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Study on current status and climatic characteristics of wine regions in China

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Summary

The aim of this paper is to improve the knowledge of the current status and climatic characteristics of Chinese wine regions. An investigation of Chinese winegrowing regions, which concerned the distribution, area and cultivars, was conducted using "questionnaires + expert consultation + available literature". On the basis of the results of the investigation, a map was drawn to depict the distribution of Chinese wine regions. Furthermore, observation records of weather stations located within winegrowing zones during 1982–2011 were employed to analyze the climatic characteristics of each region by using the climatic indices of frost-free season (FFS), dryness index (DI), and extremely low temperature (ELT). According to the findings of the investigation, wine grapes have been widely cultivated in 179 counties of China, with a total cultivation area of 163,200 ha. 'Cabernet Sauvignon' was the most widely cultivated variety. The analysis of the climatic characteristics revealed a regional difference within and between wine regions. Moreover, most wine regions were suitable for wine production in terms of the climatic indices, which in turn verified the applicability of the climate indices system.

K e y w o r d s : China; climatic characteristics; climatic indices; current status; wine regions.

Introduction

China is one of the places of origin of *Vitis* species in the world, has a long history not only of viticulture, but also of brewing wine (Jiang *et al.* 2009, McGovern 2009, He 1999). The development of Chinese wine industry was slow and experienced ups and downs over the years but its resurgent growth has been observed in recent decades (Masset *et al.* 2016). In contrast to the relatively stable trend of many countries, China's grape and wine industry shows a strong growth momentum along with the overall economic growth (Thorpe 2009, Banks and Overton 2010). According to the International Organization of Vine and Wine (OIV) statistics, in 2014, China has the second largest vineyard surface area, the seventh largest wine production, and the fifth largest wine consumption in the world of 796,000 ha, 11,600,000 hL and 15,500,000 hL, respectively (OIV 2016). It is thus clear that China has become a superpower in the global grape and wine industry, and Chinese consumers are becoming one of the main forces in global wine consumption. Nevertheless, the global grape industry is based on winemaking, but in China, priority is given to table grapes, with only 13 % of the total national grape production used for winemaking.

As a country with a developing wine industry, China has attracted the interest of both domestic and foreign investors. In recent years, increasingly more wineries have been built throughout China, and a large number of industrial clusters have gradually developed, presenting a new framework in the Chinese wine industry (Banks and Overton 2010).

Hence, there is a need to fully recognize the present situation of Chinese wine regions. However, the information of the current wine regions is not readily available in China, and limited literature has been published in the field. Jenster and Cheng (2008) provided an overview of the historical and current development of the Chinese wine industry which focused more on the market but did not provide sufficient data on wine regions. Other researches (Xi *et al.* 2008, Ye and Kou 2012, Zhang and Cao 2014) successively discussed the current situation of the Chinese wine industry, but only briefly outlined the Chinese wine regions. The first comprehensive and systematic work was published by Li and Wang (2010), providing a detailed introduction of the Chinese wine regions. Nevertheless, considering the rapid development of the Chinese wine regions, an update and supplementation with the newest data is highly necessary.

Here, we also analyzed the climate characteristics of the Chinese wine regions and their importance in wine grape production as well as their association with quality. To estimate the climatic suitability for viticulture in a particular region, several climatic indices have been proposed by different researchers worldwide, such as the Winkler index (Amerine and Winkler 1944, Winkler *et al.* 1974), the Branás heliothermic index (Branás 1974), the Huglin index (Huglin 1978, 1999), mean temperature of the warmest month (Dry and Smart 1988), growing season mean temperature (Hall and Jones 2009), the latitude-temperature index (Jackson 1988), the hydrothermic index of Branás, Bernon and Levadoux (Branás *et al.* 1946), hydrothermal coefficient (Szeljanyinov 1928), etc. In contrast to most of the wine regions around the world that benefit from a Mediterranean climate, China has a marked continental monsoonal climate characterized by hot and rainy summers, and cold and dry winters. Li *et al.* (2011a) found that the above-mentioned indices cannot be well applied to estimate the climatic suitability of a given region for commercial pro-

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duction in China. The accumulative temperature of a region in China may equal to or be even more than that of regions of the same latitude in other countries, covering up the fact that there are sharp changes in the temperature in spring and autumn, there is rain and hot weather in summer, as well as a short period of frost-free days and severe winter in most parts of China. These specific characteristics predetermine a considerable likelihood for the absence of potential for economically feasible cultivation in a given region even if the requirements of those indices have been met. After comparison and analysis of various indices, a climatic indices system specific to Chinese viticultural zoning was proposed, which includes indices, such as frost-free season, dryness index, and extremely low temperature (LI *et al.* 2011a).

