Food Sci Biotechnol (2019) 28(2):395–403
https://doi.org/10.1007/s10068-018-0492-0

Effect of sodium sulfite, tartaric acid, tannin, and glucose on rheological properties, release of aroma compounds, and color characteristics of red wine

Hao Wang[1,2] · Zhi-Jing Ni[1,3] · Wen-Ping Ma[3] · Chang-Bing Song[3] · Jian-Guo Zhang[1] · Kiran Thakur[1] · Zhao-Jun Wei[1,4]

Received: 9 May 2018 / Revised: 19 September 2018 / Accepted: 10 October 2018 / Published online: 15 October 2018

Abstract In this study, we evaluated the effect of addition of non-volatile compounds (sodium sulfite, tartaric acid, tannin, and glucose) on the rheological properties, release of aroma compounds, and color of the red wine. While determining the rheological properties of the supplemented samples, non-Newtonian fluidic and shear-thinning behavior of samples was noticed. The viscosity of these samples was found in negative correlation with the dose of addition of various non-volatile substances. The aroma profile of red wine after additions showed the change in the release of the nine key aroma compounds. Among them ethyl hexanoate, phenylethyl alcohol, octanoic acid, diethyl succinate, and ethyl octanoate were profoundly increased. Further, the color of red wines was improved in the presence of tartaric acid and tannin. Overall, supplementation of various substances during storage period of three different wines could enormously affect the sensory characteristics in a dose dependent manner.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10068-018-0492-0) contains supplementary material, which is available to authorized users.

✉ Zhao-Jun Wei
zjwei@hfut.edu.cn

Hao Wang
782012486@qq.com

Zhi-Jing Ni
lovebear@vip.163.com

Wen-Ping Ma
petermana@163.com

Chang-Bing Song
cbsongnv@sina.com

Jian-Guo Zhang
zhangjianguo@hfut.edu.cn

Kiran Thakur
kumarikiran@hfut.edu.cn

1 School of Food Science and Engineering, Hefei University of Technology, Hefei 230009, People's Republic of China

2 Anhui Habopharmqnceutical Co., Ltd, Taihe 236600, People's Republic of China

3 Biological Science and Engineering College, North Minzu University, Yinchuan 750021, People's Republic of China

4 Anhui Province Key Laboratory of Functional Compound Seasoning, Anhui Qiangwang Seasoning Food Co., Ltd, Jieshou 236500, People's Republic of China

Keywords Red wine · Addition · Rheological property · Aroma compound · Color

Introduction

Due to extremely short harvest period and shelf life of grape, it is not easily preserved and not very suitable for carriage since it is prone to spoilage at room temperature. For extending shelf life, postharvest grapes have been processed quickly in the forms of various grape products among them red wine has been the most widespread and popular drink across the globe. Nowadays, China is recognized at third rank for red wine consumption after France and Italy, and the sale quantity of red wine has been increased over the years due to high living standards and improved preference of the people for different kinds of red wines (Liu et al., 2014). Besides excellent taste and sensory properties, the grape red wine is famous for its biological activities such as aiding in improved digestion and nourishment of the skin (Yoo et al., 2011), imparting antioxidant activity (Tauchen et al., 2015), inhibiting cancer and cardiovascular disease (Greyling et., 2016) and possessing bacteriostatic and anti-viral activity (Friedman, 2014).

In the process of production and storage of red wine, some edible compounds are generally added such as Na_2SO_3 for removing oxygen (Isaac et al., 2006), tartaric acid for acidizing red wine (Gomez et al., 1993), tannin as a stabilizer (Laguna et al., 2017) and glucose as exogenous substrate in fermentation progression (18 g/L of sugar is fermented into 1% alcohol). It is reported that, besides removing oxygen, Na_2SO_3 could be used as an essential preservative to prevent microbial spoilage and extend the shelf life (Spricigo et al., 2010) as well as inhibit the browning reactions and improve the overall quality of the red wine (Guan et al., 2011). Similarly, acidity in red wine brewing process may be lower which produces an unlikely taste. Therefore, acidizing red wine is an important step in red wine making to attain the certain levels of acidity with pleasant taste for wide consumers' acceptability. Further, tannin has been reported to promote the stability of red wine by removing metal ions and lowering the content of aldehydes materials (Picariello et al., 2016) besides its bacteriostatic action (Sekowski et al., 2017). On the other hand, glucose as source of energy or substrate material for yeast used in the required fermentation is mainly resolved into ethyl alcohol and water through glycolysis.

