Oenological potential and health benefits of Chinese non-*Vitis vinifera* species: An opportunity to the revalorization and to breed new varieties

Gastón Gutiérrez-Gamboa^{1,2,*}, Shu-Yan Liu³, XiangYu Sun^{1,*}, Yulin Fang^{1,*}

¹College of Enology, Viti-viniculture Engineering Technology Center of State Forestry and Grassland Administration, Shaanxi Engineering Research Center for Viti-Viniculture, Heyang Viti-viniculture Station, Northwest A&F University, Yangling, 712100, China. *sunxiangyu@nwfau.edu.cn *fangyulin@nwsuaf.edu.cn

²Universidad de Talca, Facultad de Ciencias Agrarias, 2 Norte 685, Casilla 747, 346000, Talca, Chile. *ggutierrezg@utalca.cl

³Instituto de Ciencias de la Vid y del Vino (CSIC, Gobierno de La Rioja, Universidad de La Rioja). Carretera de Burgos, Km. 6. 26007 Logroño, Spain.

ABSTRACT

The wine industry is focused on the producing wine mostly from European grapevine varieties (*Vitis vinifera* L.). China has experienced a significant growth of the vineyard surface, based on the cultivation of these grapevine varieties. Currently, China has become one of the countries with the largest surface of planted vineyards in the world. In the last years, there has been a trend to oenologically and viticulturally revalorize certain autochthonous grapevine species. China holds a great diversity of *Vitis* species, which are being the focus of study. This could be an important alternative for the diversification of wine production, providing new products with a strong identity. Additionally, the varietal homogenization has increased the vineyard genetic vulnerability in relation to the emergence of grapevine diseases and their resistance to chemical fungicides. In this way, non-*Vitis vinifera* species are characterized by having a high resistance to a wide range of biotic and abiotic factors, which can bring an opportunity to breed new varieties. However, there is little available information about

the oenological potential of these species, which makes it a current interesting topic. Therefore, this review aims to summarize the oenological potential of non-*Vitis vinifera* species found in China, discussing their potential effects on human health and thus, to propose some Chinese wild grapes for their use in breeding programs.

Keywords: Hybrid *Vitis* varieties; *Vitis amurensis*; *V. davidii*; *V. quinquangularis*; *V. vinifera*

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1. Introduction

Currently, China has become in an interesting wine consumer market and is one of the most important wine producers worldwide (Li & Bardají). China's national wine industry contributes around of 70 % of the total wine consumed with a 1.4 billion population market and the second largest economy worldwide (Li & Bardají). Generally, grapevines are one of the most widely distributed crops and grown mostly in different temperate regions along the world and in a minority, in some tropical areas (Lakatos, 1995; da Silva Padilha et al., 2017; Gutiérrez-Gamboa, Liu, & Pszczółkowski, 2020). The *Vitis vinifera* grapevine varieties are the most cultivated worldwide due to their high fruit quality to wine production (Wang, Xie, Chen, Wang, & Li, 2008; Kobayashi et al., 2010; Goto-Yamamoto, Sawler, & Myles, 2015). However, its high susceptibility to many pest, fungal diseases, and extreme temperatures poses a major

problem in the cultivation of grapevines around the World (Wang et al., 2008; Teissedre, 2018). North American and East Asian native species are well adapted to abiotic and biotic stressors, showing different characteristics such as cold-hardiness, short-long growing season and pest resistance (de la Fuente Lloreda, 2018; Teissedre, 2018). Currently, obtain resistance varieties to grapevine diseases without loss of grape berry quality is a crucial challenge for the oenology (Teissedre, 2018). China holds an important abundance of *Vitis* germplasms resources, which are widely distributed along the country (Cheng et al., 2018). These native species found in China have high vigor, strong grapevine diseases resistance, well climate adaptation, high humidity resistance and low light resistance (Zhang et al., 2012; Liang et al., 2013; Jiao et al., 2014; Liu et al., 2015; Han et al., 2017). Native species, such as *V. davidii* F., are characterized by thick dark-red skins producing dark purple or ruby red color wines, in which C6 compounds are the predominant family of volatile compounds (Liang et al., 2013; Meng et al., 2013). On the other hand, berries from *V. quinquangularis* R., species have low sugar content, high acidity and dark-colored skins and the wines produced are characterized by pronounced acid and tannic taste (Zou et al., 2012; Cheng et al., 2018). In this way, the native wild species and their breed hybrid varieties have an important range of volatile compounds relative to varietal aroma and foxy compounds, a high concentration of anthocyanins, low content of tannins, and a considerable acidity, due to this they usually are not attractive for the elaboration of monovarietal wines (Yang, Martinson, & Liu, 2009a; Pedneault, Dorais, & Angers, 2013; Springer & Sacks, 2014; Teissedre, 2018). However, China native wild species wines contain abundant concentration of phenolic compounds with a strong antioxidant activity (Meng et al., 2012a). In this context, Eurasian hybridization might to play a key role to breed new resistant varieties with a specific productive objective in terms of wine quality. The

study of the oenological potential of these Chinese wild native species is increasing due to their possible potential of breed new varieties, which makes it in a current interesting topic. Therefore, this review summarizes the oenological potential of the most important non-*Vitis vinifera* species cultivated in China and how certain viticultural and oenological practices can modify their oenological potential.

2. China

Grapevine varieties (*Vitis vinifera* L.) have been grown in China for more than 2000 years (Li, 2001). However, grape production was negligible until the founding of the People's Republic of China (Li, 2001). Under the influence of the "red wine rush" in the Asian countries, grapevine cultivation became the focus of people's attention in China from the early nineties (Li, 2001). According to the reported by the OIV (2017), China has seen an increase of 177 % in the vineyard surface since 2000, and from 2014 to 2018, it increased by 8 % (OIV, 2019). Almost two-thirds of China's vineyard surface is used for the cultivation of table grape varieties, such as Kyoho (44 %) and Red Globe (18 %). However, in recent years there has been a relatively rapid rise in planted areas devoted to wine grape varieties, such as Cabernet Sauvignon, which is the most planted grapevine variety in China (OIV, 2017). Other varieties, such as Carmenère, Merlot, Cabernet Franc, Chardonnay, Riesling, Syrah and Pinot Noir are also widely cultivated in China (OIV, 2017). Currently, Chinese vineyards do not have phylloxera pest problems, and most of the planting material is propagated by cuttings (Li, 2001). However, in cold regions, the grapevines vines are usually grafted onto cold-resistant rootstocks, such as Beta (a probable hybrid between *V. riparia* and *V. labrusca*) and lines from *V. amurensis* (Li, 2001).

As was mentioned, China is one of the countries rich in resources of *Vitis* germplasm in the world, presenting a wide number of *Vitis* species, characterized by having little size berries with thick dark-red peels, thus they are expected to be utilized for the wine production (Jing et al., 2017). However, only a few native species, such as *V. amurensis* Rupr., *V. davidii* Foex., and *V. quinquangularis* Rehd. are the most distributed and used for vineyard cultivation and wine elaboration (Figure 1). In this way, the utilization in winemaking of other non-*Vitis vinifera* species, such as *V. heyneana*, *V. piasezkii*, *V. bryoniaefolia*, *V. amurensis*, *V. betulifolia*, *V. adenoclada*, *V. yanshanensis*, *V. pseudoreticulata*, *V. heyneana*, among others, is still limited (Yu. et al., 2017). The wild grapes in China are characterized to reach low soluble solids and high acidity content (Table 1), whereas organic acids composition is quite different (Yu et al., 2017, Jing et al., 2017). Contrary to this, hybrids from *V. labrusca* and *V. vinifera* were represented by high soluble solids content and low acidity and organic acids content (Liu, Wu, Fan, Li, & Li, 2006). In this way, the enological potential of the non-*Vitis vinifera* species cultivated in China will be described in the following sections.

2.1. China wine-growing regions

China holds a total cultivated vineyard surface of 830,000 ha (OIV, 2017) and it is the second most important grape producer after Spain (OIV, 2019). Ningxia, Xinjiang, Gansu, Shanxi, Habei, Shandong and Yunnan are the most important wine-growing regions in this country (Figures 1 and 2). China has a scattered distribution of wine-growing regions whose edaphoclimatic conditions are wide different, with a distance of over 2,000 km either from south to north or from east to west (Li, Pan, Jin, Mu, & Duan, 2011; Jiang & Zhang, 2012).

Ningxia is the largest wine region of China, accounting close to 40,000 ha of cultivated vineyards. Ningxia vineyards are located on the alluvial plain in gravelly soils at altitudes close to 1,100 m (Li et al., 2011). Climate is characterized as cool and semi-arid with a wide difference on daytime and nighttime temperature (Jiang & Zhang, 2012). The annual accumulated temperature ranged from 3,298 to 3,351 °C with low annual precipitations of around 150 and 200 mm (Li et al., 2011; Jiang & Zhang, 2012; Jiang, Xi, Luo, & Zhang, 2013). Ningxia climate conditions and the combination of vineyard locations near the foothills of the mountain ranges makes them for optimal conditions for the cultivation of European grapevine varieties, such as Cabernet Sauvignon, Cabernet Franc, Carmenère, Merlot, Syrah, Chardonnay, Riesling, Welschriesling, Semillon and Pinot Blanc.