A good understanding of Chinese wine regions will facilitate the full recognition of the ecological advantages, promote the regionalization of varieties and wine styles, and establish the optimum cultivation mode and appropriate vinification process for making wines with high quality and developing wine regions with differentiated characteristics. It is also a fundamental work to enable Chinese wine industry to reach out to the world.

In this context, the objectives of our study were to (i) conduct a comprehensive investigation of the current situation of the wine regions concerning the distribution, cultivation area, and cultivars; (ii) map the distribution of Chinese wine regions; (iii) analyze the climatic characteristics in the wine regions by three climatic indices.

Material and Methods

Study area: Based on previous studies (LI 2010, LI and WANG 2010), 11 wine regions within 21 provincial areas were chosen to conduct this research, which were delimited primarily according to the meteorological geographic divisions and administrative divisions presented in Tab. 1.

Investigation method: The investigation concerning the distribution, area, and cultivars in each wine region was conducted from January to June 2016. Several methods, including the utilization of questionnaires, expert consultation, and collection and examination of the available literature sources and websites, were used to collect information on the current status of all above-mentioned Chinese wine regions. The questionnaire survey was conducted as a primary method. The officers who were in charge of or worked at relevant government departments (e.g. Wine Bureau and Forestry Bureau), institutions (e.g. Agricultural Research Institute, Pomology Research Institute, Wine Institute, and universities), and wineries, were invited to assist in the investigation. A list of potential contacts was made through private and work relationships. We contacted them one by one over the phone to confirm whether they can provide the information and asked for their emails. Then, a final contact list, which could ensure that at least one contact was presented from each wine region, was established. Questionnaires were sent to these contacts by email in early January 2016. They needed to conduct further data collection according to the following requirements of the questionnaires at the township level: (i) distribution of wine grapes; (ii) cultivation area; and (iii) main cultivars. Besides, we also welcomed any questions, comments, or suggestions they had regarding their wine regions. Replies were received successively from April to June. Accordingly, the data resources for each region are presented in Tab. 1. On the basis of the integrity of these data, we consulted contacts and other industry insiders, and the available literature to make a supplement. Then, the gathered information was organized and summarized for further analysis. Based on the survey data, a map of Chinese wine regions was drawn with county-level precision, providing a preliminary visual representation of the distribution of wine regions.

Climatic indices and climatic data: The multicriteria climatic indices system proposed by LI *et al.*

Table 1

The geographic range and data resources of each wine region

Wine region	Geographic range	Data resources
North East	Provinces of Heilongjiang, Jilin, and Liaoning	Heilongjiang Qinggu Winery; Changbaishan Wine Group Co.; Liaoning Wunushan Milan Wine Co.
Jing-Jin-Ji	Beijing, Tianjin and Hebei Province	Beijing Comprehensive Test Station, China Agriculture Research System for Grape Industry; Fangshan Wine Association; Zhangjiakou Academy of Agricultural Sciences; Sino-French Joint-Venture Dynasty Winery
Shandong	Shandong Province	Shandong Grape Research Institute
Ancient Yellow River	The east of Henan Province, the north of Anhui Province, and the north of Jiangsu Province	Zhengzhou Fruit Research Institute, Chinese Academy of Agriculture Sciences
Loess Plateau	Shaanxi Province and Shanxi Province	Yuncheng Great Winery; Taigu Comprehensive Test Station, China Agriculture Research System for Grape Industry; Shaanxi Fruit Industry Administration
Inner Mongolia	The Inner Mongolia Autonomous Region	Inner Mongolia Hansen Winery
Helan Mountain East	The Ningxia Hui Autonomous Region	Ningxia Hui Autonomous Region Grape Industrial Development Bureau
Hexi Corridor	Gansu Province	Gansu Liquor Authority
Xinjiang	The Xinjiang Uygur Autonomous Region	Bazhou Forestry Bureau; Wine Association of Northern Piedmonts of Tianshan; http://www.wines-info.com/html/2015/8/183-62501.html
Southwest Mountain	Southeastern Tibet Autonomous Region, western Sichuan Province, and Yunnan Province	Yunnan Agricultural University
Special Region	Guangxi Zhuang Autonomous Region and Hunan Province	Hunan Agricultural University; Biotechnology Research Institute, Guangxi Academy of Agricultural Sciences; Grape and Wine Institute, Guangxi Academy of Agricultural Sciences

(2011a) was chosen for climatic analysis in this paper, in which three climatic indices have been jointly used: frost-free season (FFS), dryness index (DI), and extremely low temperature (ELT). The DI in our examination is distinct from the one defined by Tonietto and Carbonneau (2004), and the multicriteria classification is also different from that of the same authors.

The frost-free season is defined as the length (in days) of the period between the last frost day in spring and the first frost day in autumn and is determined by using the inclusive threshold of 0 °C for daily minimum temperature.

