of peaks for each attribute could be compared quantitatively based on regression coefficients and loading weights for each predictor or *X* variable used in PLSR models.

3. Results and discussion

3.1. Sensory analysis

The characteristics of five different cherry wines in respect of taste and mouthfeel were described by eight different sensory panelists. The results of sensory analysis were shown in Fig. 1 and Table 1. As shown in Fig. 1, cherry wines sensory attributes were described as sour, sweet, bitter and astringent.

Table 1
The mean score of the four attributes for the five cherry wines in descriptive sensory evaluation.*

Sample	Mean score			
	Sour	Sweet	Bitter	Astringent
W1	7.0625^{d}	3.1875^{a}	4.5^{a}	4.75^{d}
W2	3.1875^{a}	4.5^{b}	6.75^{d}	$4.1875^{c,d}$
W3	5.25^{c}	4.375^{b}	6^{c}	$3.75^{b,c}$
W4	6.5^{d}	6.25^{c}	5.25^{b}	$3.25^{a,b}$
W5	4.1875^{b}	7.0625^{d}	4.3125^{a}	3^{a}

* Mean score for each attribute within a column with different letters are significantly different ($p < 0.001$) using Duncan's multiple comparison test ($n = 16$: 8 panelists with 2 replications).

ANOVA analysis indicated that sour, sweet, bitter and astringent score of different samples are significantly different ($p < 0.001$) (Fig. 1). Duncan's multiple comparison test results (Table 1) revealed that sour, sweet and bitter taste had most significant difference, followed by astringent attribute. Therefore, the four attributes, i.e. sour, sweet, bitter and astringent, seemed to well explain the characteristics of different samples about taste and mouthfeel. As shown in Fig. 1 and Table 1, W1 had the highest sour and astringent score, but had lowest score in sweet taste. W2 presented the strongest bitter taste and the least sour taste. W5 showed the highest score in sweet taste and the least score in astringent mouthfeel. In contrast, W3 and W4 showed the intermediate intensities in sensory attributes.

3.2. Determination of taste-active compounds of five cherry wines

3.2.1. Organic acid composition

The organic acids in wine have a substantial effect on the balance of the flavor, but also influence the chemical stability and pH, and thus the wine quality [18]. They also have great importance in the detection of wine alterations and/or illnesses, because they suppose a modification of acids content, such as lactic sharpness [19]. These acids derive from fruits or specific metabolic events, such as the alcoholic fermentation, malolactic fermentation and ethanol oxidation [20].

Their concentrations in wines vary with the variety, environmental conditions and metabolic events occurring during winemaking and storage. A total of seven organic acids (Table 2) were identified in cherry wines: oxalic acid, tartaric acid, malic acid, lactic acid, acetic acid, citric acid and succinic acid. Four of them were detected in every cherry wine: oxalic acid, tartaric acid, lactic acid and succinic acid. Malic acid, which is transformed to lactic acid during malolactic fermentation, was found in all samples except W3. The degree of its degradation could always reflect the overall success of consecutive alcoholic and malolactic fermentations [21].

However, acetic acid and citric acid were detected in W1, W2 and W3. Citric acid as acidulant has the advantage of not forming insoluble precipitates with calcium and potassium in alcoholic solution, compared to tartaric acid [22]. According to Peres et al. [23], citric acid could have been added to adjust the acidity.

The most abundant organic acid was lactic acid, followed by succinic acid and tartaric acid. Similarly, lactic acid has also been identified as the predominant organic acid in red wines [24,25]. The lowest amounts correspond to oxalic acid. The organic acids content differed in individual cherry wine: oxalic acid 0.1144–0.5118 g L^{-1}, tartaric acid 0.2454–2.4150 g L^{-1}, malic acid 0.2042–2.4670 g L^{-1}, lactic acid 2.513–10.88 g L^{-1}, acetic acid 1.828–2.126 g L^{-1}, citric acid 0.4072–1.545 g L^{-1} and succinic acid 1.163–3.27 g L^{-1}.

Table 2
Mean concentrations ($g\,L^{-1}$) of organic acids of five cherry wines.