The rheological behavior of wines has not been extensively discussed. The basic rheological properties of wine have been evaluated in only a few works. Kosmerl et al. (2000) studied the thermophysical and chemical properties of wine, especially the density and viscosity data. In another study, wines produced from the grapes collected in the Czech Republic were examined for their rheological attributes (Trávnícek et al., 2016). Seven out of the eight samples behaved as non-Newtonian fluids at low temperature (5 °C); non-Newtonian behavior was changed into Newtonian at the temperature higher than 10 °C; non-Newtonian behavior was characterized as thyrotrophic behavior. Density and viscosity are properties that exert great influence on the body of wines. Neto et al. (2015) studied the effect of ethanol, dry extract and reducing sugars on density and viscosity of Brazilian red wines. Wine viscosity decreased with increasing temperature and density was directly related to the wine alcohol content, whereas viscosity was closely linked to the dry extract. Till date, the studies related to red wine were mainly focused on the design and optimization of brewing process, separation and identification of aromatic substances as well as identification of active substance in red wine. Sagratini et al. (2012) reported that main aroma volatile compounds largely responded to the aroma profile of Montepulciano wine samples, including 15 esters, five alcohols and three acids as well as seven phenols including gallic acid and caffeic acid etc. Another study quantified the contents of glutathione, catechin, and caffeic acid in grape juice and red wine by using novel ultra-performance liquid chromatography method (Fracassetti et al., 2011). However, the reports about fluid characteristics of red wine are less studied. Previously known that the level of bioactive compounds in grapes is influenced by cultivars which ultimately affects the red wine quality (Ni et al., 2017). But the effect of additions of different compounds in red wine on fluid property, visual sense, and aroma improvement are still unknown. So far, our study is first of its kind to evaluate the effects of several non-volatile substances in a dose dependent manner on the color, rheological property, and the release of aroma substances.

Materials and methods

Samples

The red wine samples including Gernischet (2013, 2014, 2015), Sauvignon (2013, 2014, 2015) and Merlot (2015) were provided from the chateau of Xixia King in Yinchuan City, Ningxia Province, China. All these samples were stored in a thermostat at a temperature ranging from 13 to 18 °C until the further analysis.

Chemicals

Chemical standards of the volatile substances including ethyl alcohol, ethyl acetate, 1-hexanol, ethyl hexanoate, phenylethyl alcohol, octanoic acid, diethyl succinate, ethyl octanoate, and ethyl decanoate were purchased by Sigma-Aldrich Co., Ltd (Shanghai, China). Tannin (food grade) was purchased from Shanghai Macklin Biochemical Co., Ltd (Shanghai, China). Na_2SO_3, Tartaric acid, and Glucose (food grade) were purchased from Sinopharm Chemical Reagent Co., Ltd (Shanghai, China). Distilled water was obtained from Hefei Corning specific water treatment equipment Co., Ltd (Hefei, Anhui, China).

Experimental design and sample pretreatment

A modified red wine system was completed by adding non-volatile substances into the red wine to study the change of the color, rheological property, and the release of volatile compounds in red wine samples. Four non-volatile components (0.1% and 1% Na_2SO_3, 0.1% and 1% tartaric acid, 0.1% and 1% tannin, and 1%, and 20% glucose) were added into each red wine with two specific doses (low and high), respectively (Supplemental Table 1). After supplementation, all the wine samples were stored at room temperature for 24 h. The normal red wine without any addition or removal was used as control for the study.

Rheological measurements

Several methods have been designed for measurement of the rheological behavior of substances with different types of measurements such as concentric cylinders, cones, and plates (parallel plates) (Vítěz and Severa, 2010). Steady-shear rheological measurements were carried out at 25 °C using a Discovery Hybrid Rheometer-3 (DHR-3) (TA instruments, New Castle, Texas, USA) equipped with a parallel plate (diameter 40 mm). The flow curves were modeled using the following model (Zhu et al., 2016):

Power Law model: $\tau = K\gamma^{n}$

where τ represented shear stress (Pa), K was consistency coefficient, n was flow behavior index and γ was shear rate (s^{-1}). The experiment was performed at an interval of the shear rate from 0.01 to 1000 s^{-1} at 25 °C.

Rheological properties of red wine

Red wine samples, including Gernischet (years of manufacture were 2013, 2014, 2015), Sauvignon (2013, 2014, 2015) and Merlot (2015), were placed into sealed glass vials and allowed to stand for 24 h at the room temperature. The apparent viscosity of all the samples was determined with a range of shear rate from 0.01 to 1000 s^{-1} at 25 °C.

Effect of additions on rheological property of red wine

After addition of high and low doses of the non-volatile substances into each red wine (Gernischet 2015), it was sealed into a glass vial for 24 h under continuous stirring to ensure complete solubilization. Viscosity flow curves were determined over the range of 0.01–1000 s^{-1} at 25 °C (Shi et al., 2016).

Analysis of volatile substances

The headspace solid-phase micro-extraction (HS-SPME) technique and chromatographic conditions were carried out according to the previously described methods with a little modification (Arcari et al., 2017). The chromatographic separation was performed using a DB-1 column (0.25 mm × 30 m × 0.25 µm) with an Agilent gas chromatography–mass spectrometry (GC–MS) (7890A-5975C) (Agilent Technologies Co. Ltd., Santa Clara, California, USA). For this, red wine samples (10 mL) were placed into headspace vials sealed with a silicone septum to isolate free and glycosidically bound flavor compounds. Then after, a fiber comprising of 50/30 µm DVB/CAR/PDMS (Supelco Inc, Bellefonte, Pennsylvania, USA) was inserted into the headspace for 30 min at 40 °C. Conditions of HS-SPME and chromatography were as followed: temperature of the GC injector and the transfer line were both set at 250 °C with a constant flow of 1.0 mL/min for the carrier gas of Helium (99.999%). The split less injection of 1.0 µL was used. The following temperature raising procedure was used for DB-1 column: after 5 min at 50 °C, the temperature was increased by 6 °C/min to 150 °C and then raised at 8 °C/min to 200 °C and finally held for 7 min. The mass parameters included electron − 70 eV, an ion source temperature of 230 °C, and a quadrupole temperature of 150 °C with a mass range of m/z 33-600.