The dryness index is calculated from April 1st to September 30th using the following equations:

$$DI = ET_C/P \quad (1)$$

$$ET_C = K_C \times ET_O \quad (2)$$

where ET_C is the evapotranspiration of grape during the growing season, P is the precipitation at the same time, K_C is the crop coefficient, and ET_O is the reference crop evapotranspiration, calculated by the Penman-Monteith method with daily time step (Allen *et al.* 1998).

The value of K_C varies in different regions and growth stages. Nevertheless, there is no detailed report of wine grape K_C value in different growing stages across China. Using the same value for all regions across the country can make the comparison and classification macroscopically viable. Considering the FAO recommended value, the climatic features, and the actual cultivation conditions in China, the upper value during the growing season of 0.8 was used here (Li and Huo 2006).

Extremely low temperature is defined as the minimum value of daily minimum temperature within a year. It is an important index to determine whether there is a need of soil burial for grape safely overwintering with the bury line set at -15 °C for *V. vinifera* (Li *et al.* 2011a).

The climatic indices of the frost-free season, dryness index, and extremely low temperature are referred to hereafter as FFS, DI, and ELT, respectively. The class limits (Li *et al.* 2011a) of the three climate indices that refer to *Vitis vinifera* are summarized in Tab. 2.

The data collected from a total number of 156 weather stations located within the winegrowing zones were used in this study. The geographic coordinates, elevation, and daily observation records of temperature (mean, maximum, and minimum), precipitation, wind speed, relative humidity, and sunshine duration over the period 1982-2011 for a set of 156 weather stations, provided by the National Climatic Center of the China Meteorological Administration, were employed to calculate the above-mentioned indices and obtain the average as the final result. This climatic database can provide information about the climatic features of the current wine regions by covering 87 % of the counties within the winegrowing zones.

Table 2

The class limits of three climatic indices

Variable	Classification	Limits
Frost-free season (FFS)	Cold	160d ≤ FFS ≤ 180d
	Temperate	180d < FFS ≤ 200d
	Warm	200d < FFS ≤ 220d
	Hot	220d < FFS
Dryness index (DI)	Semi-humid	1 < DI ≤ 1.6
	Semi-arid	1.6 < DI ≤ 3.5
	Arid	3.5 < DI
Extremely low temperature (ELT)	Soil-burying	ELT ≤ -15 °C
	Non-soil-burying	ELT > -15 °C

Results and Discussion

Cultivation distribution: According to the distribution data obtained from the survey, we preliminarily mapped the Chinese wine regions to provide a visual representation (shown in Fig. 1). According to the statistics of the Ministry of Civil Affairs of the People's Republic of China (2015), there are a total number of 2,854 of county-level administrative regions and a total number of 40,381 of township-level administrative regions in the entire territory of China. The township-level administrative region is the basic administrative unit in China. In this survey, we were not able to cover all winegrowing regions in township-level, especially in Shandong and parts of Xinjiang, for which the data could only be available at county-level. Thus, the distribution of vineyards in the entire territory of China was presented at the county level.

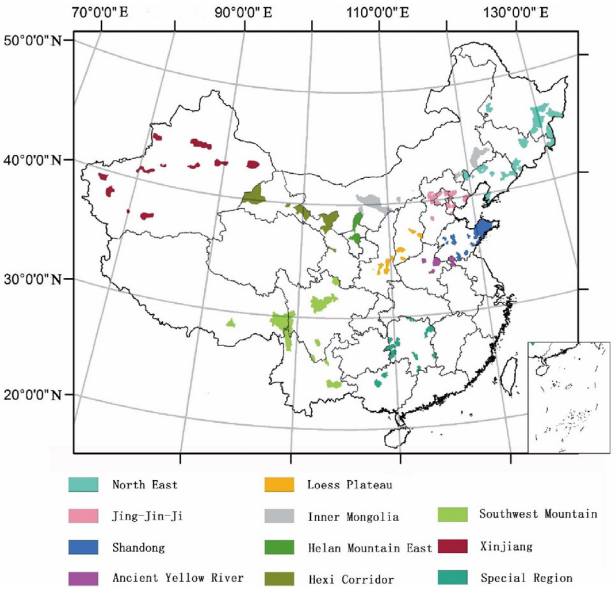

Fig. 1: The distribution of Chinese wine regions.

The map was drawn combined with the county administrative map. The existing distribution of wine regions with county-level precision could be observed, but the actual vineyard land cover was not represented on the map. Nevertheless, the county territory in Xinjiang is generally much larger than any of the other regions, and thus the cultivation zones were not strictly drawn at the county level. The winegrowing zones were widely distributed in 179 counties of China, with a range of 24-47 °N latitude and 76-132 °E longitude. World's wine regions are traditionally located between the latitude of 30-50 °N and 30-40 °S (Schultz and Jones 2010). The world wine grapes

are mainly presented by European *Vitis vinifera*, whereas in the Special Region is given priority to the East Asian *Vitis* spp. Besides, the Southwest Mountain Region has a special geography characterized by low latitude and high altitude. Thus, the distribution of wine regions was expanded to lower latitudes in these two regions in China. A great number of winemaking enterprises of different sizes had been established in each region. The county-level winegrowing zones are listed in Tab. 3.