Xinjiang accounts close to 36,700 ha of cultivated vineyards located in an average altitude of 838 m, in which the main varieties planted are Cabernet Sauvignon, Cabernet Franc and Chardonnay (Wang, Xie, Chen, Wang, & Li, 2018). This region has a semi-arid and desert climate with a wide difference on daytime and nighttime temperature during the growing-season, which allows grapes to have an adequate accumulation of soluble solids and retain high acidity (Fang, Shi, Yang, Yan, & Jiang, 2002; Shi et al., 2006). Most of the locations in Xinjiang have very dry climate conditions, so the incidence of grapevine diseases is low. Xinjiang has an extreme continentality climate, accounting high temperatures exceeding 40 °C in summer and low temperature falling close to -25 °C in winter with annual precipitations of 157.4 mm (Su, Shen, Han, Li, & Lan, 2007). In these conditions, the grapevines have to be buried in the earth every winter for their protection against the extreme coldness.

The corridor area of Gansu Province is one of the most important wine-growing regions in China (Cheng, Fa, Xi, & Zhang, 2015). In this area, there are three

representative wine-growing regions such as Zhangye, Wuwei, and Jiayuguan, in which many wineries have been established (Cheng et al., 2015). The vineyards are located on the desert edge zones at an altitude close to 1214 m (Li et al., 2011). The corridor area presents a cool-arid climate and a wide difference between daytime and nighttime temperatures (Li et al., 2011). The annual accumulated temperature reach from 2800 to 3000 °C and the annual rainfall close to 100 mm (Li et al., 2011). Soils are gravelly sandy and have a high content of salts (Cheng et al., 2015).

Shanxi vineyards have an average altitude of about 1,100 m with clay loamy soils (Jiang & Zhang, 2012; Jiang et al., 2013). Climate conditions of this region are cold and arid with a wide difference on temperature between daytime and nighttime (Jiang & Zhang, 2012; Jiang et al., 2013). The annual accumulated temperature reaches close to 3,000 °C with annual precipitations ranging from 400 to 600 mm and with an annual sunshine time of 2,200–2,500 h (Jiang & Zhang, 2012; Jiang et al., 2013).

Habei vineyards are located on plain valleys at an altitude about 212–600 m with the presence of clay and sandy soils (Li et al., 2011; Jiang & Zhang, 2012; Jiang et al., 2013; Liang et al., 2014). Habei presents cool-warm, semi-humid and semi-arid climate conditions along its surface with a wide difference on temperature between daytime and nighttime (Li et al., 2011; Jiang & Zhang, 2012; Jiang et al., 2013; Liang et al., 2014). The annual accumulated temperature varies from 3,532 to 3,940 °C. The annual sunshine time ranges from 2,600 to 3,072 h and the annual rainfall varies from 413 to 725 mm (Li et al., 2011; Jiang & Zhang, 2012; Jiang et al., 2013; Liang et al., 2014).

Shandong accounts close to 16,600 ha of cultivated vineyards, which are located on the plain zones at the altitude about 40 m with the presence of sandy soils (Li et al., 2011; Liang et al., 2014; Wang et al., 2018). Shandong presents a continental monsoon climate with warm and semi-humid conditions (Liang et al., 2014). This wine-growing

area has slight difference on daytime and nighttime temperatures (Li et al., 2011). The annual accumulated temperature ranges from 3,800 to 4,200 °C and the annual sunshine accounts close to 2,825 h (Li et al., 2011; Liang et al., 2014). The annual precipitations vary from 664 to 800 mm (Li et al., 2011; Liang et al., 2014).

Yunnan vineyards are located on the valley zones at an altitude varying from 1,900 to 3,500 m (Li et al., 2011). As the Shandong region, this wine-growing region is one of the warmest zones of China (Figure 2). Yunnan presents a warm-arid climate with a wide difference on daytime and nighttime temperature (Li et al., 2011). The annual sunshine time is close to 1,987 h, whereas the annual precipitations range from 300 to 600 mm (Li et al., 2011). Therefore, these unique edaphoclimatic conditions allows to China possess the capability to produce various types of wines with different styles and flavors and to keep a wide distribution of native wild species along its territory.

2.2. Description of non-*Vitis vinifera* species

Most of the grapevines are domesticated varieties from the *Vitis vinifera* specie, which was originated in the Caucasus and spread from there to Europe and subsequently to other grape growing regions worldwide (Terral et al., 2010; Mariani, Cola, Maghradze, Failla, & Zavatti, 2018). There are an around 60 species of the *Vitis* genus distributed broadly across the northern hemisphere, and many native wild grapevines are current used to breed new varieties since they harbor desirable traits like disease resistance and tolerance to abiotic stress (Gray, Li, & Dhekney, 2014; Goto-Yamamoto et al., 2015). Chinese native wild *Vitis* species are distributed in four main viticultural zones (Wan et al., 2008). These authors reported that the Qinling Montains, the Bashan Montains, and the provinces of Jinagxi, Hubei, Hunan, and Guangxi hold a high

diversity of non-*Vitis vinifera* species accounting over 30 species (Wan et al., 2008). These aforementioned Chinese regions may be considered as the major center of origin for *Vitis* species. Certain non-*Vitis vinifera* species, such as *V. pentagona*, *V. flexuosa*, *V. davidii*, and *V. wilsonae* have a wide eco-geographic distribution along China, whereas *V. hancockii*, *V. bellula*, and *V. sinocinerea* are tightly distributed (Wan et al., 2008). The wild *Vitis* species of China are differentiated and adapted to local climates. In this way, *V. adenoclada*, *V. romanetii*, *V. wilsonae* and *V. davidii* are tolerant species for high moisture and have little cold-hardiness and are mainly located in the middle subtropical zone of China (Wan, Schwaninger, He, & Wang, 2007; Wan et al., 2008; Meng, Fang, Qin, Zhuang, & Zhang 2012b). Other species, such as *V. pseudoreticulata*, *V. chunganensis*, *V. balanseana*, and *V. rotundifolia* have strong tolerance to moisture and heat and are located in South of China (Wan et al., 2008; Xu et al., 2014a). Certain species, mostly located in North of China, such as *V. piasezkii*, *V. bryoniaefolia*, *V. yeshanensis* and mainly *V. amurensis* have strong resistance to cold conditions, withstanding freezing temperature as low as -40°C , due to the activation of ICE1 and ICE2 genes (Wan et al., 2008; Liu & Li, 2013; Xu et al., 2014b). Certain species, such as *V. romanetii*, *V. pseudoreticulata*, *V. balanseana*, *V. adenoclada* and *V. davidii* have strong resistance to grapevine diseases affected in warm humid zones, such as powdery mildew and ripe rot (Wan et al., 2007; Li, Wan, Wang, & He, 2008; Wan et al., 2008).

Chinese wild *Vitis* species present a wide range of resistance characteristics that allows to be consider them in breeding programs (Tian, Wang, Niu, & Tang, 2008; Yu et al., 2013; de la Fuente Lloreda, 2018). Among these considerations, Wan et al. (2007) reported that *V. amurensis*, *V. romanetii*, *V. piasezkii*, *V. davidii*, *V. davidii* var. *cyanocarpa*, *V. liubanensis* and *V. bashanica* showed resistance to powdery mildew (*Uncinula necator*), whereas *V. yeshanensis*, *V. davidii* var. *cyanocarpa*, and *V.*

pseudoreticulata exhibited resistance to downy mildew (*Plasmopara viticola*). Despite these particularities, these authors reported that there was an important variation in the resistance characteristics regarding both studied diseases, between the species and also, to a lesser degree, among the studied genotypes, suggesting that these variations should be considered to obtain genotypes in breeding programs. Li et al. (2008) reported that all the studied accessions and Chinese wild species, such as *V. amurensis*, *V. quinquangularis*, *V. romanetii*, *V. adstricta*, *V. pseudoreticulata*, *V. piasezkii*, *V. davidii*, *V. davidii* var. *cyanocarpa*, *V. liubanensis*, *V. qinlingensis*, *V. bashanica*, *V. yeshanensis* and *V. hancockii* showed resistance to anthracnose (*Elsinoë ampelina*), whereas *V. quinquangularis* accessions and one accession of *V. romanetii*, *V. adstricta* and *V. pseudoreticulata* exhibited susceptibility to white rot (*Coniothyrium diplodilla*). These authors suggested that European varieties, such as Cabernet Sauvignon and Chardonnay were susceptible to anthracnose and highly susceptible to white rot. Zhang et al. (2012) reported that the following Chinese native species presented cold resistance, which are ordered from high to low resistance: *V. amurensis*, *V. yeshanensis*, *V. adstricta*, *V. pseudoreticulata*, *V. quinquangularis*, *V. piasezkii*, *V. hancockii*, *V. ficifolia*, *V. romanetii*, *V. davidii*, *V. piasezkii* var. *pagnucii*, *V. bashanica*, *V. liubaensis*, *V. qinlingensis*, *V. davidii* var. *cyanocarpa*, *V. wilsonae*, *V. baihensis*, and *V. davidii* var. *ninqiangensis*, whereas, among the American native species, *V. riparia*, *V. arizonica*, *V. rupestris*, *V. rotundifolia* and *V. californica* presented high cold-resistance, and *V. labrusca* and *V. cinerea* showed medium cold-resistance. These authors also reported that the most cold-resistant studied accession was *V. riparia* Mcadams.