Color measurements in red wine samples

For the measuring the color change in red wine, the samples were placed in vials at room temperature for 24 h after the additions of non-volatile substances with an aim to measure specific doses and the color intensity. The red wine bottles were glass sealed with rubber stopper to keep them airtight and surrounded with aluminum foil to avoid the direct contact with light. Then after a certain volume of red wine samples was taken out and collected respectively for the measurement of the color indexes. Color characteristics of the samples were determined by measuring the absorbance of samples at 420, 520, and 620 nm, respectively using A SP-752 UV-Visible Spectrophotometer (Shanghai Spectrum Instruments Co., Ltd, Shanghai, China) with a 1-mm path-length quartz cuvette. Red wine color (WC) was determined by absorbance at 520 nm. Color density (CD) was calculated by the average of the absorbance at 420, 520, and 620 nm. Colorhue (CH) was determined as the ratio of the absorbance at 420 and 520 nm; and the proportion of yellow (%Ye), red (%Rd), and blue color (%Bl) were calculated by the proportion of the respective absorbance at 420, 520, and 620 nm to the color density (Zhang and Wang, 2017).

Statistical analysis

Statistical analysis was performed using SPSS 18.0 software. A Pearson correlation test was conducted to determine the correlation between variables. Duncan's significance test at a significance level of $p < 0.05$ was carried out to determine the significant differences among mean values.

Results and discussion

Rheological properties of red wines from Xixia King Chateau

Flow experiments provided various rheological consequences among the tested red wine samples. Figure 1 showed that the viscosity diminished gradually with the increase of shear rate, which indicated the shear-thinning behavior for all tested red wine samples. The value of two rheological parameters including consistency coefficient (K) and flow behavior index (n) were presented in Table 1. All the values of flow behavior index (n) were less than 1 which proved the shear-thinning and non-Newtonian behavior of the red wine samples (Trávníček et al., 2016). Our results concerning the non-Newtonian pseudoplastic behavior of red wine samples agreed with the previous studies (De Castilhos et al., 2018). Higher K value indicated the higher apparent viscosity. Results showed a wide range of K value among the red wine samples (from 0.0173 to 0.0575) which indicated that apparent viscosity of red wine sample (Gernischet 2015) was the highest among all the red wine samples. Particularly, the age of the red wine has significantly affected the apparent viscosity. The red wine manufactured in 2015 possessed the higher consistency coefficient (K) which ultimately resulted into higher apparent viscosity as compared to the old red wines (based on year of manufacture).

Effect of addition of non-volatile compounds on rheological property of red wine samples

Several common and esculent compounds (including Na_2SO_3, tartaric acid, tannin, glucose) which are mainly used in vinification process of grape red wine and other fruits wines were studied for the rheological property of red wine samples as shown in Figs. 2 and 3. The results showed that the viscosity of the control sample was higher than the red wine samples after additions which indicated decreased viscosity with higher dose of addition (Fig. 2). Figure 3A manifested that these additions could reduce K value and lower the viscosity of red wine with different downtrend. Viscosity declined rapidly with addition of lower dosage of Na_2SO_3, tannin, and glucose; while, adding lower doses of tartaric acid caused slow decrease in viscosity which further decreased with high doses and tartaric acid at higher concentrations led to the lowest viscosity values. The n value of all the red wine samples containing non-volatile substances was higher than the control sample (Fig. 3B). The red wine sample with 20% added glucose displayed the highest n value besides the least K value among all samples. Moreover, n value was raised with the increased concentration of non-volatile substances in red wine samples. Among them, 20% glucose had shown largest change which was nearly two times of red wine sample with 1% glucose and three times of control sample. Nevertheless, all the values of n were less than 1, which illustrated that additions had negligible effect on fluid property of red wine samples.

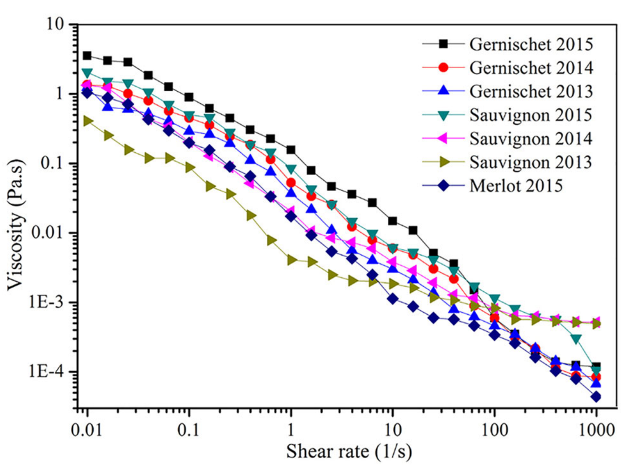

Fig. 1 Dependence of apparent viscosity on the shear rate of selected red wine samples

Table 1 Consistency coefficients (K) and the flow index (n) of the red wine samples (Xixia King)

No.	Samples	K (Pa s^n)	n
1	Gernischet 2015	0.0575	0.1586
2	Gernischet 2014	0.0385	0.1698
3	Gernischet 2013	0.0332	0.2549
4	Sauvignon 2015	0.0451	0.261
5	Sauvignon 2014	0.0173	0.3954
6	Sauvignon 2013	0.0133	0.4245
7	Merlot 2015	0.0229	0.2912

Effect of addition of non-volatile compounds on release of main aroma compound of red wine samples

Aroma components in control samples were analyzed by GC–MS, and the total ion chromatogram of aroma components in control red wine samples was depicted in Supplemental Fig. 1. A total of 18 main aroma compounds were detected which were confirmed by GC–MS, including one acid, eight esters, four alcohols, and five hydrocarbons. For this result, there was a little difference than previous study but it was in accordance with the previous finding (Sánchez-Palomo et al., 2017).

