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Historical Events, Achievements, Challenges and Prospects of the Grape Industry in Mainland of China

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Abstract

Based on over 45 years of data, this paper aims to explore the major historical events, challenges and prospects of development of the grape industry in China. Ancient Chinese collected native wild grapes as fruits 2,700 ago. The *V. vinifera* grapevines were planted in Turpan 2,300 years ago. Development of the industry has five distinctive stages from ancient China to the present. The unique ancient culture using grapevines, grapes and wines as materials was colorfully and emotionally embodied in Chinese antiques. Grapevines are currently planted in the eight regions across the country, but the wine industry is mainly distributed in five regions. Chinese wild grapes are valuable resources for resistance breeding. Though remarkable achievements in the past four decades, extension of rootstocks, improvement of field management, development of grape storage technology, are challenges in the current Chinese viticulture industry.

Introduction

Grapevine planted area and grape production have dramatically increased in the past four decades on the Mainland of China (Figure 1; FAO 2023; Liu et al. 2023). At present, both planted area and grape production on the Mainland of China are the highest among grapevine growing countries worldwide (FAO 2023). Rapid development of the grape industry on Mainland China in the past four decades has drawn attention from around the world (Duan et al. 2019; Liu et al. 2023). However, there are few English publications that contain detailed information about the industry on Mainland China. Based on over 45 years of data collection from a large number of Chinese publications, this paper aims to review the major historical events, achievements, potential risks and prospects concerning development of the grape industry on Mainland China. This review paper will not only provide basic information about Chinese grape and wine production, but it is also critical in establishing a valuable reference to the sustainable development of the industry on Mainland China.

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Major Developmental Stages of Grape industry in Mainland of China

Ancient Chinese started collection of native wild grapes as fruits 2,700 years ago in Xizhou dynasty (1046 B.C.−771 B.C.) (Ma 2015). Archaeological discovery proves that the *V. vinifera* grapevines were planted in 300−500 B.C. in Turpan basin, Xinjiang, China (Lv et al. 2004).

The Chinese grape industry experienced five development stages, and the major cultivars, viticultural technologies, regions and production sizes were distinct within each of these five stages (Liu 1983; Liu and Tang 2020; Wang et al. 2007).

Stage I (from Han dynasty (202 B.C.) to Late-Qing dynasty (1891 A.D.). The grapevine (*Vitis vinifera*) was introduced from the Western Regions (e.g. Turpan) to the Central Plains in West Han dynasty of ancient China (202 B.C. to 180 B.C.; Chen 2006; Liu 2017; Zhang et al. 1984).

In the Tang (618−907 A.D.) and Song (960-1279 A.D.) dynasties, grapevines were popular. They were planted in the vineyards of the imperial palaces and feudal yards, and grapes were used for both fresh consumption and making wines (Li 2020; Ping et al. 2015). Vigor of grapes and taste of wines were eulogized in poetries and paintings from the Tang and Song dynasties (Leizhou 2023; Li 2020; Ping et al. 2015). Scale of the grape industry was small before the Song dynasty (Li 2020; Ping et al. 2015).

Development of the grape industry attained the zenith in the Yuan dynasty (1277−1368 A.D.) in ancient China because the governors were fond of wines and liquors. They ordained wines as tributes for sacrifices which facilitated rapid development of the grape industry, further molding the unique culture using grapevines, grapes and wines as the art materials by dignitaries (Chen 2016; Wang et al. 2009). The industry was characterized by the small vineyards distributed in South China, while large vineyards and wineries were present in North China (Chen 2016; Wang et al. 2009). Prosperity of the grape industry and eight popular wine brands across the country were vividly described in the *Travels of Marco Polo* (Chen, 2016; Wang et al. 2009). Hexi Corridor, Longyou, Shanxi, Henan, Hebei, and Beijing were the major regions for the production of grapes and wines (Chen 2016; Wang et al. 2009).

The scale of the grape industry experienced an evidential drop in the Ming dynasty (1368−1644 A.D.; Pan 2011; Wang et al.,2009). The prominent event was that the health benefits of grapes and wines were elaborately described in *Compendium of Materia Medica*, a world-famous medicinal herb book collected and edited by Li Shizhen (1518−1593 A.D.; Liu and Liu 1989; Liu and Liu 1991). The industry further declined in the early- and mid-Qing dynasty (1644−1891 A.D.) due to frequent wars after the year of 1840 in recent history of China (Pan, 2011; Wang, 2009).

Six or more grape cultivars were frequently introduced in the ancient Chinese books (Liu and Liu 1991). The cultivar of ‘Sultana’ or ‘Thompson Seedless’, one of the most popular cultivars at present for fresh consumption or making raisins worldwide, has a planted history over 2,000 years in Turpan, Xinjiang, China (Liu and Liu 1991).

Stage II (from 1892 to 1949). The grape industry at that time was overall deeply affected by continuous wars and harsh policies resulting in the frequent bankruptcy of small wineries (Wang et al. 2007). The grapevine planted area and grape production were 3,200 ha and 38,000 tonnes, respectively, in 1949 (Wang et al. 2007).

Stage III (from 1950 to 1979). The industry experienced rapid expansion after the formation of the People’s Republic of China in 1949 (FAO 2023). The grapevine planted area (~30,700 ha) and grape production (~125,700 tonnes) in 1979 were 10.0-fold and 3.2-fold of

that in 1950, respectively (Cao 2009; FAO 2023; Wang et al. 2007). A large number of grape cultivars were introduced from the former Soviet Union, Eastern European countries, and Japan at this stage (Cao 2009; Duan et al. 2019). 'Muscat Hamburg', 'Longyan (Dragon Eye)' and 'Sultana' were the most popular table grapes. The wine grape cultivars were mainly introduced from former Soviet Union and Eastern European countries (Cao 2009; Duan et al. 2019). Turpan of Xinjing, Xuanhua of Hebei province, Taiyuan of Shanxi province, and Hexi Corridor of Gansu province were the major production regions for table grapes, while wineries were mainly distributed in the old Yellow River Course region at this time (Cao 2009; Duan et al. 2019).

