Food Chemistry 172 (2015) 565–574

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Evolution of phenolic compounds and sensory in bottled red wines and their co-development

Yuan Gao [a,1], Yuan Tian [a,1], Di Liu [a], Zheng Li [b], Xiao-Xu Zhang [a], Jing-Ming Li [a], Jing-Han Huang [a], Jun Wang [a], Qiu-Hong Pan [a,*]

[a] Center for Viticulture & Enology, College of Food Science and Nutritional Engineering, China Agricultural University, Beijing 100083, China
[b] Food Science and Human Nutrition Department, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611, USA

ARTICLE INFO

Article history:
Received 6 June 2014
Received in revised form 9 September 2014
Accepted 19 September 2014
Available online 28 September 2014

Keywords:
Bottle stoppers
Bottle aging
Phenolic compounds
Sensory quality

ABSTRACT

This study aimed to assess the correspondence between the evolution of phenolic compounds and the development of appearance and mouthfeel in Cabernet Sauvignon (*Vitis vinifera* L. cv.) dry red wines during 18-month aging in bottle. The wines were sealed with six types of bottle stoppers. The results showed that phenolic compounds presented four evolution patterns along with wine aging in bottle, mainly depending on their chemical nature. Most of the anthocyanins had significant differences in concentration amongst the wines sealed with the six bottle stoppers at the 18-month point. Analysis of partial least squares (PLS) revealed that wine appearance quality was positively correlated with the levels of malvidin-3-*O*-(6-*O*-acetyl)-glucoside-4-vinylguaiacol, gallocatechin and dihydrokaempferol-3-*O*-rhamnos, while the development of mouthfeel properties was positively associated with the evolutions of malvidin-3-*O*-glucoside-ethyl-(epi)catechin, peonidin-3-*O*-(6-*O*-acetyl)-glucoside, malvidin-3-*O*-(6-*O*-coumaryl)-glucoside-pyruvic acid and peonidin-3-*O*-glucoside-4-vinylphenol. No obvious association was observed between the development of wine sensory characteristics and the evolution of dissolved oxygen in wine.

1. Introduction

Phenolic compounds are responsible for sensory characteristics in wine, such as colour, mouthfeel, and flavour, and they undergo many compositional and content changes in the process of wine aging (Li et al., 2009). Generally, wine phenolic compounds are composed of two main groups, anthocyanins and non-anthocyanin phenolic compounds (namely, hydroxybenzoic acids, hydroxycinnamic acids, flavan-3-ols, flavonols and stilbenes). Besides, polymeric phenolics can be formed through condensation reactions between flavan-3-ols and anthocyanins during aging period. Amongst these compounds, anthocyanins are the main factor that determines red hues in wine (Revilla, GarcÍA-Beneytez, & Cabello, 2009). Typically, the reactions between anthocyanins and other phenolic compounds in wine change its purple tints toward ruby red (Boulton, 2001; Fulcrand, Duenas, Salas, & Cheynier, 2006). These reactions also promote the stability of wine colour and reduce the astringency of wine (Boulton, 2001). Meanwhile, the unstable anthocyanins from grape skins are converted into stable oligomeric and polymeric pigments via the combination with vinyl phenol and/or pyruvic acid during wine fermentation and aging processes (Fulcrand, Benabdeljalil, Rigaud, Cheynier, & Moutounet, 1998). Flavan-3-ols and hydroxycinnamic acids are involved in redox reactions, causing browning reactions and haze formation (Cheynier & Ricardo-da-Silva, 1991).

During bottle aging, the effect of evolution of phenolic compounds on development of wine colour and mouthfeel mainly depends on transferring oxygen through the bottle stopper (Castellari, Matricardi, Arfelli, Galassi, & Amati, 2000; Silva, Julien, Jourdes, & Teissedre, 2011). It has been confirmed that wine maturation in bottle was affected by the sealing system of bottle stoppers (Godden et al., 2001), and oxygen transfer rate (ORT) significantly determined the development of wine quality (Godden et al., 2001; Skouroumounis et al., 2005). The increase of ORT can markedly enhance the degradation speed of anthocyanins and monomer flavan-3-ols, accelerate the sulphite consumption, and increase the chromaticity (related to the decrease of sulphite content) (Wirth et al., 2010). A continuous micro-aerobic condition with appropriate OTR in bottled wine can also help to increase the accumulation of pyranoanthocyanins and remove

* Corresponding author. Tel.: +86 10 62736191; fax: +86 10 62738658.
E-mail address: panqh@cau.edu.cn (Q.-H. Pan).
[1] Both of authors equally contributed to this work.

http://dx.doi.org/10.1016/j.foodchem.2014.09.115
0308-8146/

animal odors (Wirth et al., 2012). However, some different opinions suggested that OTR only affected visual and olfactory perceptions of wine, but had little impact on ''in mouth'' attributes (Caillé et al., 2010).