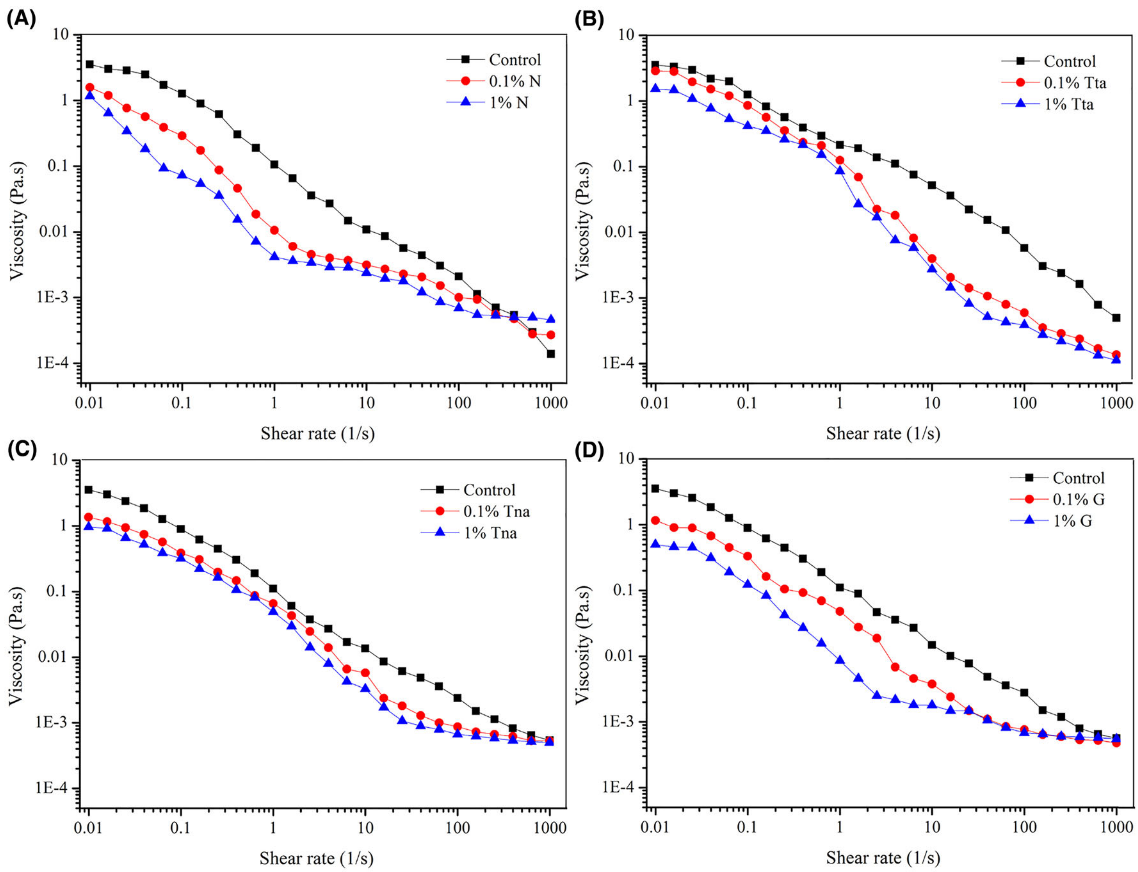

Fig. 2 Steady shear flow curves of red wine samples after addition of non-volatile compounds with different dose rate. Steady-shear rheological measurements were carried out at 25 °C

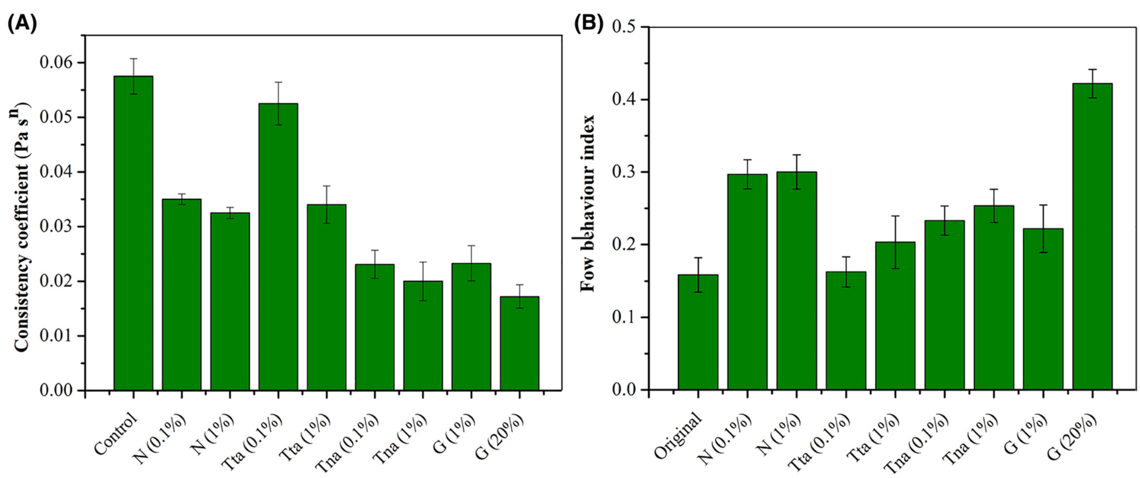

Fig. 3 K (**A**) and n (**B**) values of modified red wine samples (N) Na_2SO_3; (Tta) Tartaric acid; (Tna) Tannin; (G) Glucose