Stage IV (from 1980 to 1999). Rapid development of the grape industry in this stage attributes to improvement of viticultural technologies, extension of hybrid cultivars introduced from Japan and the Reform and Opening-up policy implemented starting from 1978 in China (Cao 2009; Duan et al. 2019). The grapevine planted area, grape production and wine production in 1999 were ~ 7.0 folds, 24.6 folds and 35.4 folds of that in 1980, respectively (Figures 1, 2; FAO 2023).

'Kyoho', 'Muscat Hamburg', 'Sultana' and 'Red Globe' were the major table grape cultivars, while 'Cabernet Sauvinon', 'Merlot', 'Pinot Noir', 'Chardonnay', 'Riesling', 'Carignan', and hybrids of *V. amurensis* were the major wine cultivars at this stage time (Cao 2009; Duan et al. 2019). Production of table grapes mainly came from northern regions of China, while production of wines was from Shandong Peninsula, Beijing, Hebei, Hexi Corridor of Gansu province (Duan et al. 2019).

Stage V (from 2000 to 2022). The grape industry experienced rapid development and reached the zenith in 2021 with planted area of 74,593 ha and grape production of ~15 m tonnes (Figure 1; FAO 2023). However, development of the wine industry showed an approximate normal distribution curve in 2000-2022 and reached the zenith in 2012 (Figure 2).

Uses of interspecific cultivars (e.g. 'Kyoho', 'Fujiminori' and 'Shine Muscat') and improved technologies (e.g. 'grape bagging' and 'rain shelter cultivation') facilitated rapid extension of the table grape industry across the country, especially to regions of South China (Cao 2009; Duan et al. 2019). Certain provinces of Ningxia, Xinjiang, Yunnan, Guizhou and Shanxi have become the new stars for wine production besides the traditional regions (Duan et al. 2019).

The Major Grape and Wine Production Regions in Mainland of China

Except the Hainan province, all other thirty-three provinces or districts are involved in grape production on Mainland China (Duan et al. 2019; Liu and Tang 2020; Yang 2007). A number of methods were used for categorization of the grape production regions across the country, however, the standard based on eco-geographical conditions is the most popular way supported by the majority of experts (Huang 1982, Luo et al. 2001). The 33 grape production provinces or districts can be categorized into eight major production regions according to eco-geographical conditions, scale of grape production and cultivar composition (Figure 3; Huang 1982, Luo et al. 2001; Yang 2007).

The Bohai Gulf region (R1). It is the largest grape and wine production region on Mainland China (Duan et al. 2019; Yang 2007). Grapevine planted area (229,670 ha), grape production (4.76 m tonnes) and wine production (100,950 tonnes) in this region in 2022 accounted for 35.2%, 37.8%, and 50.0%, respectively, of the total grapevine planted area, for grape and wine production (Duan et al. 2019; FAO 2023; Yang 2007). It can be classified into two subregions according to

distinct ecological conditions across the region: South Bohai Gulf Sub-region (SBGS) and North Bohai Gulf Sub-region (NBGS) (Huang 1982; Luo et al. 2001). The SBGS extends across most of the Shandong province, Beijing District, Tianjin District, Northeast Hebei; while NBGS extends across Liaoning province (Figure 3; Huang 1982; Luo et al. 2001).

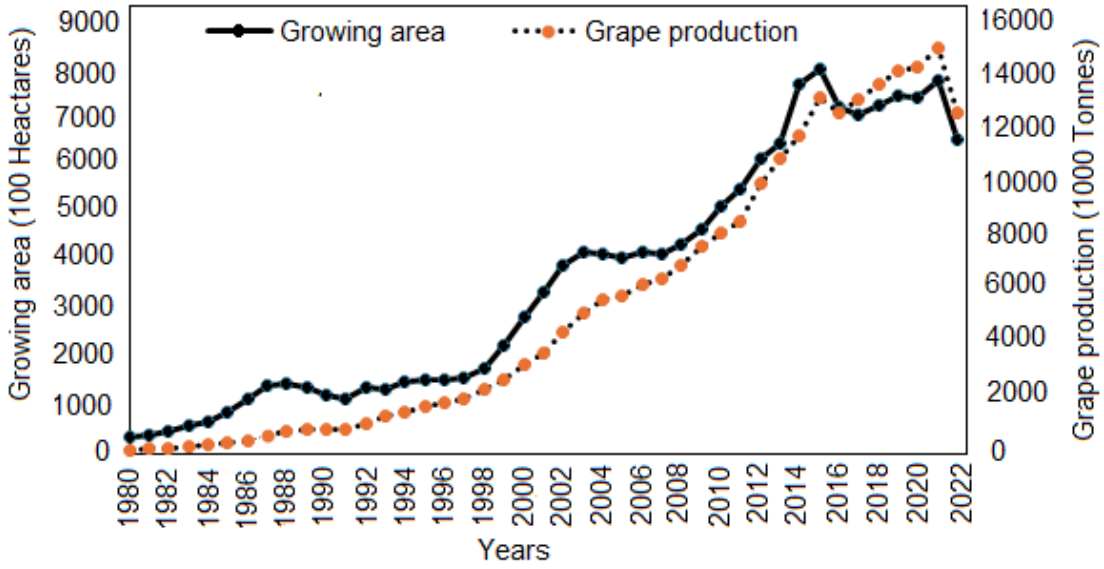

Figure 1. Grapevine planted area and grape production on Mainland of China (1980-2022, from FAO, 2023).