Below we present a summary of the available information about the oenological potential of the most important non-*Vitis vinifera* species cultivated in China (Tables 1 and 2).

2.2.1. *Vitis davidii*

Vitis davidii Foex, also known as the Chinese Bramble Grape, is an important wild grape specie in South China, that is mainly distributed in the mountains covered by the subtropical rainforest to the south of the Yangtze River (Meng et al., 2012c). Viticulturally, their shoots are glabrous and has prickles (Figure 3), which is a morphological condition wide different from other *Vitis* species (Wu, Raven, & Hong, 2004). *V. davidii* is adapted to high temperature and humidity conditions and have certain resistance to pests and diseases (Wu et al., 2004). It has been reported that single berry weight of *V. davidii* was higher than the berries harvested from other Chinese wild grape species and Cabernet Sauvignon (Yu et al., 2017). The wines obtained from *V. davidii* grapes are dark purple or ruby red and have a distinct aroma that reflect the taste of the variety (Liang et al., 2013). The aromatic descriptors of *V. davidii* wines are wild rose, violets and wild strawberries (Meng et al., 2013).

According to their oenological potential, *V. davidii* showed lower total acidity and tartaric acid to malic acid ratio than Cabernet Sauvignon (Yu et al., 2017). In addition, *V. davidii* reached higher flavanols content in skin berries than Cabernet Sauvignon samples (Jing et al., 2017). Meng et al. (2012b) reported that catechin was the most abundant phenolic compound, whereas hydroxycinnamic acids were the major family of phenolic acids in *V. davidii* in grapes. These oenological characteristics are of wide importance since these phenolics compounds play a key role on wine sensory properties, color stability and its antioxidant capacity, contributing to healthy beneficial properties (Li & Sun, 2019). Dietary flavanols have many beneficial health effects, such as antitumorigenic, antimutagenic, antipathogenic and antioxidative properties (Kondo et al., 1994; Tarola & Giannetti, 2007; Giovinazzo & Grieco, 2019). This makes

interesting the study of non-*Vitis vinifera* species because their concentrations in grapes and wines are commonly higher than European *Vitis* species. Additionally, hydroxycinnamic acids play a key role on endothelial inflammatory gene expression, which depends on their origin and absorption (Calabriso et al., 2015). Meng et al. (2012b) reported that Junzi #1, a red variety obtained from *V. davidii*, presented the highest phenolic content and the strongest antioxidant capacity compared to Junzi #2, Liantang and Baiyu (a white variety), suggesting that this wild red variety has an important utilization value and potential for development in oenology. Meng et al. (2012c) reported that the most abundant anthocyanin in wines elaborated from *V. davidii* was malvidin-3,5-diglucoside (diglc), which was also reported by Liang et al. (2013), while the flavanols were the major phenolic compounds. The scientific community has been accepted that malvidin-3,5-diglc is not synthesized in *Vitis vinifera* grapevine varieties. However, Xing et al. (2015) detected the existence of this anthocyanin at low levels in Cabernet Sauvignon grape berries from China. Malvidin-3,5-diglc is related to promotes a significant decrease of lipid peroxides in serum and thiobarbituric acid-reactive substances levels in plasma (Toaldo et al., 2015). Also, it has been reported that this anthocyanin has anti-cariogenic properties against a wide range of oral bacteria (Esmaelian et al., 2007). Liang et al. (2013) reported that quercetin-3-rhamnoside (rha) was the main singular flavonol, while coumaric acid and ferulic acid were the dominant phenolic acids in *V. davidii* grape skins. Quercetin-3-rha was reported to promote antiviral activity against influenza A/WSN/33 virus, so that quercetin-3-rha could be an attractive lead for the development of antiviral agents against influenza virus (Choi, Song, Baek, & Kwon, 2009; Choi, Song, & Kwon, 2012). Xu, Zhang, Cao and Lu (2010) showed that the grapes from Oriental *Vitis* species, such as *V. davidii* and *V. ficifolia* presented the highest values of total phenols and

flavonoids, respectively, compared to north American *Vitis* hybrids and *V. vinifera* varieties. These authors also reported that Cabernet Sauvignon presented the highest values of phenolic compounds and antioxidant properties in seeds followed by Muscadines, while the lowest values appeared in the Oriental *Vitis* species. Liang et al. (2013) reported that *V. davidii* grapes presented abundant flavonols in the early middle of ripening stages and a high level of malvidin-type anthocyanins during late maturity stage. In this way, Sun et al. (2016) reported that *3AT* (*VIT_03s0017g00870*) gen played an important role in anthocyanin acylation in *V. davidii*, whereas *GST4* (*VIT_04s0079g00690*) and *AM2* (*VIT_16s0050g00910*) genes played important roles in anthocyanins transport in *V. davidii* along fruit development stages.

Several volatile compounds such as geranylacetone, mequinol, and eugenol were isolated from the spine grape from *V. davidii*, that have not been reported for other *Vitis* species, while (E,E)-2,4-hexadienal, which is not produced by *V. vinifera*, was also found in the spine grape in a wide concentration (Meng et al., 2013). Despite this differentiating attribute reported by these authors, the (E,E)-2,4-hexadienal has been found in grape berries from different *V. vinifera* grapevine varieties, such as Airén, Cabernet Sauvignon, Chardonnay, Kyoto, Macabeo, Sauvignon Vert and Tempranillo Blanco (García, Chacón, Martínez, & Izquierdo, 2003; González-Barreiro, Rial-Otero, Cancho-Grande, & Simal-Gándara, 2015; OuYang et al., 2015; Savoi et al., 2016; Martínez, Rubio-Bretón, Vicente, & García-Escudero, 2018; Wang et al., 2019). On the other hand, it was reported that C6 compounds were the predominant family of aromatic volatile compounds in most of the *V. davidii* spine grape clones, being *trans*-2-hexenal the most predominant (Meng et al., 2013). C6 compounds are enzymatically synthesized in grapes from polyunsaturated fatty acids as consequence by mechanical damage (González-Barreiro et al., 2015). These compounds constitute the major aroma

derivatives responsible for green and herbaceous aroma (Waterhouse, Sacks, & Jeffery, 2016). C6 compounds are usually found in high quantity in the wines produced from unripen grapevines (Bindon, Varela, Kennedy, Holt, & Herderich, 2013). C6 alcohols decreased during the grapevine ripening, whereas C6 aldehydes were accumulated until the harvest maturity, and then began to decrease (Fang & Qian, 2012). Therefore, it is important to consider berry ripening behavior in breeding programs to avoid or limit these undesirable characters in the produced wines. Finally, Meng et al. (2013) suggested to the Seputao clone, (*V. davidii*) over others, such as Miputao #1, Miputao #2, Miputao #3, Xiangzhenzhu #1, Xiangzhenzhu #2, Xiangzhenzhu #3, Tianputao Baiputao, as a candidate for development of higher utilization value in oenology.

Currently, one of the biggest challenges in the wine industry is to create alternatives to process the large amount of wastes (Bordiga, 2016). In this way, vine-shoots are usually burned and disposed in the vineyard, becoming a source of ecological and environmental pollution (Sánchez-Gómez, Zalacain, Alonso, & Salinas, 2016a). Re-valorization of *V. vinifera* vine-shoots as biostimulants, biopesticides, oak chips, oenological tannins and alternative to SO₂ has been reported by certain authors, due to their wide abundance of phenolic compounds, mainly of stilbenes (Raposo et al., 2016; Sánchez-Gómez et al., 2016b, 2016c, 2017, 2017b; Cebrián-Tarancón et al., 2017, 2018a, 2018b, 2019a, 2019b). In this way, vine-shoots from *V. davidii* had higher total phenolic content, total flavonoid content and antioxidant activities than the vine-shoots from *V. vinifera*, *V. amurensis*, and *V. pentagona* (Figure 3), in which catechin, epicatechin and *trans*-resveratrol were the most abundant phenolic components of the vine-shoot extracts. Therefore, non-*Vitis vinifera* vine-shoots from annual pruning practice considered as waste material have good commercial potential for the oenology

and in their utilization as a promising natural antioxidant in the food, pharmaceutical and cosmetic industries, given its low cost and availability in large amounts.