N0.	Compounds	W1	W2	W3	W4	W5
1	Oxalic acid	0.1216 ± 0.01[a]	0.5118 ± 0.12	0.1200 ± 0.02	0.1658 ± 0.02	0.1144 ± 0.02
2	Tartaric acid	2.4150 ± 0.23	0.2454 ± 0.04	0.6952 ± 0.09	0.7810 ± 0.04	1.8840 ± 0.11
3	Malic acid	0.6478 ± 0.02	0.2042 ± 0.02	ND	2.4670 ± 0.18	0.7081 ± 0.07
4	Lactic acid	3.5290 ± 0.18	5.2830 ± 0.16	7.0110 ± 0.11	10.8800 ± 0.24	2.5130 ± 0.08
5	Acetic acid	2.1260 ± 0.10	1.8280 ± 0.07	1.8540 ± 0.08	ND	ND
6	Citric acid	0.4072 ± 0.07	0.1926 ± 0.01	1.5450 ± 0.04	ND	ND
7	Succinic acid	1.4630 ± 0.05	1.1630 ± 0.11	1.6720 ± 0.04	3.2700 ± 0.10	1.7110 ± 0.07

ND: not found.
[a] Mean standard deviation (average of triplicate).

3.2.2. Amino acids composition

It was reported that amino acids represent 30–40% of total wine nitrogen. Some amino acids would yield higher alcohols, aldehydes, esters and ketonic acids after a series of biotransformations [26]. Being precursors of such compounds, they play an important role in the organoleptic properties of wine [27].

Seventeen amino acids (Table 3), including asparagines, glutamic acid, serine, histidine, glycine, threonine, arginine, alanine, tyrosine, cysteine, valine, methionine, phenylalanine, isoleucine, leucine, lysine and praline were characterized in cherry wines. Fourteen of them were found in every cherry wine. However, histidine was detected in all samples except W4. Tyrosine and methionine were not found in W5. Quantitatively, the amino acids profiles were respectively dominated by asparagine (0.0393–1.0412 $g\,L^{-1}$), proline (0.0207–1.2491 $g\,L^{-1}$) and alanine (0.0405–0.3046 $g\,L^{-1}$). Among them, asparagine and proline represented 64.46% of total amino acid content. According to Soufleros et al. [28], alanine was also major amino acid in Greek white wines. The lowest amounts correspond to cysteine (0.0005–0.0013 $g\,L^{-1}$) and methionine (0.0007–0.0048 $g\,L^{-1}$). These two amino acids only accounted for 0.24% of total amino acid content.

The total amino acid content of W1 (1.5138 $g\,L^{-1}$), W2 (1.6105 $g\,L^{-1}$) and W3 (1.578 $g\,L^{-1}$) were similar in five cherry wines. Likewise, the total amino acid content of W4 (0.6759 $g\,L^{-1}$)) was very close to W5 (0.6687 $g\,L^{-1}$). But the concentration of individual amino acid in cherry wines differed greatly from each other. Taking proline for example, its content in W1 (1.2491 $g\,L^{-1}$) was sixty times than W4 (0.0207 $g\,L^{-1}$). Such differences may originate from the type of fermentation, grape variety, geographical origin, climatic conditions and different viticultural and enological practices adopted in wine making. Thus, the differences of amino acid profiles may be used to differentiate various wines. The investigation of amino acid composition may also be considered as a strategy to ensure the authenticity of wine. Some researchers have successfully employed the amino acid composition to differentiate wines. For example, Soufleros et al. [29] have managed to classify French wines from various regions according to their origin, type and ageing by analysis of 21 amino acids, biogenic amines and volatile substances. Barrado et al. [9] classified various Spanish wines by determination of eighty amino acids. Furthermore, amino acid composition has also been used to classify the musts and wines of the same variety according to vintage year [30]. These results mentioned above revealed that the analysis of amino acid profiles was very meaningful for us to understand the difference of various wines.

3.2.3. Phenolic acids, tannic acid and sugars composition

Phenolic compounds play an essential role in organoleptic characteristics, such as color, astringency and bitterness of wines [31], so its composition is an important aspect of high quality fruit wines.