Determination of volatile flavor has been an important indicator and standard evaluation for acceptability and popularity of almost all the foods. The variation of the release of each aroma compound in as percent rate of content of counterpart compounds in control was compared with the red wine samples. The samples containing ethyl alcohol, ethyl acetate, 1-hexanol, ethyl hexanoate, phenylethyl alcohol, octanoic acid, diethyl succinate, ethyl octanoate, and ethyl decanoate were shown in Table 2. The results were found consistent with the previous study which reported the many aroma components containing esters (50), alcohols (50), terpenes (44), acids (19), aldehydes

(15), ketones (13), lactones (8), phenols (7), furans (7) and sulfur compounds (7) (Nicolli et al., 2017). Compared to control sample, average release of eight volatile substances generally revealed an increased trend with smaller amplitude for other eight samples, despite existing small fluctuations. Among all the samples, the red wine sample with 0.1% Na_2SO_3 could inhibit the volatile flavor release (accounted for 88.32% of the control sample). However, the average release of volatile substance was least affected by the additions as well as their doses as compared to control sample. In case of ethyl alcohol and ethyl acetate release, there was not much significant effect of additions. Furthermore, there was drop trend behavior along with a little fluctuation for other additions on release of volatile in general. However, for ethyl hexanoate, ethyl hexanoate, and diethyl succinate, there was a significant difference on release of volatile compound in relation to these additions. Besides, the dose of additions had the stronger positive correlation with the release of ethyl hexanoate, ethyl hexanoate, and diethyl succinate. Additions consisting of tartaric acid, tannin, glucose, and low concentration of Na_2SO_3 could strengthen the release of octanoic acid. On the contrary, 1% Na_2SO_3 had a negative correlation with the release of octanoic acid, which was attributed to a series of complex redox reactions with substances in red wine due to reducibility of high dose of Na_2SO_3. In addition, except 0.1% tartaric acid, other additions increased the release of 1-hexanol. Meanwhile, with the greater dose, the higher release was observed especially for 1% tannin where the release of 1-hexanol was nearly 30 times of the control sample. Whereas the release of 1-hexanol was only 77.90% of control sample for 0.1% tartaric acid. In terms of phenylethyl alcohol, glucose could increase its release while tannin had an opposite effect with small effect for tartaric acid. In addition to this, ethyl decanoate was detected for the samples added with tannin and glucose.

Aroma compounds are important factors that affect grape flavor and quality, and contribute to the sensory character of wine. Previous study demonstrated that nonvolatile composition of wines robustly influenced the volatility of wine aroma compounds which further affected its physicochemical properties (volatility and hydrophobicity) (Rodríguez-Bencomo et al., 2011). The presence of nonvolatile substances in wines contributing to wine quality is a critical subject in current enological research. Studies have reported that wines were evaluated as high-quality wines by experts based on the presence of higher concentrations of these substances (Sáenz-navajas et al., 2010). Many studies have revealed the role of fruits and microbial glycosidase (non-volatile substances such as β-glucosidases, esterases, phenolic acid decarboxylases and citrate lyases) for contributing the aroma to grape wines (Cappello et al., 2017).

Another study demonstrated the effect of vine foliar treatments on the release of aroma compounds in grape wines and observed that glycosidically-bound aroma precursors were released in the wines over the sampling period (Pardo-garcía et al., 2014). Previous study reporting the effect of methyl jasmonate (plant-specific elicitors signaling molecules that activate several important physiological and developmental processes) on the aroma of Sangiovese grapes and wines showed the delayed grape technological maturity and a significant increase in the concentration of

Table 2 The change of release quantity of nine key aroma components in modified red wine samples

	Ethyl alcohol	Ethyl acetate	1-Hexanol	Ethyl hexanoate	Phenylethyl alcohol	Octanoic acid	Diethyl succinate	Ethyl octanoate	Ethyl decanoate	Sum
Na_2SO_3 1%	79.74*	77.02*	379.48*	1013.87*	239.98*	66.27*	631.81*	2407.18*	–	88.32*
Na_2SO_3 0.1%	109.47*	115.78*	179.56*	390.51*	70.35*	204.12*	118.10*	648.82*	–	113.43*
Tartaric acid 1%	100.38	98.51	284.56*	510.93*	91.11	246.67*	149.06*	989.76*	–	102.03
Tartaric acid 0.1%	96.30	98.27	77.90*	195.59*	116.58*	244.65*	136.99*	771.57*	–	98.08
Tannin 1%	100.96	93.55	368.77*	494.88*	2.77*	2976.94*	138.57*	56,955.63*	+	106.98
Tannin 0.1%	98.59	89.75*	132.86*	668.90*	60.18*	136.90*	178.36*	948.89*	+	96.07
Glucose 1%	96.09	89.44*	139.07*	460.72*	139.89*	145.23*	203.25*	1004.57*	+	95.41
Glucose 20%	98.58	81.49*	340.48*	314.36*	133.43*	175.70*	274.32*	1992.47*	+	93.85