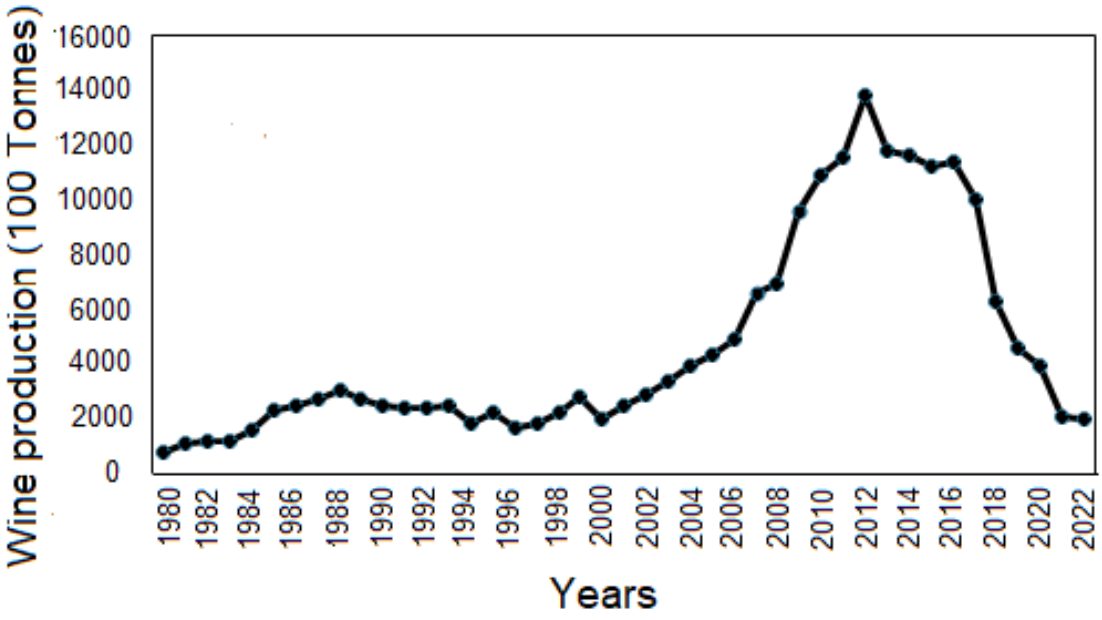

Figure 2. Grapes harvested for wine production on Mainland China (1980-2022; FAO 2023).

SBGS has a temperate climate with the annual average temperature of 10 to 13 °C, an average temperature of −1 to −3 °C in January, an absolute minimum temperature lower than −16 °C, an average temperature of 20 °C from April to October, and a frost-free period of 180−220 days. Additionally, it has an annual precipitation of 600−700 mm and sunshine of over 2,400 h (Huang 1982; Luo et al. 2001; Wu 1998). NBGS has a temperate to cool climate with the annual average temperature of 9 to 10 °C, an average temperature of −3 to −13 °C in January, an absolute minimum temperature lower than −25 °C, an average temperature of 17 °C from April to October, and a frost-free period of 180−200 days. Additionally, it has an annual precipitation of 560−700 mm and sunshine of over 2,500 h (Huang 1982; Wu 1998; Luo et al. 2001).'Kyoho', 'Muscat Hambury', 'Longyan', 'Zexiang', 'Red Globe', 'Autumn Black', 'Shine Muscat', 'Rizamat', 'Jingya', 'Kangtai', 'Zizhenxiang', 'Xiangyue', 'Jumeigui', 'Xixianghong', 'Augusta', 'Zana', 'Italian', 'Centenial Seedless' are the main table grape cultivars in this region (Duan et al. 2019; Yang 2007). 'Cabernet Sauvignon', 'Cabernet Franc', 'Merlot', 'Chardonnay', 'Italian Riesling', 'Cabernet Gernischt', 'Carignan' and 'Ugni Blanc' are the main wine grape cultivars in this region (Duan et al. 2019; Liu and Tang 2020; Yang 2007).