Phenolic acids, as important composition in phenolics, are widespread plant secondary metabolites, virtually derived from benzoic acid and cinnamic acids [32]. They have been shown to have beneficial effects on human health [33]. Five phenolic acids (Table 4) were observed, including gallic acid (0.0066–0.0836 $g\,L^{-1}$), 4-hydroxy benzoic acid (0.0003–0.0509 $g\,L^{-1}$), chlorogenic acid (0.0011–0.0213 $g\,L^{-1}$), vanillic acid (0.0044–0.0408 $g\,L^{-1}$) and caffeic acid (0.0003–0.1359 $g\,L^{-1}$).

Among them, caffeic acid was the most abundant phenolic acid and accounted for 48.31% of the phenolic acids on average. Furthermore, it was found in every cherry wine and reached the highest level of 0.1359 $g\,L^{-1}$ in W3. Similarly, according to Zheng Li et al. [34], the content of cafferic acid was the highest in various hydroxycinnamic acids of Carbernet Sauvignon wines. In contrast, chlorogenic acid was the lowest abundant phenolic acid in cherry wines and only accounted for 5.67% of the phenolic acids on average. And it was detected in W2, W3 and W4.

Tannic acid, which is a kind of phenolic compounds, is related to astringent mouthfeel in wine. It has been selected as standard solution for tannins quantification in wines by the official AOAC method [35]. The concentration of tannic acid in cherry wines ranged from 0.0566 to 0.1327 $g\,L^{-1}$. Tannic acid (Table 4) reached the highest content of 0.1327 $g\,L^{-1}$ in W1. In contrast, it had the lowest content of 0.0566 $g\,L^{-1}$ in W4 and W5. Interestingly, the content of tannic acid in W4 was the same as in W5.

Sucrose, glucose and fructose (Table 5) were determined as sugar components in cherry wines. Total amounts of sugar differed from each other. They were ascending from W1 to W5, and ranged from 1.31 $g\,L^{-1}$ to 4.19 $g\,L^{-1}$. The lowest sum of sugars was found in W1. Sucrose reached the highest content of 1.57 $g\,L^{-1}$ in W4. Glucose accounted for 40% of the total sugars and reached the highest level of 1.65 $g\,L^{-1}$ in W5. The concentration of fructose was close in W1, W2, W3 and W4, and reached the highest content of 1.17 $g\,L^{-1}$ in W5. The sugar profile and content of specific sugars have been reported as a key indicator for sweet cherry [36,37] and fruit wine [8].

3.3. Relationship between wine samples, sensory attributes and taste-active compounds

ANOVA-PLSR was used to process the mean data accumulated from HPLC, UP-LCMS analysis and sensory evaluation by the panelists. Thirty-three taste-active compounds were used as variables in the subsequent PLSR analysis. The *X*-matrix was designed as taste-active compounds; the *Y*-matrix was designed as wine samples and sensory variables. The calibrated explained variance for this model was PC1 = 41% and PC2 = 28%. PC1 versus 2 (Fig. 2) and PC2 versus 3 were explored. PC2 versus 3 results was not presented here, as the additional information was not gained through their examination. Further, PCs did not provide any predictive improvement in the *Y*-matrix obtained. Fig. 2 was presented as correlation loadings plot. The big circles indicated 50% and 100% explained variances, respectively [38]. Six *Y* variables (W1, W3, sour, sweet, bitter, astringent) and twenty-three *X* variables including tartaric acid, acetic acid, citric acid, asparagines, histidine, glycine, arginine,

Table 3
Mean concentrations (g L^{-1}) of amino acids of five cherry wines.