2.2.2. *Vitis amurensis*

Vitis amurensis Rupr is an Asian native *Vitis* specie, coming from the Amur Valley in Russia, which is characterized by an exceptional wild growing behavior that can survive under a wide range of cold conditions (Xu et al., 2014c). Due to these characteristics, current studies have been developed to understand the underlying cold-adaptive mechanisms associated with its gene regulation (Wan et al., 2008; Zhang et al., 2012; Xu et al., 2014b, 2014c). This *Vitis* specie has a strong root system and high vigor allowing it to resist temperature bellow to -40°C without the need to bury its vines, offering also strong resistant to white rot and anthracnose (Liu & Li, 2013). Thus, this specie is often used as a disease-resistant stock as well as the most powerful cold-resistant rootstock to breed materials for novel cultivars (Liu & Li, 2013).

Zhang and Li (2006) reported that *V. amurensis* grape berries contains a wide range of nutrients, such as glucose, sucrose, proteins and vitamins, suggesting that this specie could provide excellent raw materials for wine making. According to the showed by Liu and Li (2013), at the moment when the grape berries reach their optimal maturation, they turn to purple-black color with a thick pericarp, containing less juice, but with a fine taste, presenting two or four seeds. These authors stated that this *Vitis* specie requires an effective accumulated temperature of 2000 to 2200 $^{\circ}\text{C}$ to complete its annual vegetative growth. Zhao, Duan and Wang (2010) exhibited that the most abundant anthocyanin in *V. amurensis* wines was malvidin-3,5-digluc, following by delphinidin-3,5-digluc and they were characterized by an unusual color, aroma and taste, quite different from the wines made from *V. vinifera*. Due to the high concentration of

these anthocyanins, mostly by delphinidin and the must pH, the produced *V. amurensis* wines present a characteristic dark color. Zhao et al. (2010) also reported that the anthocyanins profile of grape skins contains mono-glucosides, di-glucosides and pyrano-anthocyanins, whereas pelargonidin-3,5-diglc was found in the skins and wines. Generally, pyrano-anthocyanins are important components aged wine color, contributing to its orange color. Additionally, these compounds are very little sensitive to changes in pH and discoloration with SO₂, so they are chemically very stable (Francia-Aricha, Guerra, Rivas-Gonzalo, & Santos-Buelga, 1997; Sarni-Manchado, Fulcrand, Souquet, Cheynier, & Moutounet, 1999; Waterhouse et al., 2016). On the other hand, the anthocyanins concentration found by Zhao et al. (2010) in the wines produced from *V. amurensis* and its hybrids was widely higher than to those reported in wines from different *V. vinifera* grapevine varieties (Portu, López, Baroja, Santamaría, & Garde-Cerdán, 2016; Carrasco-Quiroz, Martínez-Gil, Gutiérrez-Gamboa, & Moreno-Simunovic, 2020; Gutiérrez-Gamboa et al., 2017, 2018a, 2019a, 2020).

Berry skins from *V. amurensis* grapevines contains high content of flavanols and pigments, which results in the production of dark color wines with a strongly astringent mouthfeel (Liu & Li, 2013). Song et al. (2001) proposed a differentially winemaking process to improve these undesirable mouthfeel characteristics of *V. amurensis* wines. In this way, grape skins were fermented during 3 to 4 days, followed by an immediately pressure, and a subsequent fermentation of the obtained middle-fermented juice. This allowed to obtain a ruby red color dry wine with sweet flowery and fruity aromas, reducing bitterness and astringency. However, the key factor to obtain high quality wines is the deacidification of wines, which is usually performed by the winemakers and has been the subject of study by some researchers. Lv, Feng and Yan (2005) reported that the free must deacidification before alcoholic fermentation and then

mixing it with the grape pomace for the further alcoholic fermentation allowed to modify wine acidity, avoiding the decrease in the production of fermentative volatile compounds. Jiang, Nan and Li (2008) studied different methods to the deacidification of *V. amurensis* wines, reporting that the must deacidification before alcoholic fermentation did not affect wine body, avoided the production of undesirable aroma in wines but nevertheless, the mouthfeel sensations were not enterally acceptably. These authors reported that the use of an anion exchange column to deacidify the wines was the best method, however the wine sensory attributes were diluted, and the economical inputs increased. Similar results were found when the authors used acid decreased yeast strains to carry out alcoholic fermentation of wines from this native *Vitis* specie.

Beihong is a late-ripening red variety derived from Muscat Hamurg and *Vitis amurensis* (Du et al., 2012). This variety presents a value of soluble solid that range between 23.8 to 27.9 % (w/w), pH values varying from 3.2 to 3.4, presenting high concentration of esters, mainly of ethyl octanoate and ethyl decanoate responsible for fruity and floral descriptors (Du et al., 2012). Beihong is highly resistant to cold and can be cultivated in most places in Northern China without needing to be covered in winter when the temperature is usually very low (Du et al., 2012). Additionally, Beihong has a high resistance to disease and can grow in some of the warm humid areas of Southern China (Du et al., 2012). C6 compounds were the dominant volatiles compounds in grapes harvested from *V. amurensis*, *V. vinifera* and hybrids between *V. vinifera* with *V. thunbergii* or *V. amurensis* (Yang et al., 2009b). Alcohols and carbonyls were relatively low in all *Vitis* germplasm studied, while terpenoids were abundant in *V. vinifera* with muscat aroma, and esters were dominant in *V. labrusca* and its hybrids with *V. vinifera* or *V. amurensis* (Yang et al., 2009b).

Current wine market has experienced several changes in relation to diversify its productivity towards more healthy wines (Dunn, Xu, & Schwimmer, 2008; Pastor et al., 2017). Low and non-alcoholic beverages have been introduced into the wine marking with an incipient acceptability (Smith & Solgaard, 2000; Bruwer, Jiranek, Halstead, & Saliba, 2014). These consumer behaviors have changed the market trend from high-alcohol wines to low-alcohol or no-alcohol wines. However, during the last years, the viticulture has experienced a series of modifications due to the increase in temperatures, which advanced grapevine ripening and producing by consequence unbalances between phenolic and technological maturity (Meléndez, Ortiz, Sarabia, Íñiguez, & Puras, 2013; Van Leeuwen & Darriet, 2016; Gutiérrez-Gamboa et al., 2019b). The production of low-alcoholic wines from *V. vinifera* grapevines, high cost demand since the grapes tend to accumulate a higher sugar content than the grapes from other *Vitis* species, phenomenon that deepens due to the current unsustainable rise in temperatures (Jones, White, Cooper, & Storchmann, 2005; Duchêne, Huard, Dumas, Schneider, & Merdinoglu, 2010; Sgubin et al., 2018). In this way, the elaboration of low alcoholic wines from *V. amurensis* grape berries could be a suitable alternative based on the aforementioned characteristics (Table 1). The dry wines from *V. amurensis* can reach between 8 to 9 % (v/v) alcoholic degree. Ice wines are novel products that are mainly produced in cold wine-growing, such as Canada, and could be a potential alternative for *V. amurensis* diversity of its production (Bowen & Reynolds, 2012; Slegers, Angers, Ouellet, Truchon, & Pedneault, 2015). According to this, Li et al. (2016) studied phenolic and chromatic characteristics of ice wines made from Beibinghong, a hybrid cultivar resulting from the crossing between *V. vinifera* and *V. amurensis*. These authors reported that phenolic acids were the primary non-anthocyanin phenolics reached from 6.6 % to 7.5 % of total phenolic composition. These findings were also reported by

Kilmartin, Reynolds, Pagay, Nurgel and Johnson (2007) in ice wines elaborated from Riesling and Vidal varieties. Li et al. (2016) also reported that 3,5-diglc anthocyanins and protocatechuic acid, differentiated Beibinghong dry wines compared to *V. vinifera* dry red wines, which were positively correlated with the hue and yellow % of the wine.

Grape pomace, as well as leaves and canes generated by the wine industry are excellent and valuable resources to recover polyphenolic compounds with strong antioxidant capacity with potential health benefits (Fontana, Antonioli, & Bottini, 2013; Sánchez-Gómez et al., 2014, 2017b; Aguilar et al., 2016, 2018; Ju et al., 2016; Peixoto et al., 2018). Leaves, shoots (Figure 3) and roots of *V. amurensis* have been used since several hundred years in the conventional Chinese medicine (Liu & Li, 2013; Chen, Diao, Song, & Zhu, 2018). According to this, *V. amurensis* has been used to treat stranguries, rheumatoid arthritis-associated edema, chronic hepatitis, nephritis, chronic arthritis and traumatic hemorrhage (Chen et al., 2018). These beneficial health properties are related to its high content of several secondary metabolites, such as oligo-stilbenes, flavonoids, and anthocyanins, phytochemicals that are associated with antioxidant, anti-inflammatory, antibacterial and cardioprotective activities (Shrikhande, 2000; Leifert & Abeywardena, 2008; Guilford & Pezzuto, 2011; Calabriso et al., 2015; Fernandes, Pérez-Gregorio, Soares, Mateus, & de Freitas, 2017; Chen et al., 2018; Giovinazzo & Grieco, 2019). According to this, Zhang, An and Yu (2007) reported that polyphenols from *V. amurensis* could reduce hypertension induced by angiotensin II. Weidner, Karamać, Amarowicz, Szypulska and Gołgowska (2007) reported that seed extracts from *V. amurensis* germinated under osmotic stress conditions contained a wide range of flavonoids and non-flavonoids compounds with strong anti-free radical activities. Huang, Lin, Yu, and Kong (2000) reported that root extracts from *V. amurensis* contain a wide range of phenolic compounds, such as oligo-stilbenes,