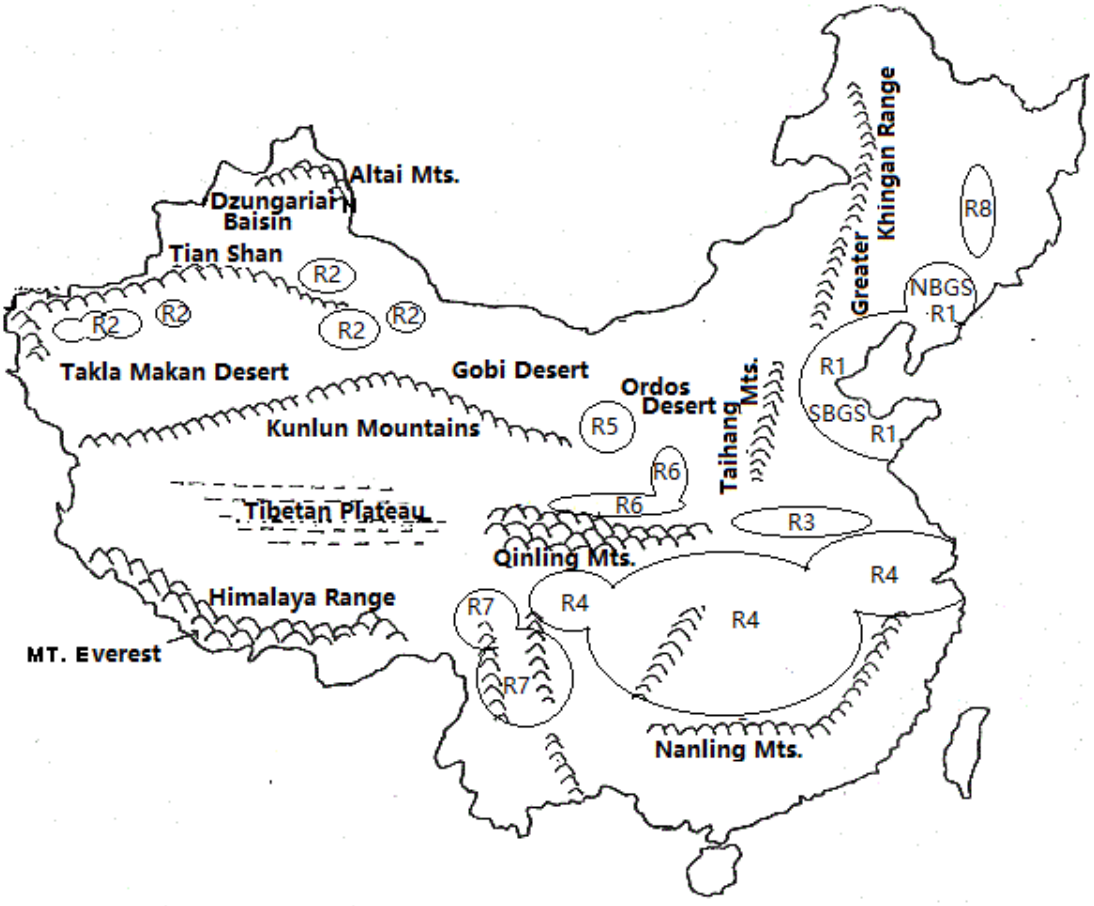

Figure 3. Schematic map representing the major grape production regions on Mainland China (2023). R1, the Bohai Gulf region; R2, Xinjiang region; R3, the Ancient Yellow River Course plain region; R4, South China grape production region; R5, East Hexi corridor and Inner Mongolia region; R6, the Loess Plateau and Guanzhong Basin region; R7, Yun-Gui-Chuan Plateau region; R8, the Northeast region. Source map from: http://afe.easia.columbia.edu/china/geog/maps.htm#1b.

Xinjiang region (R2). Xinjiang is the second largest grape production region on Mainland China. Grapevine planted area (124,000 ha), grape production (2.72 m tonnes) and wine production (12,000 tonnes) in Xinjiang in 2022 accounted for 19.0%, 21.5% and 5.9%, respectively, of the total grapevine planted area for grape and wine production on Mainland China (Duan et al. 2019; FAO 2023; Yang 2007). Turpan is the largest grape production area in Xinjiang and the grape production was 52.8% of the total production in Xinjiang in 2022 (Duan et al. 2019; Yang 2007). Turpan is also the largest raisin production in China (Duan et al. 2019; Yang 2007).

This region can be classified into three subregions according to distinct eco-geographical conditions among them, the Desert Basin Harsh Subregion (DBHS, e.g. Turpan), the Desert Drought Subregion (DDS) covering Hami and counties of South Xinjiang and the Continental Semi-drought Climate Subregion (CSCS) covering counties of North Xinjiang (Figure 3; Huang 1982; Luo et al. 2001; Wu 1998).

Turpan is enclosed by mountains to form special DBHS ecological conditions: an annual average temperature of 13.9 ℃, very hot during the summer (commonly with maximum temperatures over 45 ℃ and occasionally over 50 ℃), cold in the winter (commonly with minimum temperatures below −28 ℃). Additionally, DBHS has low annual precipitation below 15 mm, high annual evaporation over 3,000 mm, a larger temperature difference between day and night during the growing seasons (over 16 ℃) and high annual sunshine duration over 3,200 hours (Huang 1982; Luo et al. 2001; Wu 1998). ‘Sultana’, ‘Centennial Seedless’, ‘Melissa Seedless’, ‘Dawn Seedless’, ‘Rizamat’, ‘Red Globe’, ‘Autumn Black’, ‘Muscat Hamburg’ were the major table grape cultivars in Turpan and Hami (Duan et al. 2019; Yang 2007).

Ecological conditions in the DDS are milder than those of DBHS, especially with a lower maximum temperature and duration and a higher annual precipitation (40 mm) in DDS. However, the minimum temperature in winter, annual evaporation and annual sunshine duration are very close between the two subregions (Huang, 1982; Wu, 1998; Luo et al., 2001). South Xinjiang includes Hotan, Kashgar, Aksu, Artux. ‘Hotan Red’, ‘Red Globe’, ‘Autumn Black’, ‘Italian’, ‘Christmas Rose’, ‘Honggao’ (a mutant from ‘Italian’) are the main table grape cultivars in South Xinjiang (Duan et al. 2019; Liu and Tang 2020; Yang 2007).

Sunburn on leaves and berries is the biggest viticultural problem in DBHS and DDS (Aibulitipu et al. 2005). Grape powdery mildew and downy mildew diseases are also a problem in these two regions (Wupuer et al. 2008). Salinization as a result of high evaporation is an increasing problem for agriculture in these two subregions (Pataer 2019). Snow water from Tianshan Mountain and the Kunlun Mountains and karez, an ancient underground-ditch irrigation system, are used for irrigation in DBHS and DDS (Aibulitipu et al. 2005; Pataer 2019).

CSCS includes counties of Shihezi, Kuitun, Wusu, Jinghe, Changji, Karamay, Ili and suburbs of Urumqi. Eco-geographical conditions in CSCS are diverse because of distinct topographic features within CSCS (Huang, 1982; Wu, 1998; Luo et al., 2001). The typic conditions of the grape industry in CSCS are: annual precipitation of 400 to 600 mm, annual average temperature of 10 to 12.4 ℃, the annual maximum temperature of 28 to 33 ℃, the annual minimum temperature of −25 to −28 ℃ and annual sunshine duration over 2600 hours (Huang, 1982; Wu, 1998; Luo et al., 2001). Early- and midseasonal-ripening cultivars including ‘Kashihare’, ‘Muscat Hamburg’, ‘Pink Toffee’, ‘Rizamat’ and ‘Kyoho’ are the main table grape cultivars in North Xinjiang (Yang, 2007; Duan et al., 2019). Grape downy mildew and powdery mildew

diseases are the main viticultural problems in North Xinjiang (Duan et al. 2019).