The change of release quantity of aroma compound in modified red wine samples was expressed by the percentage of the release quantity in the control sample

+, – represents the aroma component could be detected and not detected respectively

*Represented the release of aroma compounds differ from control significantly ($p < 0.05$)

Table 3 Effect of addition of non-volatile compounds and their content on the red wine color (WC), color density (CD), browning index (BI), color hue (CH), %Ye, %Rd, %Bl of red wine (Xixia King, 2015)

Addition (w/v %)	Red wine	1% Na_2SO_3	0.1% Na_2SO_3	1% tartaric acid	0.1% tartaric acid	1% tannin	0.1% tannin	1% glucose	20% glucose
WC									
Gernischet	0.9	0.564*	0.664*	1.187*	0.959*	1.076*	0.959*	0.903*	0. 938*
Sauvignon	1.42	1.097*	1.292*	1.553*	1.429*	1.456*	1.638*	1.509*	1.523*
Merlot	0.873	0.733*	0.833*	1.022*	0.955*	0.979*	1.051*	1.032*	1.060*
CD									
Gernischet	1.906	1.468*	1.515*	2.228*	1.98*	2.237*	2.035*	1.919*	1.890*
Sauvignon	3.025	2.622*	2.752*	3.216*	2.991*	3.109*	3.62*	3.258*	3.268*
Merlot	2.063	1.862*	1.965*	2.466*	2.327*	2.375*	2.573*	2.526*	2.612*
BI									
Gernischet	0.777	0.667*	0.682*	0.845*	0.796*	0.889*	0.818*	0.780	0.770
Sauvignon	1.143	1.016*	1.06*	1.208*	1.131*	1.174*	1.357*	1.229*	1.232*
Merlot	0.917	0.857*	0.86*	1.071*	1.009*	1.018*	1.081*	1.06*	1.066*
CH									
Gernischet	0.863	1.080*	1.027*	0.712*	0.830*	0.826*	0.853	0.864	0.862
Sauvignon	0.805	0.981*	0.820*	0.778*	0.803	0.806	0.828*	0.804	0.802
Merlot	1.050	1.169*	1.062*	1.048	1.050	1.040*	1.029*	1.027*	0.996*
%Ye									
Gernischet	0.408	0.450*	0.450*	0.379*	0.402	0.397	0.402	0.406	0.407
Sauvignon	0.378	0.410*	0.385*	0.376	0.378	0.378	0.375	0.371*	0.374
Merlot[c]	0.444	0.460*	0.441	0.434*	0.434*	0.429*	0.420*	0.404*	0.420*
%Rd									
Gernischet	0.472	0.417*	0.438*	0.533*	0.484	0.481	0.471	0.471	0.472
Sauvignon	0.469	0.418*	0.469	0.483*	0.471	0.468	0.452*	0.463*	0.466
Merlot	0.423	0.394*	0.424	0.414*	0.410*	0.412*	0.408*	0.409*	0.406*
%Bl									
Gernischet	0.120	0.133	0.121	0.088*	0.114	0.122	0.127	0.123	0.120
Sauvignon	0.153	0.171*	0.145*	0.141*	0.151	0.154	0.173*	0.160*	0.160*
Merlot	0.132	0.146*	0.138*	0.156*	0.151*	0.159*	0.171*	0.172*	0.190*

*Represented the color differ from control significantly ($p < 0.05$)

several berry aroma classes (monoterpenes) (D'Onofrio et al., 2018).

Effect of addition of non-volatile compounds and their dose on the color characteristics of red wine samples

Among the organoleptic properties of any foodstuff or beverage, color is the first one that decides consumer's acceptance (Cesa et al., 2017). After adding Na_2SO_3 in red wine samples (Gernischet, Sauvignon and Merlot), WC, CD, BI, %Rd, and %Bl were significantly lowered than control samples; while, CH and %Ye were obviously higher than the control samples. Moreover, with the higher dose of Na_2SO_3, the faster decline of WC, CD, BI, %Rd, and %Bl was observed as shown in Table 3. These results revealed that Na_2SO_3 could significantly inhibit the color of red wine and escalate the yellow tones which might be due to some complex chemical reactions or pigment degradation with decolorization of Na_2SO_3, resulting in decreased visible spectrum especially at the absorbance 520 nm and 620 nm. As reported previously, phenolic substances serve as main color materials in red wine. One reason for fading the color of red wine may be due to inhibition of the polymerization and agglutination of pigment substances by Na_2SO_3 (Czibulya et al., 2015).

The opposite effect of $Na_2SO_3$was reported after addition of tartaric acid and glucose which could obviously intensify the WC, CD, BI, %Rd, and %Bl with decrease of CH and %Ye. Moreover, the changing trends of these red wine color indexes were coinciding with the changes in the doses of these additions. As mentioned above, deep color of red wine could be caused by the polymerization and agglutination of pigment substances. Therefore, tartaric acid and glucose could enhance the polymerization and agglutination of pigment substances, sequentially improving and deepening the color of red wine. However, glucose had a positive effect on the color of three red wine samples (Gernischet, Sauvignon and Merlot). Overall, the changes in color index of all the red wine samples were not obvious after addition of glucose. It was relatively significant that the values of WC, CD, BI, %Rd, and %Bl were increased initially and then decreased by raising of dose of tannin, but the value of CH and %Ye decreased following the increase of tannin. This might be due to the positive effect of tannin on agglomeration of pigment. But with the increasing dose of tannin, the red wine color index including WC, CD, BI, %Rd, and %Bl could decrease due to the coagulation sedimentation for tannin (Bindon et al., 2014).