resveratrol trimers of amurensins C and D and resveratrol pentamers of amurensins E and amurensins F with a great potential to inhibit biosynthesis of leukotriene B₄ (LTB₄). Yim et al. (2010) found that *V. amurensis* leaves and vine-shoots contain different polyphenols and oligo-stilbenes with antimicrobial effects against *Streptococcus mutans* and *S. sanguis*, which are related to tooth decay and periodontal disease, respectively. Nguyen et al. (2011) reported that *V. amurensis* extracts have a wide range of oligo-stilbenes, which showed synergistic effects on controlling influenza infections and could be the neuraminidase inhibitors of the novel influenza A (H1N1). Due to its wide content of bioactive compounds, the by-products of *V. amurensis* could be used for developing new pharmaceutical and food products, such as functional juices, food additives, drugs, beverages, vinegars, textile dyeing, oils, among others. Additionally, due to these aforementioned bioactive characteristics, *V. amurensis* vine-shoots could also be used as biostimulants, biopesticides, oak chips, oenological tannins and alternative to SO₂ as was previously discussed. Therefore, *V. amurensis* should be considered in the current breeding programs for obtain new cultivars, which deserves further study.

2.2.3. *Vitis quinquangularis*

Vitis quinquangularis Rehd is a native wild specie locally known as the pentagon-leafed grape, which is distributed in south of the Yellow River (South of China) in regions that have sufficient sunshine and are at an altitude lower than 1,500 m (Liang et al., 2013). This *Vitis* specie is susceptible to downy mildew, but nevertheless they have strong resistance to powdery mildew and gray mold (He & Niu, 1989; Wan et al., 2008; Zou, 2008). In addition, *V. quinquangularis* has good adaptability to high temperature and high humidity climate conditions (He & Niu, 1989; Zou, 2008). In

terms of grape quality, *V. quinquangularis* grape berries accumulate low soluble solids content and high acidity (Table 1), and present dark-colored skin (Liang et al., 2013). The wines produced from this *Vitis* specie have a characteristic varietal aroma and pronounced acidity and tannic taste (Zou, 2008; Liang et al., 2013). The wines from Chinese wild grape species such as *V. amurensis*, *V. davidii*, *V. quinquangularis* and their hybrids are characterized by fruity, roast, and herbaceous notes due to their differences on esters, aldehydes and terpenes concentration (Wei, Liu, Huang, Lu, & Zhang, 2018). In this way, *V. quinquangularis* were characterized by nonanal, decanal, decanoic acid ethyl ester, 4-ethylguaiaicol, whereas the esters reached higher odor activity values (OAV) compared to most of the wines produced from other *Vitis* species (Wei et al., 2018).

The flavonoids composition of *V. quinquangularis* presented a high percentage of 3',4'-substituted anthocyanins generated from the F3'H branch pathway and a relatively high percentage of 3',4',5'-substituted flavanols synthesized through the F3'5'H branch pathway (Liang et al., 2013). Additionally, in this specie, delphinidin derivatives (47.86 %) were the most important anthocyanins, following by cyanidin (17.54 %), petunidin (15.36 %), malvidin (10.88 %) and finally by peonidin (8.37 %) derivatives instead of *V. davidii*, in which malvidin-type (88.58 to 98.15 %) anthocyanins were the most abundant (Liang et al., 2013). Stability of anthocyanins increases with the number of methoxyl groups linked to the B-ring and decreases with the number of hydroxyl groups linked to this ring. In this way, the most stable anthocyanin is malvidin, following by petunidin and peonidin, whereas the least stable anthocyanin is delphinidin (Escribano-Bailón, Rivas-Gonzalo, & García-Estévez, 2019). Additionally, these both aforementioned species presented very high levels of anthocyanidin di-glucosides compared to the mono-glucosides, presenting similar levels

of non-acylated and acylated anthocyanins, with very high levels of coumaroylated anthocyanins (Liang et al., 2013). The presence of glycosylated of anthocyanins enhanced its stability, so anthocyanin di-glucosides are more stable than their corresponding mono-glucoside derivatives, although their products are prone to be involved in browning reactions (Hrazdina, 1970; Escribano-Bailón et al., 2019). In this way, Stintzing, Stintzing, Carle, Frei and Wrolstad (2002) showed that the type of glycosidic and acylation substitution influences the anthocyanin tone. Glycosidic substitutions in position 5 as well as aromatic acylations, produce a shift towards purple hues. Thus, anthocyanin composition of *V. vinifera* grapes is widely different than these aforementioned *Vitis* species, in which non-acylated derivatives represent between 57 to 75 % of total anthocyanins compared to acetyl, coumaroyl and caffeoyl derivatives (Núñez, Monagas, Gomez-Cordovés, & Bartolomé, 2004; González-Neves et al., 2007; Castillo-Muñoz, Fernández-González, Gómez-Alonso, García-Romero, & Hermosín-Gutiérrez, 2009; Gutiérrez-Gamboa et al., 2017). Colorimetric analysis showed that the wines from *V. quinquangularis* specie presented the most saturated red color compared to other *Vitis* germplasms cultivated in South of China, such as Moldova (*V. vinifera* × *V. labrusca*), Conquistador and Saint-Croix (*V. labrusca*), Yenang No.2 (*V. quinquangularis*), NW196 (*V. quinquangularis* and *V. vinifera*), Xiangniang No.1 (*V. davidii*) and Noble (*V. rotundifolia*), which was in accordance to the sensory evaluation performed by the judges (Cheng et al., 2018). On the other hand, Wei et al. (2018) reported that total phenolic content in *V. quinquangularis* wines were lower than the wines from Cabernet Sauvignon and Carmenère. However, it is possible that the warm and humid conditions in which *V. quinquangularis* grapevines are cultivated allowed to the degradation of phenolic compounds and by consequence reach a lower total phenolic content than the *V. vinifera* wines (Mori, Goto-Yamamoto, Kitayama, &

Hashizume, 2007; Azuma, Yakushiji, Koshita, & Kobayashi, 2012) Despite this, similar results were showed by Xu et al. (2010), who reported that *V. quinquangularis* seeds presented lower total phenol content than several interspecific hybrids. However, *V. quinquangularis* skins presented the highest total phenol content compared to *V. amurensis* and *V. rotundifolia* species, and Euro-Asian and Euro-American hybrids.

The Chinese *V. quinquangularis* specie has a higher production of resveratrol than *V. vinifera* due to the expression of stilbene synthase, highlighting the *VqSTS6* gene (Shi et al., 2014; Cheng et al., 2016; Yin et al., 2017). In this way, grape berries from the Danfeng-2 Chinese accession (*V. quinquangularis*) contains widely higher levels of resveratrol at harvest than others, including certain *V. vinifera* varieties, such as Pinot Noir and Cabernet Sauvignon (Shi et al., 2014). The wild *V. quinquangularis* accession Danfeng-2 originates from the North-West of China and is characterized by having a highly resistant to powdery mildew and by its high levels of resveratrol in grape berries, which make it is suitable for winemaking (Wang, Ruan, & Li, 2000). Therefore, these characteristics lead to a high potential to wild Chinese grape species for their use in breeding, which would raise both the disease resistance and the oenological quality of *V. vinifera* grapevines.

Recently, the study about yeast diversity in spontaneous fermentations and their possible correlation with grape varieties grown in an ecological environment is increasing due to its economic, biological and sustainable implications (Drumonde-Neves et al., 2018). The yeast species and their corresponding populations exhibited differences among the grape varieties and species (Ye et al., 2019). In this way, *Kazachstania hellenica* was the dominant yeast species in *V. amurensis* (51.3 %) fermentations probably due to the humid summer of Zhengzhou (Ye et al., 2019). *Hanseniaspora uvarum* was the predominant yeast species in *V. davidii* (66.3 %)

fermentations. On the other hand, *Hanseniaspora thailandica* started the spontaneous fermentation of *V. quinquangularis* wines and then, *H. opuntiae*, *H. occidentalis*, *H. guilliermondii*, *Saturnispora diversa* were developed and, finally these yeasts species were replaced and dominated by *Saccharomyces cerevisiae* (Yang et al., 2016). In addition, in ecological environment of *V. quinquangularis* producing area of Guangxi, *H. guilliermondii* was the dominant yeast species on grape skins (Yang et al., 2016).