Most of the wineries mainly are distributed in Turpan, Yanqi Basin and North Tianshan Mountain (Duan et al. 2019). 'Cabernet Sauvignon', 'Cabernet Gernischt', 'Merlot', 'Cabernet France', 'Riesling', 'Italian Riesling', 'Carignan', and 'Saperavi' are the main wine grape cultivars in Xinjiang (Duan et al. 2019; Liu and Tang 2020; Yang 2007).

The Ancient Yellow River Course plain region (R3). This region is located in the plain between the Yellow River and the Huai River (Duan et al. 2019; Wu 1998; Yang 2007). It extends across the Yellow River Downstream Plain covering four provinces of North Henan, North Anhui, North Jiangsu and Southeast Shandong (Figure 3; Duan et al. 2019; Wu 1998; Yang 2007). Grapevine planted area (70,467 ha) for grape production (1.56 m tonnes) and wine production (4500 tonnes) in this region in 2022 accounted for 10.8%, 12.4% and 2.2%, respectively, of the total grapevine planted area for grape and wine production on Mainland China (Duan et al. 2019; Yang 2007).

The Huai River and Qinling Mountains are widely regarded as the eco-geographical line to classify North China and South China (Wu 1998). The region has a typical continental climate with an annual average temperature between 12.0 and 14.0 °C, average temperatures of 26-28 °C in July and -2.0 to -0.5 °C in January with an average frost-free period of 210 to 230 days. Additionally, it has an average annual precipitation of 750 to 1000 mm (Huang 1982; Luo et al. 2001; Wu 1998).

'Kyoho', 'Red Globe', 'Shine Muscat', 'Autumn Black', 'Ribier', 'Victoria' are the main table grape cultivars, 'Cabernet Franc', 'Cabernet Sauvignon', 'Merlot', 'Saperavi', 'Italian Riesling' and 'Riesling' are the main wine grapes in this region (Duan et al. 2019; Yang 2007).

South China grape production region (R4). This region is located in the Yangtze River Plains, the Yangtze River Tributary Plains and north to the five mountains (Yuechengling, Dupangling, Mengzhuling, Qitianling, Dayuling; Yang 2007). It extends across nine provinces of Anhui, Jiangsu, Zhejiang, Hubei, Hunan, Jiangxi, North Fujian, North Guangxi, East Sichuan and two districts of Shanghai and Chongqing (Figure 3; Yang 2007).

Grapevine planted area (73,070 ha) and grape production (1.29 m tonnes) in South China in 2022 accounted for 11.2% and 10.3%, respectively, of the total grapevine planted area and grape production on Mainland China (Duan et al. 2019; Yang 2007). Wine production in this region is negligible in comparison with other major wine production regions in China (Duan et al. 2019; Yang 2007).

Natural conditions of hot summers and mild winters in this region belong in subtropical zone with typical continental climate of annual average temperature between 14.0 and 16.1 °C, average temperatures of 28-33 °C in July and 3 to 5 °C in January, with an average frost-free period of 240 to 350 days and average annual precipitation of 800 to 1,600 mm (Wu 1998).

'Kyoho', 'Fujiminori', 'Pione', 'Kangtai', 'Shine Muscat', 'Jingchao', 'Benizuiho', 'Jixiang', 'Himrod', 'Italian', 'Christmas Rose', 'Ribier', 'Minicure Finger', 'Pannortiavinesa', 'Zana', 'Red Globe', 'Autumn Black', and 'Shine Muscat' are the main table grape cultivars in this region (Duan et al. 2019; Yang 2007).

East Hexi corridor and Inner Mongolia region (R5). This region is located in East Hexi Corridor and in the middle of the Yellow River Basin with an altitude of 1,150−1,500 m. It extends across three provinces of Gansu, Ningxia and Inner Mongolia (Figure 3; Huang 1982; Luo et al. 2001; Wu 1998). Grapevine planted area (33,270 ha) for grape production (478,800 tonnes) and wine production (23,016 tonnes) of this region in 2022 accounted for 5.1%, 3.8% and 11.4%, respectively, of the

total grapevine planted area for grape and wine production on Mainland China (Duan et al. 2019; Yang 2007).

The region has typical continental plateau desert climate with average annual temperature between 7.1 and 10.9 °C, average temperatures of 20−22 °C in July and −7 to −5 °C in January, and an annual average temperature difference between day and night of 12.1 to 15.2 °C. Additionally, this region has an absolute minimum temperature of −22 to −30 °C, and an average frost-free period of 150 to 162 days. Sunshine is abundant with annual accumulations of 2,800-3,020 hours, average annual precipitation of 200 to 263 mm and average annual evaporation of 1,550 to 2,600 mm (Huang 1982; Luo et al. 2001; Wu 1998).

'Sultana', 'Red Globe', 'Shine Muscat', 'Jumeigui', 'Kyoho', 'Centennial Seedless', 'Minicure Finger', 'Zana', 'Early Muscat', 'Manaizi', 'Daqing', 'Ruby Seedless' are the main table grape cultivars, and 'Cabernet Sauvignon', 'Cabernet Gernischt', 'Chardonnay', 'Pinot Noir', 'Merlot', 'Cabernet Franc', 'Syrah', 'Italian Riesling' are the main wine grape cultivars in this region (Duan et al. 2019; Liu and Tang 2020; Yang 2007).

The Loess Plateau and Guanzhong Basin region (R6). This region is located east of the Loess Plateau with an altitude of 800-1,500 m and Guanzhong Basin with an altitude of 200-400 m (Huang 1982; Luo et al. 2001; Wu 1998). It extends across two provinces covering Xi'an, Baoji, Tongchuan, Weinan, Yanan, Yulin of Shaanxi province, Taigu, Qingxu, Xiangning, Yuncheng and Ruicheng of Shanxi province (Figure 3; Huang 1982; Luo et al. 2001; Wu 1998). Grapevine planted area (424,110 ha) for grape production (630,000 tonnes) and wine production (4,500 tonnes) of this region in 2022 accounted for 6.5%, 5.0%, and 2.2% respectively, of the total grapevine planted area on Mainland China (Duan et al. 2019; Yang 2007).