The development of Chinese wine regions is still incomplete, and differs from region to region. Except for Shandong, Gansu, Ningxia, Xinjiang, Hebei, and Liaoning, there are no specialized grape and wine administrative departments in the other regions. Besides, there is not yet a complete and effective system of geographical indication protection for wine products in China. Up to now, only Huanren Ice wine, Tonghua Amur Grape Wine, Shacheng Wine, Changli Wine, Yantai Wine, Minquan Wine, Helan Mountain East Wine, Hexi Corridor Wine, Turpan Wine, Yanjing wine, Heshuo Wine, and Du'an Wild *Vitis quinquangularis* Wine have been approved as national products of geographical indications by the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ, http://www.cgi.gov.cn/), accounting for only a small percentage of all regions.

Cultivation area: According to investigation result, the vineyards covered a total area of about 163,200 ha, accounting for approximately 1/5 of the area of all grapes.

Table 3

The county-level winegrowing zones in each wine region

Wine region	County-level winegrowing zones
North East	Jianshan, Hua'nan, Qitaihe, Mishan, Linkou, Hailin, Dongning, Yilan, Ang'angxi, Liuhe, Ji'an, Tonghua, Jiaohe, Huanren, Benxi, Longcheng, Jianping, Liaozhong, Fuxin, Jinzhou, Wafangdian
Jing-Jin-Ji	Fangshan, Miyun, Yanqing, Ninghe, Hangu, Dagang, Jixian, Wuqing, Beichen, Huailai, Zhuolu, Xuanhua, Changli, Lulong, Funing, Xinglong, Dingzhou
Shandong	Penglai, Longkou, Laizhou, Zhaoyuan, Qixia, Laishan, Laiyang, Haiyang, Rushan, Pingdu, Jimo, Laixi, Laoshan, Jiaonan, Changle, Gaomi, Wulian, Hedong, Licheng, Pingyin, Daiyue, Decheng, Shanting
Ancient Yellow River	Minquan, Lankao, Qixian, Suixian, Ningling, Huiji, xihua, Xiaoxian, Fengxian, Peixian
Loess Plateau	Jingyang, Sanyuan, Weicheng, Yangling, Huxian, Pucheng, Heyang, Linwei, Lantian, Fugu, Taigu, zuoquan, Qingxu, Xiangning, Xiangfen, Xiaxian
Inner Mongolia	Alxa Zuoqi, Wuhai, Dengkou, Ejin Horo Banner, Hanggin Banner, Togtoh, Jining, Harqin Banner, Khorchin, Kailu, Naiman Banner
Helan Mountain East	Dawukou, Huinong, Pingluo, Yinchuan, Helan, Yongning, Qingtongxia, Hongsipu
Hexi Corridor	Dunhuang, Jiayuguan, Su'nan, Linze, Gaotai, Ganzhou, Liangzhou, Minqin, Lanzhou
Xinjiang	Yining, Huocheng, qapqal, Shihezi, Manas, Hutubi, Changji, Wujiaqu, Miquan, Fukang, Yanqi, Hejing, Heshuo, Bohu, Toksun, Shanshan, Kumul, Aksu, Kashgar, Makit, Shufu, Hotan, Yutian, Minfeng
Southwest Mountain	Xiaojin, Jinchuan, Danba, Maoxian, Lixian, Jiuzhaigou, Batang, Derong, Xichang, Panzhihua, Deqin, Weixi, Mile, Qiubei, Dongchuan, Langxian, Zogang, Markam
Special Region	Zhijiang, Zhongfang, Jingzhou, Huitong, Chenxi, Xinhuang, Lixian, Pingjiang, Datonghu, Fenghuang, Changsha, Yanling, Lanshan, Qiyang, Du'an, Luocheng