2.2.4. Other non-*Vitis vinifera* species

As was previously stated, only a few Chinese native species, such as *V. davidii*, *V. amurensis* and *V. quinquangularis* are used in oenology, whereas the utilization of other non-*Vitis vinifera* species is still limited in the Chinese wine industry. Liang, Yang, Cheng and Zhong (2012) reported that both, mono and di-glucoside anthocyanins were abundantly presented in berry grapes from all the studied Chinese wild species, such as *V. acerifolia*, *V. aestivalis*, *V. amurensis*, *V. cinerea*, *V. labrusca*, *V. riparia*, *V. rupestris*, *V. vulpine*, *V. yenshanensis*, *V. palmata*, *V. andersonii*, *V. champinii*, *V. doaniana*, *V. novaeangliae*, *V. monticola* and *V. coignetii*. These authors also observed that more than 60 % of the anthocyanins were non-acylated in all the studied Chinese non-*Vitis vinifera* species with the exception of *V. labrusca*, in which non-acylated anthocyanins reached 35 % of total anthocyanins. The anthocyanins have low stability of flavylium nucleus, which allows it to reach a high reactivity, reason for that the anthocyanins are involved in several reactions along winemaking and aging of wines contributing to wine color stability (Escribano-Bailón et al., 2019). In this way, anthocyanins with aromatic acyl residues have more stable colors and higher molar absorption coefficients in weakly acidic solutions than anthocyanins devoid of them (Escribano-Bailón et al., 2019).

Respect to the rest of *Vitis* species studied by Liang et al. (2012), *V. coignetii*, *V. acerifolia* and *V. riparia* species presented small berries, whereas *V. labrusca*, *V. champinii*, *V. novaengliae* species presented large berries compared to the rest of the Chinese native *Vitis* species. These aforementioned conditions limited the soluble solids content in grapes of the different Chinese non-*Vitis vinifera* species due to dilution and concentration effects since soluble solids content in *V. coignetii*, *V. acerifolia* and *V. riparia* were higher than the rest of the studied *Vitis* species. The most abundant phenolic compounds in these *Vitis* species were anthocyanins, hydroxycinnamic acids and flavanols (Liang et al., 2012). Total anthocyanin concentration in grapes from *V. rupestris*, *V. acerifolia*, *V. riparia*, *V. doaniana* and *V. novaengliae* species was widely higher than the grapes from the rest of the studied *Vitis* species (19.1, 18.3, 15.7, 15.4 and 14.3 mg/g of fresh weight (FW), respectively). Total flavanol concentration in grapes from *V. palmata* was the highest among the studied *Vitis* species (1.903 mg/g of FW), followed by *V. coignetii* (1.209 mg/g of FW). Total concentration of flavanols in grapes from *V. riparia*, *V. andersonii*, *V. novaeangliae*, *V. doaniana* and *V. yenshanensis* species was 0.729, 0.783, 0.635, 0.744, 0.762 mg/g of FW, respectively. In addition, grapes from *V. moticolia* and *V. champinii* species contained the lowest total flavanols concentration (0.289 and 0.318 mg/g of FW, respectively). The concentration of total hydroxycinnamic acids (HCAs) in grapes of *V. coignetii*, *V. aestivalis* and *V. labrusca* species were the highest accounting 1.095, 0.875 and 0.868 mg/g of FW, respectively. Contrary to this, *V. cinerea*, *V. champinii* and *V. moticolia* species had the lowest content of total HCAs in grapes, accounting 0.281, 0.283, and 0.305 mg/g of FW, respectively. Caftaric acid was the most abundant HCA found in grapes from these Chinese *Vitis* species, accounted around 72.2 % of the total HCAs, whereas coumaric acid was the second most abundant HCA, accounting around 17.1 % of the total HCAs

(Liang et al., 2012). Caftaric and coutaric acids are the most abundant HCAs in grapes from *V. vinifera* grapevines varieties with similar concentrations between them or in some cases half the content of Caftaric acid (Castillo-Muñoz et al., 2009; Portu et al., 2015, 2016; Martínez-Gil, Gutiérrez-Gamboa, Garde-Cerdán, Pérez-Álvarez, & Moreno-Simunovic, 2017; Gutiérrez-Gamboa & Moreno-Simunovic, 2018; Gutiérrez-Gamboa et al., 2018b). The concentration of resveratrol in grapes ranged from 0.0003 to 0.013 mg/g of FW in *V. labrusca* to and *V. aestivalis* species, respectively. The concentration of *V. palmata* and *V. riparia* reached 0.008 and 0.006 mg/g of FW, respectively (Liang et al., 2012). According to report performed by Liang et al. (2011), the concentration of resveratrol in *V. vinifera* grapes was about 0.002 mg/g of FW, only about a half that of the Chinese wild *Vitis* species. Xu et al. (2010) reported that Oriental grapes from *V. ficifolia* (Sangye) grapevines presented much higher total phenols, flavonoids and anthocyanins than *V. vinifera* and *V. rotundifolia* species as they had higher total phenols, flavonoids and anthocyanins in skin than others. Similar results were reported by certain authors, who found that total phenols in skin extracts of *V. vinifera* and *V. rotundifolia* were lower than in seed extracts (Striegler et al., 2005; Iacopin, Baldi, Storchi & Sebastiani, 2008). Therefore, Chinese *Vitis* germplasm holds a richness about phytochemicals and polyphenols which differed from *V. vinifera* varieties. These aforementioned characteristics lead to us valuable information and give to the *Vitis* germplasm the potential to breed new varieties for studies over the next few years.

3. Eurasian hybridization, the potential to breed new varieties

Until today, Eurasian grapevine varieties, such as Cabernet Sauvignon, Merlot, Cabernet Franc, Chardonnay, Riesling, among others, are still the main cultivars of

Chinese wine grapes. (Li, 2014; Ma et al., 2014; de la Fuente Lloreda, 2018). In particular, Marselan (Cabernet Sauvignon x Grenache) has achieved large-scale development in various production areas across the country in recent years due to its good growth adaptability and excellent wine-making performance in China (Li et al., 2019).

China has only begun to develop wine grapes since the early 1990s, nevertheless grape resources collection and breeding began in the 1950s (Li, 2014). Grapevine breeding history in China can be divided into the following six stages. (i) Between 1950 and 1959, under the influence and guidance of the experts of the former Soviet Union, the main target of breeding was to obtain grape varieties with resistance to biotic and abiotic stresses by using Eurasian and Chinese mountain grapes. The 蓼莪 (Yīng Yù) grape was selected as a parent for breeding, and the varieties Beichun, Beihong, Beimei and Beizi were obtained (Figure 4 and Table 3). (ii) From 1960 to 1969, the Chinese returnees from the Soviet Union were the main researchers/breeders. Early and middle-ripening time and high-quality varieties were the main goals of breeding, among which Zhuosexiang and Yan 73 varieties stand out (Table 3). (iii) During the period of 1970-1979, the breeding of wine grapes was based on the high-quality wild mountain grape resources selected in China, in which Shuangfeng, Beiquan, Shuanghong, and Huapu n°1 varieties were selected due to their resistance to cold and diseases (Figure 4 and Table 3). The inheritance of resistance to the grapevine diseases discussed in the above sections is somewhat related to the Chinese wild grapes, indicating that multiple resistance to different diseases in Chinese wild grapes can pass down to a handful of the F1 individuals in certain crosses (Wang, Liu, He, Lamikanra, & Lu, 1998). (iv) Between 1980 and 1989, wine grapes were crossed many times, using many different parents, and the finest varieties, such as Meili, Ecolly, Zuohongyi, Zuoyouhong and Beiguolan

were selected (Table 3). (v) During the period of 1990-1999, since the root nodule and root-knot nematode began to spread in China, breeding of wine grapes was still dominated by the disease resistance and cold resistance characteristics, what gave place to the selection of Qiniang n° 1, Lingyou and Beibinghong varieties (Table 3). (vi) After 2000, the genetic pool of grape breeding began to diversify, and it focused especially in the breeding of high-quality wild grape resources, such as *Vitis davidii* and *V. quinquangularis* (Figure 5 and Table 3). Additionally, other hybrids were developed by crosses between recent new grape varieties, such as Shine-Muscat and Xinyu (Figure 6). Breeders have also evolved from being limited to scientific and technical personnel to a large number of folk breeders (Zhang & Zhang, 2015). Thus, a large number of breeding trials have been carried out in various wineries, large-scale agricultural companies, planting cooperatives, and large-scale viticulturists (Fan et al., 2015a; Zhang & Zhang, 2015). Table 3 shows some of the new grape varieties that have been reported in China since the 1950s.

In summary, breeding of Eurasian species and Chinese wild grape resources has provided a number of excellent grape varieties. Breeding goals have focused on the obtention of high-quality grapes and excellent wine-making characteristics from Eurasian varieties, and the resistance to pest and diseases, as well as to cold and drought from Chinese wild grape resources.