The region can be classified into two subregions, the Loess Plateau Subregion (LRS) and the Guanzhong Basin Subregion (GBS) (Figure 3; Huang 1982; Luo et al. 2001; Wu 1998). The LRS has a typical continental plateau climate with an average annual temperature between 10.2 and 12.6 °C, average temperatures of 19−22 °C in July and −5 to −9°C in January. The annual average day/night temperature is 12.1 to 15.2 °C, with an absolute minimum temperature of −25 to −28°C, an average frost-free period of 160 to 180 days, annual sunshine of 2,500−2,900 hours, average annual precipitation of 400 to 460 mm (Huang 1982; Luo et al. 2001; Wu 1998).

The GBS has a typical continental climate with an average annual temperature between 12 and 13.6 °C, average temperatures of 23−27 °C in July and 3 to −3°C in January. The annual average day/ night temperature difference is 7.1 to 12.2 °C, with an absolute minimum temperature of −15 to −16 °C, and an average frost-free period of 210 to 222 days. Additionally, the GBS has annual sunshine of 2,100−2,400 hours and an average annual precipitation of 500 to 700 mm (Huang 1982; Luo et al. 2001; Wu 1998).

'Kyoho', 'Red Globe', 'Shine Muscat', 'Summer Black', 'Hutai No.8', 'Golden Finger', 'Red Rose', 'Muscat Hamburg', 'Zana', 'Hetianhong', 'Cuibao Seedless', 'Crimson Seedless', 'Rizamat' are the main table grape cultivars. 'Cabernet Franc', 'Cabernet Sauvignon', 'Merlot', 'Italian Riesling' and 'Riesling' are the main wine grapes in this region (Duan et al. 2019; Yang 2007).

Yun-Gui-Chuan Plateau region (R7). This region is located in Southeast of the Qinghai-Tibet Plateau with an altitude of 1,800−2,200 m (Huang 1982; Luo et al. 2001; Wu 1998). It extends across three provinces covering Kunming, Chuxiong, Dali, Yuxi, Qujing, Honghe of Yunnan province, Central and

South Guizhou province and West Sichuan province (Figure 3; Huang 1982; Luo et al. 2001; Wu 1998). Grapevine planted area (32,600 ha) for grape production (504,000 tonnes) and wine production (22,000 tonnes) of this region in 2022 accounted for 5.0%, 4.0% and 10.9%, respectively, of the total grapevine planted area on Mainland China (Duan et al. 2019; Yang 2007).

It has a continental plateau climate with an annual average temperature between 15.0 and 17.7 °C, average temperatures of 24−28 °C in July and 5 to 8 °C in January with an annual average day/night temperature difference of 12.2 to 15.4 °C, an average frost-free period of 280 to 300 days and average annual precipitation of 550 to 560 mm (Huang 1982; Luo et al. 2001; Wu 1998).

'Kyoho', 'Red Globe', 'Early Black Honey', 'Niagara', 'Shine Muscat', 'Summer Black', 'Centennial Seedless', 'Crimson Seedless', 'Minicure Finger' are the main table grape cultivars, and 'Merlot', 'Cabernet Sauvignon', 'Grenache', 'Italian Riesling', 'Chardonnay' and 'Ugni Blanc' are the main wine grape cultivars in this region (Duan et al. 2019; Liu and Tang 2020; Yang 2007).

The Northeast region (R8). This region extends across two provinces covering Jingyu, Ji'an, Gongzhuling, Tonghua of Jilin province, and Harbin and Boli of Heilongjiang province (Figure 3; Huang 1982; Luo et al. 2001; Wu 1998). Grapevine planted area (19,574 ha) for grape production (302,400 tonnes) and wine production (12,000 tonnes) of this region in 2022 accounted for 3.0%, 2.4% and 5.9%, respectively, of the total grapevine planted area, on Mainland China (Duan et al. 2019; Yang 2007).

It has continental cool climate with annual average temperature between 5.2 and 5.6 °C, average temperatures of 22−26 °C in July and −12 to −18 °C in January, an minimum temperature of −25 to −30 °C in January, an average frost-free period of 135 to 145 days and average annual precipitation of 550 to 870 mm (Huang 1982; Luo et al. 2001; Wu 1998).

'Kyoho', 'Summer Black', 'Jingya', 'Shine Muscat' are the main table grape cultivars and hybrids of *V. amurensis*, e.g. 'Gongniang No.2', 'Beibinhong', 'Shanputao' are the main wine grape cultivars in this region (Duan et al. 2019; Liu and Tang 2020; Yang 2007).

Three Distinctive Viticultural Technologies Used on Mainland China

Grapevine burying technology. This is one of the most important technologies used in the cool climate regions on Mainland China (Dong et al. 2003; Jiao 2005; Lv 1996). The regions including NBGS of R1, R2, R5, LPR of R6, and R8 described previously account for over 40% of grape production and over 35% of wine production. These regions need grapevine burying to ensure safe overwintering for the grapevines (Liu 2023). Timing is crucial for successful grapevine burying (Dong et al. 2003; Jiao 2005; Lv 1996). If grapevines are buried before grapevines show signs of dormancy, it will result in nutrient losses during grapevine pruning before the nutrients have translocated to the trunk and roots. Grapevines may also be sensitive to bruising or bending when metabolism of the grapevine is highly active (Jiao 2005; Liu 2023). It is difficult to bury grapevines late in the season when the soil is frozen (Jiao 2005; Liu 2023).