During red wine-making and aging, several reactions take place among them oxidation is one of the important phenomena which leads to decreased color stabilization. In previous study, the red wine samples administered with a higher dose of tannins showed a marked improvement of color intensity with oxidation mainly due to an increase in polymeric pigments (Picariello et al., 2016).

Another study reported the effect of two commercially available maceration enzymes and two enological tannins on chromatic characteristics, color stability, and sensory properties of Monastrell wines. The authors reported the highest differences at the beginning of the winemaking process which diminished in the finished wines. As compared to enzymes treated wine, tannins had shown no improvement in the chromatic and sensory characteristics of the wines, besides resulting into deep yellow color and lower scores in the color, aroma, and sensory characteristics, accompanied by a higher astringency, dryness, and bitter sensory sensations (Bautista-ortín et al., 2005).

Effects of addition of non-volatile compounds (sodium sulfite, tartaric acid, tannin, and glucose) on the rheological properties, release of aroma compounds, and color of the red wine were experimentally detected. It was found that supplemented samples showed non-Newtonian fluidic and shear-thinning behavior which indicated the dependence of apparent viscosity on the shear rate of selected red wine samples. The viscosity of these samples was found in negative correlation with the dose of addition of various non-volatile substances. Besides, the rheological attributes, the sensory characteristics such as aroma profile and color of red wines were also improved after specific additions. The effects of the various additions on the color, aroma, and taste would help to further explore the exact content required and their mechanism of action to obtain the optimal conditions for best sensory characteristics of red wines.

Acknowledgements This study was supported by the Major Projects of Science and Technology in Anhui Province (17030701024, 17030701028, and 17030701058), the Breeding Program of Ningxia Agriculture (NXNYYZ20150201), and Program of Ningxia Grape and Wine innovation center.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

Arcari SG, Caliari V, Sganzerla M, Godoy HT. Volatile composition of Merlot red wine and its contribution to the aroma: optimization and validation of analytical method. Talanta. 174: 752–766 (2017)

Bautista-ortín AB, Martínez-cutillas A, Ros-garcía JM, López-Roca JM, Gómez-Plaza E. Improving colour extraction and stability in red wines: the use of maceration enzymes and enological tannins. Int. J. Food Sci. Technol. 40: 867–878 (2005)

Bindon KA, Mccarthy MG, Smith PA. Development of wine colour and non-bleachable pigments during the fermentation and ageing of (*Vitis vinifera* L. Cv.) Cabernet Sauvignon wines differing in anthocyanin and tannin concentration. LWT Food Sci. Technol. 59: 923–932 (2014)

Cappello MS, Zapparoli G, Logrieco A, Bartowsky EJ. Linking wine lactic acid bacteria diversity with wine aroma and flavour. Int. J. Food Microbiol. 243: 16–27 (2017)

Cesa S, Carradori S, Bellagamba G, Locatelli M, Casadei MA, Masci A, Paolicelli P. Evaluation of processing effects on anthocyanin content and color modifications of blueberry (*Vaccinium spp.*) extracts: Comparison between HPLC-DAD and CIELAB analyses. Food Chem. 232: 114–123 (2017)

Czibulya Z, Horváth I, Kollár L, Nikfardjam MP, Kunsági-Máté S. The effect of temperature, pH, and ionic strength on color stability of red wine. Tetrahedron. 71: 3027–3031 (2015)

De Castilhos MBM, Betiol LFL, De Carvalho GR, Telis-Romero J. Experimental study of physical and rheological properties of grape juice using different temperatures and concentrations. Part II: Merlot. Food Res. Int. 105: 905–912 (2018)

D'Onofrio C, Matarese F, Cuzzola A. Effect of methyl jasmonate on the aroma of Sangiovese grapes and wines. Food Chem. 242: 352–361 (2018)

Fracassetti D, Lawrence N, Tredoux AGJ, Tirelli A, Nieuwoudt HH, Toit WJD. Quantification of glutathione, catechin and caffeic acid in grape juice and wine by a novel ultra-performance liquid chromatography method. Food Chem. 128:1136–1142 (2011)

Friedman M. Antibacterial, antiviral, and antifungal properties of wines and winery byproducts in relation to their flavonoid content. J. Agric. Food Chem. 62: 6025–6042 (2014)

Gomez BJ, Delgado GMM, Martin DJ. Study of the acidification of sherry musts with gypsum and tartaric acid. Am. J. Enol. Vitic. 44: 400–404 (1993)

Greyling A, Bruno RM, Draijer R, Mulder T, Thijssen DHJ, Taddei S, Virdis A, Ghiadoni L. Effects of wine and grape polyphenols on blood pressure, endothelial function and sympathetic nervous system activity in treated hypertensive subjects. J. Funct. Foods. 27: 448–460 (2016)

Guan YG, Zhu SM, Yu SJ, Xu XB, Shi WH. $SO3^{2-}$ effects the 5-hydroxymethyl-2-furaldehyde content in ammonium sulphite–glucose solutions. Int. J. Food Sci. Technol. 46: 1007–1013 (2011)