Table 4

Main cultivars and varietal characteristics in each wine region

Wine region	Main cultivars	Varietal characteristic
North East	*Vitis amurensis* Rupr. spp., Vidal	Asian species with cold resistance
Jing-Jin-Ji	Cabernet Sauvignon, Cabernet Gernischt, Merlot, Muscat Hamburg Chardonnay, Italian Riesling, Longyan	*Vitis vinifera* with moderate resistance (in most regions)
Shandong	Cabernet Sauvignon, Cabernet Gernischt, Merlot, Cabernet Franc Chardonnay, Italian Riesling	
Ancient Yellow River	Cabernet Sauvignon, Merlot Chardonnay	Asian species with cold resistance (in parts of Inner Mongolia)
Loess Plateau	Cabernet Sauvignon, Merlot, Cabernet Gernischt Chardonnay, Ugni blanc	
Inner Mongolia	*Vitis amurensis* Rupr. spp., Cabernet Sauvignon	
Helan Mountain East	Cabernet Sauvignon, Merlot, Cabernet Gernischt Chardonnay, Riesling	Hybrid cultivars of *Vitis vinifera* and *Vitis labrusca* with better resistance than *Vitis vinifera* (in parts of Southwest Mountain)
Hexi Corridor	Pinot Noir, Cabernet Sauvignon Chardonnay, Italian Riesling	
Xinjiang	Cabernet Sauvignon, Merlot, Yan73 Chardonnay, Riesling	
Southwest Mountain	Cabernet Sauvignon, Merlot, Rose Honey Crystal Grape	
Special Region	*Vitis davidii* Foëx. spp., *Vitis quinquangularis* Rehd. spp.	Asian species with high temperature and humidity resistance

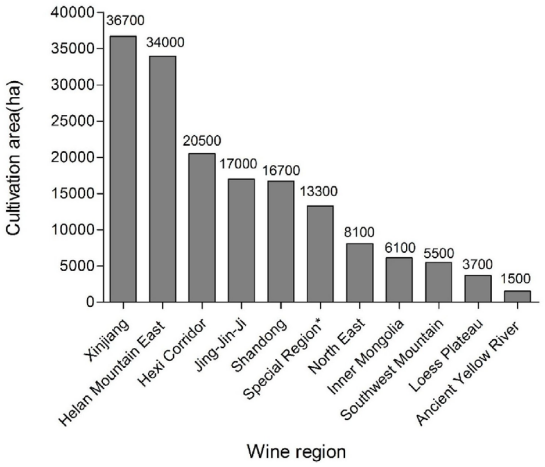

Fig. 2: The cultivation area of wine grapes in each wine region. Note that the cultivation area of Special Region may include grapes for fresh consumption and processing.

The bar chart in Fig. 2 shows the cultivation area of each wine region. Xinjiang was ranked in the first place with a cultivation area of 36,700 ha, followed by Helan Mountain East with 34,000 ha. Hexi Corridor ranked third, covering an area of 20,500 ha. The top three regions accounted for approximately 55 % of the total wine grape cultivation area in the whole of China. The grape cultivars in the Special Region are utilized for fresh consumption, juice production, and winemaking. Hence, accurate statistics of the cultivation area used only for winemaking was not easy to obtain. In recent years, a sharp decrease in viticultural area has occurred in the Ancient Yellow River due to the climate constraint and other various factors; this area was the smallest of all regions examined in this research.

Considering the wide distribution of Chinese wine regions, the completeness of the survey is difficult to guarantee. Especially in Xinjiang, no data were available for all sub-regions, and thus we could only consult the website to make a supplement as detailed and precise as possible. Besides, wine regions in China are in their early development stage; thus, the size of areas occupied by vineyards has been regularly changing. On the one hand, new vineyards are being developed constantly; on the other hand, some vineyards are disappearing because of policy change and weather disasters. Thus, this was just relatively rough statistics about the current area of Chinese wine regions.

Cultivars: The distribution of the cultivars in different regions of China are provided in Tab. 3. *Vitis amurensis* Rupr. is widely distributed in the North East and parts of Inner Mongolia, whereas *Vitis davidii* Foex. and *Vitis quinquangularis* Rehd. are dominant species that are widely distributed in South China. The three species are wild germplasm resources belonging to East Asian populations of *Vitis*. *Vitis amurensis* is a cold-resistant species, with a great application value (Ha *et al.* 2009). The latter two species are characterized by strong resistance to high temperature, high humidity, and diseases (Wang *et al.* 1995, He 2012, Meng *et al.* 2013). Despite all these advantages, high acidity and low sugar content are the biggest disadvantages that restrict the development of these wild species.

The wine grapes cultivated in other regions are mainly internationally recognized cultivars belonging to *Vitis vinifera*. We found that 'Cabernet Sauvignon' was the most widely cultivated red variety that was found in most regions, followed by 'Merlot' and 'Cabernet Gernischt', whereas 'Chardonnay' was the most widely planted white variety. According to the *Vitis* International Variety Catalogue (*V*IVC, www.vivc.de), which is the most important online database concerning grapevine genetic resources, 'Cabernet Gernischt' has been identified as a synonym of 'Carmenère'. 'Longyan' (*V. vinifera*) is an ancient variety which has been cultivated in China for thousands of years and can be utilized for fresh consumption and winemaking (Xiu *et al.* 1991). 'Yan 73' and 'Yan 74' are colour varieties, obtained by hybridization of 'Muscat Hamburg' with 'Alicante Bouschet' in 1966 (Luan *et al.* 2014). Serious homogeneity seemed to be present in these regions, which might have had adverse impacts on the establishment of unique regional characteristics.