The primary procedures for grapevine burying include pruning the vines when over 85% of leaves have fallen or the grapevines are fully defoliated, tying up the pruned shoots, creating a 30-50 cm deep ditch between the planting lines, covering the soil over the entire grapevine after gently placing all grapevines in the line into the ditch, compacting the soil, thoroughly watering the vineyard, performing one or two irrigations during the winter, and removing the soil and repositioning the vines on the trellis in the following spring when the season begins budding (Figure 4; Dong et al. 2003; Jiao 2005; Lv 1996). The required soil

depth for grapevine burying is determined by the minimum temperature and its duration in winter at the specific locality (Dong et al. 2003; Jiao 2005; Lv 1996). Currently, most of the work involved in grapevine burying is performed by machines, including ditching, soil covering, and the removal of most of the soil (Dong et al. 2003; Jiao 2005).

The economic lifespan of grapevines utilizing the burial technology is decreased by 20−30% compared to non-buried grapevines, due to damage sustained by the grapevines as a result of this technological practice (Dong et al. 2003; Jiao 2005).

Figure 4. Grapevine burying technology is widely practiced in Northern regions of China. The entire grapevine is buried in the soil before the ground is frozen in the fall or the early winter.

Grape bagging technology. Most table grape growing regions have a continental climate on Mainland China (Wan and Lu 2016). This climate is conducive grape disease epidemics (Wan and Lu 2016). Consequently, two technologies, namely grape bagging and rain shelter cultivation, have been developed and implemented within the table-grape industry for the past two decades (Wan and Lu 2016; Xin et al. 2024).

Our group established a bagging technology and a patented product twenty-five years ago to protect the berries from pest damage (Wan and Lu 2016). This patented product has been remarkably extended to 80% of the table grape industry in China (~ 521,980 ha; Wan and Lu 2016).The key points to use this technique successfully are as follows: trim the grape bunches 20−25 days post flowering, thoroughly spray fungicide on grapevines and grape bunches, bag the grape bunches within 12 hours after spraying (otherwise re-spraying is necessary), thoroughly spray fungicide 12 hours before removing the bags, and remove the bags for berry coloring 12 to 15 days before harvest (Wan and Lu 2016). Bagging the grape bunches can be performed on either sunny or cloudy days; however, it cannot be applied on the rainy days (Wan and Lu 2016).

This technology is important to improve berry quality (Zheng et al. 2014) and berry appearance (Wan 2002; Zheng et al. 2014). Little dust is deposited on the bagged berries (Figure 5); thus, the appearance of the bagged berries is brighter and more appeals to consumers than non-bagged berries (Zheng et

al. 2014). The pesticide residues in the bagged berries can be reduced to ~10 % of the residues in the non-bagged berries (Wan and Lu 2016).

Rain shelter cultivation. More and more table grape growers are using technology of rain shelter cultivation in most of grape growing regions in China except R2 and R5 (Xin et al. 2024). A shelter of plastic film is built 50 to 80 cm up on the grapevine trellis (Figure 6; Wan et al. 2000). Cost of this technology is only 30-40% used for the greenhouse, but the technology has some advantages over greenhouse production: more ventilation leads to fewer grape diseases and more convenience for the field practices (Wan et al. 2000; Xin et al. 2024).

Figure 5. Grape bagging technology. The technology has been extended to 80% of the table grape production on Mainland China. It can improve berry qualities and reduce pesticide residues in berries.

Installation of the plastic film shelter should be done prior to rainy season (Xin et al. 2024). Usually remove the plastic film after harvest of grapes (Xin et al. 2024). However, it is suggested to postpone removal of the plastic film after the rainy season in the fall (Xin et al. 2024).

This technology has a number of benefits (Xin et al. 2024). It has extensively enlarged eco-geographical range to South China for cultivation of grapevines (Xin et al. 2024). It reduces incidence of grape diseases and reduces pesticide uses for pest control, facilitating production of green products in China (Xin et al. 2024). The technology can improve berry quality, facilitate accumulation of sugar and increase soluble solid content in the berries (Sun et al. 2021, Xin et al. 2024). The technology can also promote labor efficiency because field practices of spraying, tyin shoots to the trellis, shoot trimming, and thinning of flower- and grape-bunches, etc., can be performed during rain events (Sun et al. 2021, Xin et al. 2024).

Achievements on Studies of Viticulture and Enology

Northwest A&F University has been collecting and researching wild grape germplasm for forty-five years, achieving significant results, including studies on the eco-geographic distribution of wild grape species in China (Wan et al. 2008b), species nomenclature and identification China (Wan et

al. 2008c), comprehensive evaluation and analysis of agronomic traits in Chinese wild grapes and screening superior accessions for use in the grape breeding programs (Wan et al. 2008a). Certain accessions of *V. quinquangularis, V. amurensis, V. yeshanensis, V. romanetii, V. liubanensis* have high berry quality and high disease resistance and are suggested as the first potential materials chosen for breeding (Wan et al. 2008a). Our studies have caused international attention, and western breeders have started to use certain Chinese wild grape materials in their grape resistance breeding programs according to our reports (Schwander et al. 2012; Riaz et al. 2020).

Figure 6. Rain shelter cultivation technology. This technology has dramatically extended the eco-geographical range to South China for grapevine cultivation. It can also improve berry quality and reduce pesticide use in viticulture.

Grape cultivar collection and grape breeding. The China National Grape Germplasm Resource (CNGGR) is located at Zhengzhou Fruit Tree Research Institute (Duan et al. 2019). CNGGR has collected 2005 accessions of grapes, most of them are grape cultivars (Duan et al. 2019).

Mainland China has released over 400 cultivars in the past seven decades, including cultivars used for table grapes, wine grapes, rootstocks, juices and raisins (Zhuge et al. 2023). Over 333 cultivars are used for table grapes, accounting for 82.8% of the total released cultivars. But none of these cultivars have become the dominant contributors to table grape production. 'Muscat Hamburg' and 'Kyoho' are the two cultivars predominantly used for parents in the breeding programs (Zhuge et al. 2023).