Isaac A, Livingstone C, Wain AJ, Compton RG, Davis J. Electroanalytical methods for the determination of sulfite in food and beverages. TrAC Trends Anal. Chem. 25: 589–598 (2006)

Kosmerl T, Abramoviè H, Klofutar C, The rheological properties of Slovenian wines. J. Food Eng. 46: 165–171 (2000) (**in Slovenian**)

Laguna L, Sarkar A, Bryant MG, Beadlingc AR, Bartoloméa B, Moreno-Arribas MV. Exploring mouthfeel in model wines: Sensory-to-instrumental approaches. Food Res. Int. 102: 478–486 (2017)

Liu HB, Mccarthy B, Chen T, Guo S, Song XG. The Chinese wine market: a market segmentation study. Asia Pac. J. Mark. Log. 26: 450–471 (2014)

Neto FS, de Castilhos MB, Telis VR, Telis-Romero J. Effect of ethanol, dry extract and reducing sugars on density and viscosity of Brazilian red wines. J. Sci. Food Agric. 95: 1421–1427 (2015)

Ni ZJ, Ma WP, Wang H, Song CB, Thakur K, Zhang H, Wei ZJ. Stability of health-promoting bioactives and enzymes in skin and pulp of grape during storage. Curr. Top. Nutraceutical Res. 15: 103–110 (2017)

Nicolli KP, Biasoto ACT, Souza-Silva ÉA, Guerra CC, Dos Santos HP, Welke JE, Zini CA. Sensory, olfactometry and comprehensive two-dimensional gas chromatography analyses as appropriate tools to characterize the effects of vine management on wine aroma. Food Chem. 234: 103–117 (2017)

Pardo-garcía AI, De La Hoz KS, Zalacain A, Alonso GL, Salinas MR. Effect of vine foliar treatments on the varietal aroma of Monastrell wines. Food Chem. 163: 258–266 (2014)

Picariello L, Gambuti A, Picariello B, Picariello L. Evolution of pigments, tannins and acetaldehyde during forced oxidation of red wine: Effect of tannins addition. LWT Food Sci. Technol. 77: 370–375 (2016)

Rodríguez-Bencomo JJ, Muñoz-González C, Andújar-Ortiz I, Martín-Álvarez P J, Moreno-Arribas MV, Pozo-Bayón MA. Assessment of the effect of the non-volatile wine matrix on the volatility of typical wine aroma compounds by headspace solid phase microextraction/gas chromatography analysis. J. Sci. Food Agric. 91: 2484–2494 (2011)

Sáenz-navajas MP, Tao YS, Dizy M, Ferreira V, Fernández-zurbano P. Relationship between nonvolatile composition and sensory properties of premium Spanish red wines and their correlation to quality perception. J. Agric. Food Chem. 58: 12407–12416 (2010)

Sagratini G, Maggi F, Caprioli G, Cristalli G, Ricciutelli M, Torregiani E, Vittori S. Comparative study of aroma profile and phenolic content of Montepulciano monovarietal red wines from the Marches and Abruzzo regions of Italy using HS-SPME–GC–MS and HPLC–MS. Food Chem. 132: 1592–1599 (2012)

Sánchez-Palomo E, Trujillo M, Ruiz AG, Viñas MAG. Aroma profile of malbec red wines from La Mancha region: Chemical and sensory characterization. Food Res. Int. 100: 201–208 (2017)

Sekowski S, Bitiucki M, Ionov M, Zdeba M, Abdulladjanovac N, Rakhimovc R, Mavlyanovc S, Bryszewskab M, Zamaraevaa M. Influence of valoneoyl groups on the interactions between Euphorbia tannins and human serum albumin. J. Lumin. 194: 170–178 (2017)

Shi JJ, Zhang JG, Sun YH, Xu QX, Li L, Prasad C, Wei ZJ. The rheological properties of polysaccharides sequentially extracted from peony seed dreg. Int. J. Biol. Macromol. 91: 760–767 (2016)

Spricigo R, Richter C, Leimkühler S, Gortonb L, Schellera FW, Wollenbergera U. Sulfite biosensor based on osmium redox polymer wired sulfite oxidase. Colloid Surf. A. 354: 314–319 (2010)

Tauchen J, Marsik P, Kvasnicova M, Maghradze D, Kokoska L, Vanek T, Landa P. In vitro antioxidant activity and phenolic composition of Georgian, Central and West European wines. J. Food Compos. Anal. 4: 113–121 (2015)

Trávníček P, Burg P, Krakowiak-Bal A, Junga P, Vítěz T, Ziemiańczyk U. Study of rheological behavior of wines. Int. Agrophys. 30: 509–518 (2016)

Vítěz T, Severa L. On the rheological characteristics of sewage sludge. Acta Univ. Agric. Silvic. Mendelianae Brun. 58: 287–294 (2010)

Yoo YJ, Prenzler PD, Saliba AJ, Ryan D. Assessment of some Australian red wines for price, phenolic content, antioxidant activity, and vintage in relation to functional food prospects. J. Food Sci. 76: 1355–1364 (2011)

Zhang QA, Wang TT. Effect of ultrasound irradiation on the evolution of color properties and major phenolic compounds in wine during storage. Food Chem. 234: 372–380 (2017)

Zhu H, Qiu J, Li ZG. Determination of rheological property and its effect on key aroma release of Shanxi aged vinegar. J. Food Sci. Technol. 53: 3304–3311(2016)