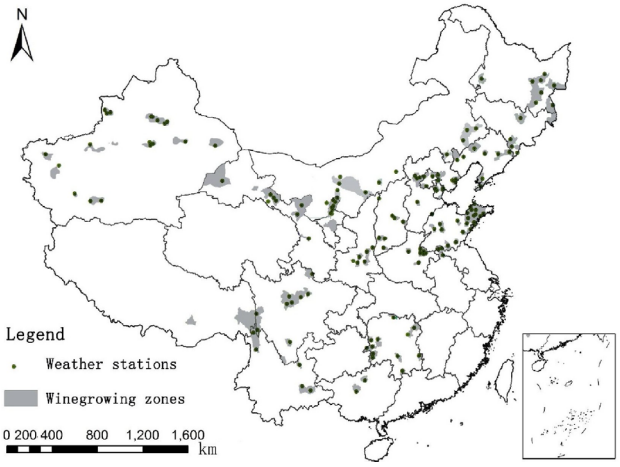

Fig. 3: Spatial distribution of weather stations within winegrowing zones.

Climatic characteristics: The weather stations located within the above-mentioned winegrowing zones were employed for climatic analysis. The spatial distribution of these weather stations is shown in Fig. 3. The number and elevation of the weather stations in each wine region are summarized in Tab. 5.

These regions differed greatly in their elevation. Southwest Mountain Region was the highest region among all regions with an average elevation of approximately 2,000 m, showing a geographic feature of high altitude and low latitude. Hexi Corridor was the second highest region with an altitude of 1,517 m, and the third was Helan Mountain East Region with about 1,111 m. Located in the Mongolian plateau, the Inner Mongolia Region had a relatively high altitude of 911.6 m. Other regions were located mainly in plain, hilly, or basin areas with relatively moderate altitudes. Intra-regional differences were present, more notably in the Southwest Mountain Region, situated in the Hengduan Mountains. Its standard deviation reached nearly 580 m.

The geographical and topographic differences resulted in distinct differences in the climatic characteristics within and between wine regions. The dispersion of the three climatic indices in each region is illustrated in Figs 4, 5 and 6 by using boxplot graphs.

According to the thermal index of FFS, the suitable areas can be classified into four climate zones. Fig. 4 illus-

Table 5

The number and elevation of weather stations of each wine region

Wine region	Number	Elevation (m)				
		Min.	Median	Max.	Mean	SD
North East	20	12.2	176.5	422.0	207.2	108.1
Jing-Jin-Ji	16	1.3	47.0	629.3	190.8	254.8
Shandong	22	4.8	51.5	171.5	68.6	48.3
Ancient Yellow River	10	34.7	55.4	110.4	57.8	22.1
Loess Plateau	13	402.9	540.2	1134.6	654.2	253.4
Inner Mongolia	11	178.7	1024.0	1561.4	911.6	474.9
Helan Mountain East	8	1092.5	1112.3	1128.8	1110.9	11.5
Hexi Corridor	8	1139.0	1468.2	2311.8	1517.0	345.7
Xinjiang	20	1.0	753.6	1422.0	837.6	401.2
Southwest Mountain	14	1254.1	1918.6	3319.0	1986.3	579.6
Special Region	14	40.2	248.4	355.5	218.6	108.7

Max: maximum; Min: minimum; SD: standard deviation.

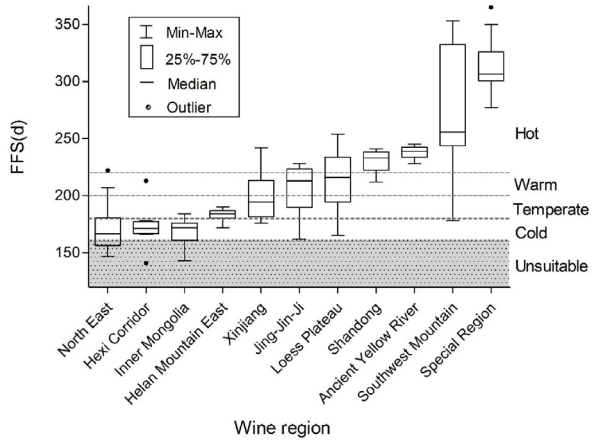

Fig. 4: Frost-free season in each wine region.