Chinese breeders made efforts in improvement of grapevine hardiness using species of *V. amurensis*. Over a dozen superior hybrids were selected in the past 70 years and used in northeast China for making wines (Duan et al. 2019). These selections or cultivars harbor high hardiness and disease resistance to downy mildew (Zhuge et al. 2023). Wine production made from the *V. amurensis* hybrid grapes was 12,000 tonnes in 2022 in the provinces of Jilin and Heilongjiang (Duan et al. 2019; Liu and Tang 2020; Zhuge et al. 2023). Usage of high hardiness rootstocks

(e.g. 'Beta') and hybrids of *V. amurensis* greatly reduce labor for grapevine burial practices in Jilin and Heilongjiang (Duan et al. 2019; Liu et al. 2014).

Selections of wild species of *V. quinquangularis* were used for making wines in two counties of Du'an and Luocheng in Guangxi province in the past two decades. Wine production made from the *V. quinquangularis* grapes was ~ 4,000 tonnes in 2022 (Liu et al. 2014).

Challenges and Prospects

Soil erosion is a problem in certain regions of R3, R6 and R7 (He 1999). Root nematodes cause significant decreases in grape production without use of resistant rootstocks in China (He 1999). Chinese species of *V. pseudoreticulata* and *V. quinquangularis* demonstrated high resistance to root nematodes (He 1999). Conventional methods for soil management and irrigation are used in most of the vineyards (Duan et al. 2019). However, drip irrigation systems increasingly appeal to grape growers.

Grapevines without rootstocks (on their own roots) are predominantly used in China (Duan et al. 2019). Use of grape rootstocks accounts for ~ 15 % grapevine acreage (Duan et al. 2019). Grape rootstocks have numerous advantages as improvement of hardiness and grapevine disease resistance (Granett et al. 2001). Grape phylloxera is a major problem in America and Europe (Granett et al. 2001). Grape phylloxera was found in China, but it was promptly controlled and eliminated through quarantine. The lack of phylloxera-resistant rootstocks poses a significant risk to grape growers in China if grape phylloxera outbreaks are not controlled (Duan et al. 2019; Granett et al. 2001; Li et al. 2016).

Seedless grapes appeal to consumers (Li 2020). The supply of seedless grapes is about 18% of the fresh consumption market on Mainland China. Technology improvement in seedless grapevine production and increased supply of seedless grapes are required to fill in the gap of marketing demand (Duan et al. 2019; Li 2020).

The table grape supply exhibits a clear seasonal pattern, with approximately 90% of the supply occurring from mid-June to mid-November (Duan et al. 2019; Li 2020). Technology improvement for grape storage is required to prolong supply of table grapes on Mainland China (Duan et al. 2019; Li 2020).

Conclusions

Ancient Chinese collected the native wild grapes as fruits 2,700 years ago (Ma 2015). Archaeological artifacts were discovered that show *V. vinifera* grapevines were planted in the Turpan basin 2,300 years ago and were introduced to the Central Plains of China 2,200 years ago (Lv et al. 2004).

The Chinese grape industry experienced five development stages according to records (Liu and Tang 2020; Wang et al. 2007). Before the Song dynasty (960−1279 A.D.), the scale of the grape and wine industry was small, and grapevines were mainly planted in the imperial palace and feudal yards (Li 2020; Ping et al. 2015). Development of the industry reached a peak in the Yuan dynasty (1277−1368 A.D.) in ancient China (Chen 2016; Wang et al. 2009; Yang 2008).

The health benefits of grape and wine consumption were elaborately expounded in the *Compendium of Materia Medica* by Li Shizhen (1518−1593 A.D.; Liu and Liu 1989; Liu and Liu 1991). Modern viticulture and enology practices were introduced to China in 1892. However, the grape industry was small at that time and was deeply influenced by continuous wars and harsh policies (Wang et al. 2007; Wang et al. 2009).

The Chinese grape industry experienced rapid development in the past four decades, particularly in the past two decades (Duan et al. 2019; Liu and Tang 2020). The grapevines are currently planted in the eight regions across the country with distinctive eco-geographical

conditions, but the wine industry is mainly distributed in five regions (R1, R2, R5, R7, R8) (Figure 3; Duan et al. 2019; Liu and Tang 2020; Yang 2007). ‘Kyoho’, ‘Shine Muscat’, ‘Red Globe’, ‘Muscat Hamburg’ and ‘Sultana’ are the major table grape cultivars. ‘Cabernet Sauvignon’, ‘Cabernet Franc’, ‘Merlot’, ‘Chardonnay’, ‘Italian Riesling’ are the major winegrape cultivars (Duan et al. 2019; Liu and Tang 2020; Yang 2007). Hybrids of *V. amurensis* are used for making wines in the provinces of Jilin and Heilongjiang (Duan et al. 2019; Liu and Tang 2020). Selections of *V. quinquangularis* were used for making wines in Southeast of China (Liu et al. 2014; Zhuge et al. 2023).

Three viticultural technologies of ‘grapevine burying’, ‘grape bagging’ and ‘rain-shelter cultivation’ are extensively applied in the regional viticulture of China (Jiao 2005; Wan et al. 2000; Wan and Lu 2016; Xin et al. 2024). The grapevine burying technology is used for winter freeze protection of the grapevines (Jiao 2005). Both grape bagging and rain shelter cultivation can reduce pesticide use and improve berry quality during grape production (Wan and Lu 2016; Wan et al. 2000; Xin et al. 2024).

China has achieved remarkable research in grape breeding and wild grape germplasm evaluation (Wan et al. 2008c; Zhuge et al. 2023). However, it is necessary to enhance rootstock research and education, improve field management practices, and advance berry storage technology to ensure the sustainable development of China's grape industry (Duan et al., 2019; Liu and Tang, 2020).

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