No.	Compounds	W1	W2	W3	W4	W5
8	Asparagine	0.0393 ± 0.02[a]	1.0412 ± 0.06	0.7994 ± 0.07	0.3327 ± 0.06	0.1968 ± 0.01
9	Glutamic acid	0.0264 ± 0.01	0.0132 ± 0.01	0.1037 ± 0.03	0.0612 ± 0.02	0.0417 ± 0.01
10	Serine	0.0156 ± 0.01	0.0275 ± 0.01	0.0567 ± 0.02	0.0470 ± 0.02	0.0109 ± 0.01
11	Histidine	0.0151 ± 0.01	0.0190 ± 0.01	0.0383 ± 0.01	ND	0.0052 ± 0.00
12	Glycine	0.0039 ± 0.00	0.0080 ± 0.00	0.0831 ± 0.05	0.0132 ± 0.01	0.0144 ± 0.01
13	Threonine	0.0113 ± 0.01	0.0238 ± 0.01	0.0506 ± 0.02	0.0404 ± 0.01	0.0094 ± 0.00
14	Arginine	0.0368 ± 0.01	0.0161 ± 0.01	0.0353 ± 0.01	0.0159 ± 0.01	0.0005 ± 0.00
15	Alanine	0.0405 ± 0.02	0.3046 ± 0.03	0.1168 ± 0.03	0.0682 ± 0.04	0.2021 ± 0.06
16	Tyrosine	0.0108 ± 0.03	0.0050 ± 0.01	0.0217 ± 0.03	0.0132 ± 0.01	ND
17	Cysteine	0.0013 ± 0.00	0.0005 ± 0.00	0.0022 ± 0.00	0.0012 ± 0.00	0.0008 ± 0.00
18	Valine	0.0041 ± 0.00	0.0213 ± 0.01	0.0169 ± 0.01	0.0093 ± 0.00	0.0164 ± 0.01
19	Methionine	0.0048 ± 0.00	0.0007 ± 0.00	0.0007 ± 0.00	0.0022 ± 0.00	ND
20	Phenylalanine	0.0086 ± 0.00	0.0478 ± 0.02	0.0538 ± 0.02	0.0009 ± 0.00	0.0236 ± 0.01
21	Isoleucine	0.0076 ± 0.00	0.0208 ± 0.01	0.0223 ± 0.01	0.0208 ± 0.01	0.0192 ± 0.01
22	Leucine	0.0160 ± 0.01	0.0264 ± 0.01	0.0453 ± 0.01	0.0177 ± 0.01	0.0200 ± 0.01
23	Lysine	0.0226 ± 0.01	0.0100 ± 0.00	0.0431 ± 0.01	0.0113 ± 0.00	0.0019 ± 0.00
24	Proline	1.2491 ± 0.08	0.0246 ± 0.01	0.0881 ± 0.04	0.0207 ± 0.01	0.1058 ± 0.03

ND: not found.
[a] Mean standard deviation (average of triplicate).

Table 4
Mean concentrations (g L^{-1}) of phenolic acids and tannic acid of five cherry wines.

No.	Compounds	W1	W2	W3	W4	W5
25	Gallic acid	ND	0.0350 ± 0.01	0.0836 ± 0.03	0.0066 ± 0.00	0.0078 ± 0.00
26	4-Hydroxy benzoic acid	ND	0.0128 ± 0.01	0.0509 ± 0.02	0.0003 ± 0.00	0.0011 ± 0.00
27	Chlorogenic acid	ND	0.0132 ± 0.00	0.0213 ± 0.02	0.0011 ± 0.00	ND
28	Vanillic acid	0.0403 ± 0.01[a]	0.0051 ± 0.00	0.0408 ± 0.02	0.0044 ± 0.00	ND
29	Caffeic acid	0.0518 ± 0.01	0.1018 ± 0.02	0.1359 ± 0.03	0.0003 ± 0.00	0.0133 ± 0.00
30	Tannic acid	0.1327 ± 0.02	0.0748 ± 0.01	0.0848 ± 0.03	0.0566 ± 0.02	0.0566 ± 0.02

ND: not found.
[a] Mean standard deviation (average of triplicate).

Table 5
Mean concentrations (g L^{-1}) of sugars of five cherry wines.