4. Conclusions

During the last decade, there has been a tendency to revalorize and preserve the non-*Vitis vinifera* species in the current Chinese wine scenario. China has experienced an important increase on its vineyard surface during these last years. However, the current Chinese wine industry is focused on the production of the most famous

European grapevine varieties. The knowledge about the oenological potential of non-*Vitis vinifera* species give us the possibility to diversify the current wine market. In this way, non-*Vitis vinifera* species have distinctive oenological characteristics compared to the commonly *V. vinifera* varieties, presenting wide differences, mainly on their profile of anthocyanins and stilbenes with imbalances in their sensory attributes in relation to its aromatic, acidity and alcoholic content. Chinese *Vitis* species are characterized by having mono-glucosides and di-glucosides anthocyanins, in which malvidin-3,5-diglucoside is the most representative, giving place the production of wines with purple hues. Additionally, these native species hold a wide range of oligo-stilbenes in leaves, grapes and shoots, which provide them resistance to pest and diseases and several potential health benefits. Due to these characteristics, vine-shoots from Chinese *Vitis* species could be used as biostimulants, biopesticides, oak chips, oenological tannins and as alternative to SO₂ as was reported by different authors, who used *V. vinifera* vine shoots to reach these goals. On the other hand, the study of yeast populations from the Chinese non-*Vitis vinifera* vineyards, constitute a solid base for future programs of wine yeast selection, particularly oriented for sustainable wine production. Lastly, the current subject towards the development of a sustainable viticulture opens an important opportunity to breed new varieties, providing them resistant to pests and diseases and a great antioxidant capacity.

ACKNOWLEDGMENTS

This study was supported by the National Nature Science Foundation Project of China (31901971).

Conflict of interest

None.

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Figure Captions

Figure 1. Distribution of *Vitis amurensis*, *Vitis davidii* and *Vitis quinquangularis* in China. Footnote: Figure obtained from the reported by Wei et al. (2018).

Figure 2. China wine growing regions. Footnote: Figure obtained from the reported by the Asian wine review (2018).

Figure 3. Vine-shoots from different *Vitis* species. Footnote: From left to right, *Vitis vinifera*, *Vitis pentagona*, *Vitis davidii* and *Vitis amurensis*. Figure obtained from the reported by Ju et al. (2016).

Figure 4. Clones and hybrids grapevine varieties produced from *Vitis amurensis*.

Figure 5. Clones and hybrids grapevine varieties produced from *Vitis davidii*, *Vitis quinquangularis* and *Vitis flexuosa*.

Figure 6. Cross breeding and its variability. (A) Female parent, Shine-Muscat; (B) Male parent, Xinyu; (C), (D), and (E), three completely different progeny.

Table 1. Representative concentration of grape berry parameters in different *Vitis* species.

Wine component	<i>Vitis vinifera</i>	<i>V. riparia</i>	<i>V. labrusca</i>	<i>V. davidii</i>	<i>V. amurensis</i>	<i>V. quinquangularis</i>
Weight of berry (g)	1.15 ^a	1.56 ^a	NF	2.60 ^a	0.68 ^a	NF
pH	3.79 ^a	NF	4.21 ^a	3.16-3.77 ^b	2.88 ^a	NF
Titrateable acidity (g/L as tartaric)	5.0-6.5 ^c	35 ^c	9.5 ^c	3.1-3.3 ^{a, d}	9.47 ^a	37.82 ^{f*}
Soluble solids (°Brix)	23.0 ^a	18.3 ^a	14.5-15.0 ^f	9.5-16.0 ^a	13.5 ^a	10.0 ^{f*}
Total shoot phenolic content (mg GAE/g)	53-101 ^g	NF	NF	170-225 ^g	120-141 ^g	NF
Total skin stilbenes (µg/g fresh weight)	26.83-167.06 ^h	NF	NF	36.46-53.35 ⁱ	13.87-89.89 ⁱ	21.31-74.92 ⁱ
Total C ₁₃ norisoprenoids (µg/kg)	0.91-2.36 ^j	NF	NF	0.68-3.01 ^b	NF	NF
Total terpenes (µg/kg)	1.96-2.25 ^j	NF	NF	0.00-2.17 ^b	NF	NF
Total C ₆ compounds (µg/kg)	0.33-0.45 ^j	NF	NF	1,241-4,781 ^b	NF	NF
Total phenol content (g/L)	1.31-1.35 ^k	NF	NF	1.18 ^k	1.28 ^k	0.78 ^k

^aYu et al. (2017), ^bMeng et al. (2013), ^cTeissedre (2018), ^dJin et al. (2015), ^eMeng et al. (2012b), ^fCheng et al. (2018a), ^gJu et al. (2016), ^hZhu et al. (2012), ⁱZhou et al. (2015), ^jPedroza et al. (2010), ^kWei et al. (2018). NF: Not found. *Titrateable acidity concentration not defined.

Table 2. Summary of the oenological potential of non-*Vitis vinifera* species cultivated in China.

Specie	Color	Description	References
<i>Vitis davidii</i>	Red	Lower total acidity and tartaric acid to malic acid ratio than Cabernet Sauvignon	Yu et al. (2017)
		Catechin was the most abundant phenolic compound, whereas hydroxycinnamic acids were the major family of phenolic acids in grapes	Meng et al. (2012b)
		Junzi #1, a red variety obtained from <i>V. davidii</i> , presented the highest phenolic content and the strongest antioxidant capacity compared to Junzi #2, Liantang and Baiyu	Meng et al. (2012b)
		The most abundant anthocyanin in wines elaborated from <i>V. davidii</i> was malvidin-3,5-diglucoside (diglc)	Meng et al. (2012c); Liang et al. (2013)
		Quercetin-3-rhamnoside (rha) was the main flavonol, while coumaric acid and ferulic acid were the dominant phenolic acids in <i>V. davidii</i> grape skins	Liang et al. (2013)
		Grapes presented the highest values of total phenols and flavanoids respect to <i>Vitis</i> hybrids and <i>V. vinifera</i> species	Xu et al. (2010)

<i>Vitis amurensis</i>	Red	(E,E)-2,4-hexadienal was found in the spine grape in a wide concentration	Meng et al. (2013)
		C6 compounds were the predominant family of aromatic volatile compounds in most of the <i>V. davidii</i> spine grape clones, being <i>trans</i> -2-hexenal the most predominant	Meng et al. (2013)
<i>Vitis quinquangularis</i>	Red	Grape berries contain a wide range of nutrients, such as glucose, sucrose, proteins and vitamins	Zhang and Li (2006)
		The most abundant anthocyanin in wines was malvidin-3,5-digluc, following by delphinidin-3,5-digluc	Zhao et al. (2010)
		The anthocyanins profile of grape skins contains mono-glucosides, di-glucosides and pyrano-anthocyanins	Zhao et al. (2010)
		Pelargonidin-3,5-digluc was found in the skins and wines	Zhao et al. (2010)
		High anthocyanins concentration in wines	Zhao et al. (2010)
		Berry skins contains high content of flavanols and pigments	Liu and Li (2013)
		Produced low alcoholic wines	Yu et al. (2017)
		Produced dark color wines with a strongly astringent mouthfeel	Liu and Li (2013)
		Grape berries accumulate low soluble solids. They present high acidity and dark-colored skin	Liang et al. (2013)
		The wines have a characteristic varietal aroma, pronounced acidity and tannic taste	Zou (2008); Liang et al. (2013)
		The wines were characterized by nonanal, decanal, decanoic acid ethyl ester, 4-ethylguaiacol.	Wei et al. (2018)
		Delphinidin derivatives (47.86 %) were the most important anthocyanins, following by cyanidin (17.54 %), petunidin (15.36 %), malvidin (10.88 %) and finally by peonidin (8.37 %) derivatives	Liang et al. (2013)
		Total phenolic content in wines were lower than the presented in Cabernet Sauvignon and Carmenère wines	Wei et al. (2018); Xu et al. (2010)
		Grape berries had a higher production of resveratrol than <i>V. vinifera</i> due to the expression of stilbene synthase, highlighting the VqSTS6 gene	Shi et al. (2014); Cheng et al. (2016); Yin et al. (2017)

Table 3. New wine grape varieties approved in China in the past 70 years based on hybrid breeding techniques.