The level of dissolved oxygen in bottled wine mainly depends upon oxygen concentration in the headspace at bottling and the ingress rate of oxygen into the bottle through stoppers (Godden et al., 2001). Therefore, bottle stoppers determine the dissolved oxygen concentration in wine to a large extent. Generally, synthetic plugs lead to higher oxygen transmittance, whereas the lower oxygen concentration is observed in screw-cap bottled wines, compared to other types of stoppers, such as technical corks and natural corks (Lopes, Saucier, Teissedre, & Glories, 2006, 2007). Polymer synthetic plugs have a good sealing capacity due to good performance on pullout force and resilience, which leads wines to a good quality at least within 24 months after bottle aging (Silva, Lambri, & Faveri, 2003). Synthetic plugs tend to retain more volatile acid and free and total SO_2 in wine after 8 months of bottling. Beyond these, some studies suggested that wines sealed with synthetic plugs lacked fruity aroma and exhibited weak anti-oxidative activity (Godden et al., 2001; Kwiatkowski, Skouroumounis, Lattey, & Waters, 2007; Marin, Jorgensen, Kennedy, & Ferrier, 2007; Silva et al., 2003). However, it also has been reported that synthetic plugs effectively prevented the generation of 'corked taste' and provided white wine with fruity aromas (Francis, 2003). Besides bottle stoppers, storage temperature also can cause some differences in aroma, mouthfeel, and colour of bottled wines (Hopfer, Buffon, Ebeler, & Heymann, 2013).

Bottle-aging is a necessary stage in the production process of wines because it helps to modify various organoleptic properties for good wine quality. The amount of oxygen ingress related to bottle stopper types plays an important role in development of wine organoleptic properties. However, most of the studies so far have been undertaken to study the impact of stopper types on the chemical composition, colour, and flavour of the bottled wines. The literature is scarce on the establishment of the association between the variation of phenolic compounds and the development of wine colour and mouthfeel properties in bottled wines. In the present study we used the wine aged in advance in oak barrels for 12 months, and sealed the wine with six types of bottle stoppers to provide different oxygen environments for post-bottling maturation. Phenolic compounds were qualitatively and quantitatively examined using high performance liquid chromatography-mass spectrometry (HPLC–MS). Sensory evaluation was carried out by a trained panel (20 tasters). The co-development between phenolic compounds and the properties of colour and mouthfeel was assessed by means of statistical tools. The results screened out some phenolic compounds that played a critical role in the evolvement of colour and mouthfeel in wine during bottle-aging, and thus provided important references for improvement of Chinese wine quality.

2. Materials and methods

2.1. Wine samples

The wine samples used for this trial were produced in Beijing Dragon Seal Winery Company during a 2009 vintage from 'Cabernet Sauvignon' (*Vitis vinifera* L. cv.) grapes grown in Huailai County, Hebei Province, China. These wines had been aged in French oak barrels (Shenyang Fresh Wood Industry Co., Ltd. China) for 12 months prior to being bottled. Bottling was performed in mid January 2011 at the packaging line of this winery. Six types of stoppers were used. For each type of stopper, about 100 bottles were required and each bottle was filled with a volume of 750 mL wine. The bottles were held upright for at least 12 h. At the following day, the wines were delivered to the underground cellar of our Center for Viticulture and Enology. All the bottles were stored at a constant temperature of 16–18 °C and a humidity of 60–70% for a period of 18 months. Ten bottles of wines for each stopper type were taken out from the cellar at an interval of three months. Four bottles (considered four biological replicates) were used for the measurements of phenolic compounds, colour parameters, and dissolved oxygen amount. The others were used for sensory evaluation analysis.

2.2. Stoppers

Six types of stoppers used in this experiment included three types of polymer synthetic plugs (named as synthetic plug-1, synthetic plug-2 and synthetic plug-3, respectively), one agglomerated cork, one '1 + 1 technical' cork, and one natural cork. These six bottle stoppers (synthetic plug-1, synthetic plug-2, synthetic plug-3, aglomerated cork, '1 + 1 technical' cork and natural cork) were represented by A, B, C, D, E, and F, respectively. The physical index of the bottle closures is shown in Table 1. Chemical composition differences exist between the polymer synthetic plug-1 and synthetic plug-2/plug-3. The chemical composition of the polymer synthetic plug-2 is similar to that of plug-3, but the length of the plug-2 is 8-mm shorter than the plug-3. The diameter of these three synthetic plugs is smaller than that of the other three corks. The synthetic plugs showed much lower moisture content and much higher density compared with the other three corks, indicating that the polymer synthetic plugs possess poor elasticity.

2.3. Chemicals and standards

Ethyl acetate (analytical grade) was purchased from Beijing Chemical Reagent Company (Beijing, China). Acetonitrile, methanol, formic acid, and acetic acid (HPLC grade) were obtained from Fisher Scientific Co. (Fairlawn, NJ, USA). Deionised water (<18 MΩ resistivity) was obtained from a Milli-Q Element water purification system (Millipore, Bedford, MA).

Table 1
Physical index of various bottle closures used in this study (n = 10).

Physical index	Closure types					
	Synthetic plug-1	Synthetic plug-2	Synthetic plug-3	Agglomerated cork	Technical' cork	Natural cork
Diameter (mm)	21.74	21.58	21.49	23.37	23.36	23.33
Length (mm)	44.72	36.41	44.05	44.07	43.27	43.98
Ovality (mm)	0.18	0.2	0.18	0.24	0.32	0.32
Moisture content (%)	1	0.9	1.4	16	16.6	13
Density (kg/m^3)	514	501	522	284	288	256
Percentage of compression to the original diameter (%)	72	72	73	67	67	67
Rebound rate (%)	98	99	98	97	98	97