trates the FFS range in each region. North East and Inner Mongolia were dominated by cold climate, with partial areas that can be characterized as temperate climate zones. There were also parts of some areas with FFS below 160d, indicating no potential for cultivation of *Vitis vinifera*, but Asian species were widely distributed in these regions. Hexi Corridor was entirely classified as a cold climate zone, except Su'nan and Lanzhou. The FFS in Su'nan was below 160d, and wine grapes were cultivated only in a small area there. Lanzhou, which was identified as a warm climate zone, is an emerging wine region located in central Gansu Province. Helan Mountain East was dominated by temperate climate, with some areas classified as a cold climate zone. Xinjiang, Jing-Jin-Ji, and Loess Plateau were spread across four climate zones, whereas the climate in Xinjiang was predominantly temperate, whereas the warm climate was more widespread in Jing-Jin-Ji, and the warm and hot climate in Loess Plateau. Shandong, the Ancient Yellow River, the Southwest Mountain, and the Special Region were characterized mainly by hot climate. The range of FFS was quite considerable in Southwest Mountain, with a minimum value of 178d and a maximum value of 353d. The Special Region was the hottest region among all regions, of which the lowest FFS had reached up to 277d. The temperatures that contribute to chilling fulfillment in grapevine are reported to be between 0 °C and 7 °C, although there are variations among varieties (DOKOOZLIAN 1999). Little is known about the chilling requirements of the two wild *Vitis* species in South China. However, in warm regions where winter temperatures rarely fall below 7 °C, the insufficient chilling can result in delayed and desynchronized budburst, and the use of dormancy breaking agents can contribute to increase budburst (LONDO and JOHNSON 2014). Combined with other techniques, dormancy breaking agents are also used in Guangxi for the realization of one-year-two-harvest cultivation.

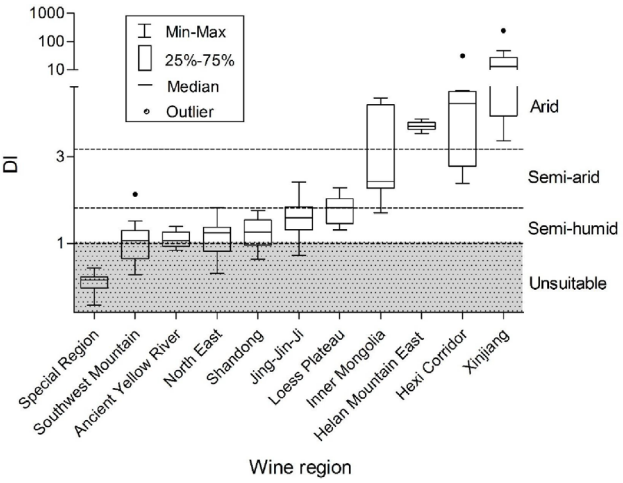

Fig. 5: Dryness index in each wine region.

According to the water index of DI, the suitable areas can be classified into three climate zones. Fig. 5 illustrates the DI dispersion in each region. From a general view, the distribution of DI was concentrated in the semi-humid zone for most regions. Indeed, precipitation is the main factor restricting the development of China's viticulture. The Special Region was the only region that was entirely classified as unsuitable zone. Thus, the wine industry mainly depends on the production by *V. davidii* and *V. quinquangularis*. Therefore, it is exceedingly important to improve cultivation management patterns to reduce diseases occurrence here. The Southwest Mountain Region ranged from humid to semi-humid, with a minimum DI value of 0.66 which indicated unsuitability. However, the topography was complex with mountains and elevations in this region, ensuring good drainage in vineyards located on hills with a slope. Besides, the grapes are mainly hybrids of *V. vinifera* and *V. labrusca* which show a better resistance than *V. vinifera*. The Ancient Yellow River, North East, Shandong, and Jing-Jin-Ji were primarily characterized as semi-humid zones. Approximate-

ly a quarter of Jing-Jin-Ji Region belonged to the semi-arid zone, and only minor areas were unsuitable based on DI. The management of the vineyards in these regions should focus more on the control of diseases and pests, and the use of cultivars with high resistance should also be considered. The Loess Plateau Region had a semi-humid and semi-arid climate, while the climate of the Inner Mongolia Region was semi-arid and arid. The entire region of the Helan Mountain East belonged to the arid zone, the minimum DI of which was 4.31. The Hexi Corridor was dominated by the arid zone, with a small area classified as a semi-arid zone, and Dunhuang was characterized by an extremely high DI value (31.42). Xinjiang was classified as an entirely arid zone and was the driest wine region in China. The value of DI reached up to nearly 50 in Xinjiang, and an extremely high value of 246.45 was established in Toksun. Therefore, efficient irrigation is necessary for high-quality production of wine grapes in these regions (Lopez *et al.* 2009).