N°	Year of crossing	Year of release	Variety name	Parents	Species	Main features	Breeding unit	Use
1	1953	2006	Beifeng ²	<i>Vitis flexuosa</i> and Muscat (<i>V. vinifera</i>)	<i>V. flexuosa</i> <i>V. vinifera</i>	Late ripening, high yield, high resistance to cold and diseases.	Institute of Botany, The Chinese academy of sciences	Winemaking

N°	Year of crossing	Year of release	Variety name	Parents	Species	Main features	Breeding unit	Use
2	1953	2006	Beizi ³	<i>Vitis flexuosa</i> and Muscat (<i>V. vinifera</i>)	<i>V. flexuosa</i> <i>V. vinifera</i>	Late ripening, early fruit, cold resistance, drought resistance and disease resistance.	Institute of Botany, The Chinese academy of sciences	Winemaking
3	1953	2006	Beixiang ¹	<i>Vitis flexuosa</i> and Flame Muscat	<i>V. flexuosa</i> <i>V. vinifera</i>	Very late maturity, high yield, strong resistance to stress.	Institute of Botany, The Chinese academy of sciences	Winemaking Juice making
4	1954	1965	Beichun ¹	Muscat Hamburg and <i>Vitis amurensis</i>	<i>V. amurensis</i> <i>V. vinifera</i>	Late ripening, high yield, cold resistance, strong adaptability, good wine quality.	Institute of Botany, The Chinese academy of sciences	Winemaking
5	1954	2008	Beihong ¹	Muscat Hamburg and <i>Vitis amurensis</i>	<i>V. amurensis</i> <i>V. vinifera</i>	Late ripening, high yield, resistant to cold, disease, and good wine quality.	Institute of Botany, The Chinese academy of sciences	Winemaking
6	1954	2008	Beimei ¹	Muscat Hamburg and <i>Vitis amurensis</i>	<i>V. amurensis</i> <i>V. vinifera</i>	Late ripening, strong cold and disease resistance, good wine quality.	Institute of Botany, The Chinese academy of sciences	Winemaking
7	1954	2013	Beixi ⁴	Muscat Hamburg and <i>Vitis amurensis</i>	<i>V. vinifera</i> <i>V. amurensis</i>	High resistance to cold and diseases. The red wine is deep ruby red with aromas of blackcurrant and blueberry. Wine presents a good structure and is smooth and round in mouth with a long aftertaste.	Institute of Botany, The Chinese academy of sciences	Winemaking
8	1954	2013	Beixin ⁵	Unknown	<i>V. amurensis</i> <i>V. vinifera</i>	High yield and resistance to cold and diseases. The wine is bright ruby, clear and translucent with aromas of rose flower, rich and well balanced on the palate. Early fruit.	Institute of Botany, The Chinese academy of sciences	Winemaking
9	1956	1982	Zexiang ¹	Muscat Hamburg and Longyan	<i>V. vinifera</i>	Mid-late maturity, high yield, disease resistance, and strong adaptability.	Pingdu Hongshan Gardening Farm	Winemaking Table grape
10	1961	2009	Zhuosexiang ¹	Meiguilu and Vitis Brighton	<i>V. vinifera</i> <i>V. labrusca</i>	Early-middle-maturing varieties, purple-red color, thin skin, soft flesh, very sweet, jasmine flavor, cold resistance, strong disease resistance.	Liaoning Yanjiandi Liyong Institute	Winemaking Table grape

N°	Year of crossing	Year of release	Variety name	Parents	Species	Main features	Breeding unit	Use
11	1966	1981	Yan 73 ¹	Muscat Hamburg and Alicante Bouschet	<i>V. vinifera</i>	Medium ripe, peel and flesh are colored, fuchsia, high yield. Strong adaptability and good disease resistance. High pigment content, suitable for toning varieties.	Yantai Changyu Pioneer Wine Company Limited	Winemaking
12	1975	1995	Shuangfeng ¹	Tonghua n°1 and Shuangqin	<i>V. amurensis</i>	High yield, high sugar content, cold resistance, disease resistance, good wine quality.	Institute of special animal and plant sciences of CAAS	Winemaking
13	1977	1985	Beiquan ¹	Beichun and Dakeman	<i>V. amurensis</i> <i>V. vinifera</i>	Resistant to cold and disease.	Institute of Botany, The Chinese academy of sciences	Winemaking
14	1977	1998	Shuanghong ¹	Tonghua n° 3 and Shuangqin	<i>V. amurensis</i>	Resistant to downy mildew, high yield, excellent sweet red wine.	Institute of special animal and plant sciences of CAAS Tonghua Grape Wine	Winemaking
15	1979	2011	Huapu n°1 ⁶	Zuoshan n° 1 and Maturana Blanca	<i>V. amurensis</i> <i>V. vinifera</i>	High yield, cold tolerance and disease resistance. Dry-red and ice-red wine has high quality. Good rootstock for table grape grafting.	Research institute of pomology of CAAS	Winemaking Rootstocks
16	1982	2011	Meili ⁷	Merlot, Riesling, Muscat Hamburg	<i>V. vinifera</i>	Meili shows characters of disease resistances to downy mildew and white rot of grape. Medium ripe, high yield and stable yield.	Northwest A&F University	Winemaking Table grape
17	1983	1998	Ecolly ⁸	Chenin blanc, Chardonnay, Riesling	<i>V. vinifera</i>	Cold-resistant, disease-resistant, good quality, dry white wine has a strong rose fragrance.	Northwest A&F University	Winemaking
18	1984	1998	Zuohongyi ¹	Zuoshan n° 2, Muscat rouge, <i>Vitis amurensis</i> , Shuangqin	<i>V. amurensis</i> <i>V. vinifera</i>	High yield, strong cold resistance, disease resistance.	Institute of special animal and plant sciences of CAAS	Winemaking
19	1987	2005	Zuoyouhong ¹	<i>Vitis amurensis</i> , Shuangqin	<i>V. amurensis</i> <i>V. vinifera</i>	Medium ripe, good wine quality, strong cold resistance, disease resistance, high yield.	Institute of special animal and plant sciences of CAAS	Winemaking
20	1988	2014	Beiguolan ⁹	Zuoshan n°1, Shuangqin	<i>V. amurensis</i>	Medium to late maturity, cold resistance and disease resistance, the original wine has a black gem luster, pleasant aroma, full body.	Institute of special animal and plant sciences of CAAS	Winemaking

N°	Year of crossing	Year of release	Variety name	Parents	Species	Main features	Breeding unit	Use
21	1991	2014	Qiniang n° 1 ¹⁰	Muscat Hamburg, Gongniang n° 2, <i>Vitis amurensis</i> , Baiya	<i>V.amurensis</i> <i>V.vinifera</i>	Cold resistance. The fruit is nearly round, the skin is black, and the flesh is colorless.	Instituto de investigación en Qiqihar	Winemaking
22	1995	2005	Lingyou ¹	<i>Vitis quinquangularis</i> , Trebbiano	<i>V.quinquangularis</i> <i>V.vinifera</i>	Strong adaptability, disease resistance, high juice yield, good wine quality.	Northwest A&F University Guangxi Academy of Agricultural Sciences	Winemaking
23	1995	2008	Beibinghong ¹	Zuoyouhong, F2 (86-24-53)	<i>V.amurensis</i> <i>V.vinifera</i>	Short maturity, round fruit, blue-black color, thick skin. The ice-red wine is dark ruby red, with a rich honey and almond aroma.	Institute of special animal and plant sciences of CAAS	Winemaking
24	2000	2016	Ruidukem ei ¹¹	Italia, Muscat Louis Thallosy	<i>V. vinifera</i>	Medium ripening, with strong rose fragrance, fruit without cracking, high yield.	Beijing Agriculture and Forestry Academy of Sciences Forestry Guoshu Institute	Winemaking
25	2001	2012	Xuelanhong ¹²	Zuoyouhong, Beibinghong	<i>V.amurensis</i>	The grapes are large in size, high in sugar and juice yield, low in total acid and tannin, non-splitting, disease-resistant and cold-resistant, early-yielding, and good quality dry red mountain wine.	Institute of special animal and plant sciences of CAAS	Winemaking
26	2004	2013	Xinbeichun ¹³	Selected by 'Beichun' bud mutation	<i>V.amurensis</i> <i>V.vinifera</i>	wine is deep bright ruby, clear and translucent with aromas resembling a hint of raspberry and litchi, rich and well balanced on the palate. It has high yield and resistance to cold and diseases.	Institute of Botany, The Chinese academy of sciences	Winemaking
27	Unknown	2005	Lingfeng ¹	<i>Vitis quinquangularis</i> , Fenhongmeigui	<i>V. quinquangularis</i>	Strong adaptability, disease resistance, high juice yield, good wine quality.	Northwest A&F University Guangxi Academy of Agricultural Sciences	Winemaking
28	Unknown	2012	Guipun ²¹⁴	<i>Vitis quinquangularis</i> × <i>Vitis labrusca</i>	<i>V.quinquangularis</i> <i>V. labrusca</i>	Humidity and heat resistance, disease resistance.	Guangxi Academy of Agricultural Sciences	Winemaking

¹Liu et al. (2014). ²Fan et al. (2007). ³Fan et al. (2006). ⁴Wang et al. (2014). ⁵Fan et al. (2015). ⁶Wang et al. (2012). ⁷Zhang et al. (2013). ⁸Li et al. (2000). ⁹Zhang et al. (2016). ¹⁰Bi et al. (2014). ¹¹Sun et al. (2017). ¹²Song et al. (2012). ¹³Fan et al. (2015). ¹⁴Zhang et al. (2015).

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Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.

Figure 6.

(A)

(B)

(C)

(D)

(E)

Highlights

- China holds a great diversity of non-*Vitis vinifera* species
- This bring an important alternative for the diversification of wine production
- These native species hold a wide range of oligo-stilbenes in leaves, grapes and shoots
- They could be used as bio-stimulants, chips, tannins and alternative to SO₂
- Big opportunity to breed new varieties, providing resistant and antioxidant capacity

The authors declare that they have no conflicts of interest.