No.	Compounds	W1	W2	W3	W4	W5
31	Sucrose	0.0800 ± 0.02[a]	0.0900 ± 0.01	0.1100 ± 0.03	1.5700 ± 0.08	1.3700 ± 0.07
32	Glucose	0.6500 ± 0.06	0.6700 ± 0.07	0.9600 ± 0.08	0.6700 ± 0.05	1.6500 ± 0.10
33	Fructose	0.5800 ± 0.10	0.6700 ± 0.05	0.6700 ± 0.06	0.5900 ± 0.09	1.1700 ± 0.11

ND: not found.
[a] Mean standard deviation (average of triplicate).

alanine, tyrosine, valine, methionine, phenylalanine, isoleucine, leucine, lysine, proline, gallic acid, 4-hydroxy benzoic acid, chlorogenic acid, vanillic acid, caffeic acid, sucrose, tannic acid were placed between the inner and outer ellipses, r^2 = 0.5 and 1.0, respectively, indicating they were well explained by the PLSR model.

As revealed from Fig. 2, W1 covaried with sour attribute. This was in agreement with the sensory evaluation result (Fig. 1), where

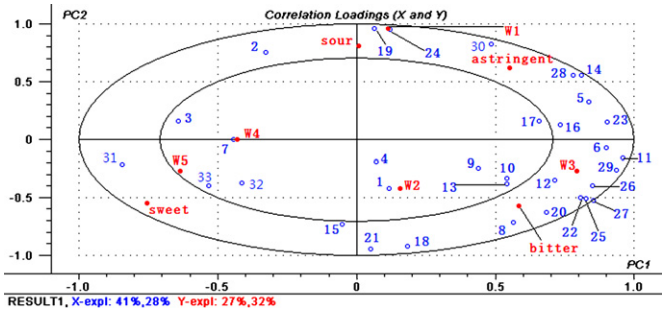

Fig. 2. An overview of the variation found in the mean data from the partial least squares regression (PLSR) correlation loadings plot for cherry wine samples. The model was derived from taste-active compounds as the *X*-matrix and samples and sensory attributes as *Y*-matrix. Elipses represent r^2 = 0.5 and 1.0, respectively.

W1 had highest score in sour attribute. In additional, sour attribute covaried with tartaric acid, methionine and proline. W2 was in the lower right hand quadrant, correlated to oxalic acid, lactic acid, glutamic acid and alanine. Compared with other samples, W3 was associated with more taste-active compounds including citric acid, histidine, glycine, leucine, gallic acid, 4-hydroxy benzoic acid, chlorogenic acid and caffeic acid. W4 did not covary well with any sensory attribute. This was in accordance with the sensory evaluation results (Fig. 1), where W4 did not have highest score in some sensory attributes. Nevertheless, W4 covaried with two compounds including malic acid and succinic acid. W5 only covaried with sweet taste. It also had good correspondence to the sensory evaluation result, W5 exhibiting the strongest taste intensities in sweet. Sweet taste covaried with sucrose, glucose and fructose. Additionally, bitter taste was related to asparagines, serine, glycine, threonine, phenylalanine, leucine, gallic acid and chlorogenic acid. Astringent mouthfeel covaried with vanillic acid, arginine and tannic acid. From the above results, it was revealed that tartaric acid, methionine, proline, sucrose, glucose, fructose, asparagines, serine, glycine, threonine, phenylalanine, leucine, gallic acid, chlorogenic acid, vanillic acid, arginine and tannic acid made a great contribution to cherry wine. Because these compounds were associated with sensory attribute. Therefore, the taste or mouthfeel characteristic of cherry wine could be modified by compensating some

typical taste-active compounds. For instance, sour taste could be improved by compensating suitable amount of tartaric acid.

4. Conclusions

Four sensory attributes (sour, sweet, bitter and astringent) of 5 cherry wines were evaluated by quantitative descriptive sensory analysis. The sensory result demonstrated that 5 cherry wines had different taste and mouthfeel characteristics. Thirty-three taste-active compounds were correlated to sensory attributes and wine samples through PLSR. The correlation analysis clearly showed that some taste-active compounds mostly contributed to characteristic taste or mouthfeel of cherry wines. To sum up, the taste and mouthfeel characteristics of cherry wines could be improved by modifying fermentation parameters or making up for these typical taste-active compounds after alcoholic fermentation.

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