Different from other wine production countries that are mainly with a Mediterranean climate with a cool and wet winter (Hannah *et al.* 2013), there was a marked continental monsoonal climate in China, with cold and dry winters in most northern regions (Li and Wang 2010). As the species cultivated is mainly *Vitis vinifera,* for protection against winter chill, in China, grapevines must be buried with soil when the temperature is as low as -15 °C (Li and Wang 2010). Certainly, this value is not absolute. Taking into account the complex mechanism of freezing tolerance, the varietal difference, and the influence of other environment

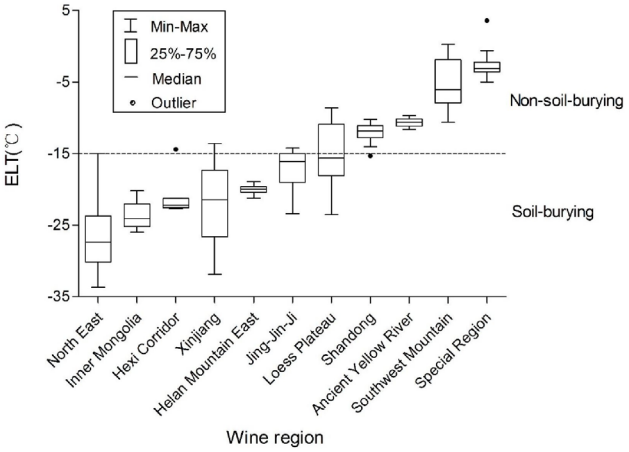

Fig. 6: Extremely low temperature in each wine region.

factors should also be considered (Fennell 2004, Li and Wang 2010). Fig. 6 illustrates the ELT dispersion in each region. All weather stations of North East, Inner Mongolia, Hexi Corridor, Helan Mountain East, Xinjiang, and Jing-Jin-Ji were with an ELT value of below -15 °C, except Lanzhou and some small areas of Xinjiang and Jing-Jin-Ji. The Loess Plateau stretched across the soil-burying zone and non-soil-burying zone. Shandong was at the border between these two zones. Shallow cover is still indispensable where the events of ELT ≤ -15°C occur more than three times in 30 years (Li 2008). The Ancient Yellow River, the Southwest Mountain, and the Special Region were the only three regions where grapevines could successfully overwinter without covering with soil. Soil burial is imperative in the majority of the Chinese wine regions. Performing this measure is indeed an essential factor that affects the income and management of vineyards (Li 2008). Introduction of more cold-resistant varieties can be attempted in the regions at the border of bury line. For example, *V. amurensis* is an extremely cold-resistant species that can safely survive at temperatures as low as -40 °C (Wan *et al.* 2008), which is a good resource for breeding cold-hardy hybrids.

In general, most of these wine regions were located within the suitability zones defined by climatic indices, except the North East and the Special Region in which special germplasm resources were widely distributed. In turn, the applicability of this climate indices system was also verified by these results.

However, the weather stations selected as representative of a region may not truly reflect the climate condition of this area, especially in mountain areas. Deqin is the highest winegrowing region in China, in which wine grapes are cultivated in dry and hot valley areas with an altitude of 1,900 to 2,900 m (Yang *et al.* 2014). The wine produced there was found to contain extremely high concentrations of cyanidin and quercetin derivatives (Li *et al.* 2011b). In addition, in this region, the numbers of volatile compounds in the vine increased with altitude elevation, whereas the concentration of the total volatiles decreased (Yue *et al.* 2015). Considering the sparse distribution of weather stations in Southwest Mountain Region, we had to use a site with an altitude of 3,319 m as representative of this region. Nevertheless, this altitude may exceed the upper altitude limit of suitability. Therefore, a further study aimed at determination of the limit of the wine grape cultivation altitude in this region is needed. Thus, it was just a general analysis of the climatic characteristics in each region at macroclimate scale (a regional scale of tens to hundreds of kilometers), without considering the details in mesoclimate scale (a vineyard scale of tens to hundreds of meters) (Robinson 2006).

Conclusions

Based on the results of a comprehensive investigation, we established that at the time of study wine grapes were cultivated in 179 counties in China with a total area of 163,200 ha. *Vitis amurensis*, *Vitis davidii*, and *Vitis quinquangularis* are three distinctive germplasm resources in China that still have not been effectively developed and utilized. The internationally recognized cultivars are widely cultivated in China with high a homogenization in different regions; Cabernet Sauvignon accounts for a large proportion as well. The climatic characteristics of each region were estimated by climatic indices system that employed the values of FFS, DI, and ELT. Distinct regional differences and generally good viticultural suitability were revealed by our analysis. The results presented in this paper may facilitate the improvement of the knowledge of Chinese wine regions.

Nevertheless, the development of Chinese wine regions still faces great challenges, including insufficient utilization of wild germplasm resources, the lack of a complete wine geographical indication protection system, homogenization

of the cultivar structure, etc. We hope to encourage further studies of viticultural zoning, variety regionalization, wine-style design, etc., to promote the development of Chinese wine-production regions.

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