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History, status and prospects of the apple industry in China

Huike Li[1], Yizhen Wan[2, 4], Man Wang[2], Mingyu Han[2, 4], and Xuexi Huo[3, 4]

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Abstract

Rapid development of the apple industry over the past few decades in China has resulted in a dramatic increase in farmers' incomes in low income regions of the country and improved ecological conditions, particularly a major reduction of soil erosion and an increase in humidity and precipitation in arid areas. Nonetheless, there have been and remain many problems in the apple industry in China. The most prominent problem is that a standard tree size is mainly used in production and this has numerous disadvantages. The poor health of nursery trees (especially virus-infection) is also a negative factor in the development of the industry. Further, monoculture based on a few cultivars may be a high risk. The relatively high cost of production and low yield per hectare are challenges faced in competing with foreign producers for market share. The Chinese government and experts in pomology have recognised these problems and are making efforts to solve them to ensure healthy and sustainable development of the apple industry in China.

Both apple production and planted area have increased markedly in the past 30 years in China (Fig.1) (Li et al., 2008; Yang et al., 2012). The planted area and production were about 700,000 ha and 2.5 m tonnes in 1981, respectively, and these figures increased to 2.14 m ha and ~ 41 m tonnes in 2014, respectively (Wang, 2014; Yang et al., 2012; Zhai et al., 2007). At present, both apple production and planted area are the highest among apple growing countries worldwide (FAO, 2013). Annual apple production in China was over nine-fold that of the United States in 2014 (Wang, 2014). Rapid development of the apple industry in China in the past few decades has drawn attention from around the world (Li et al., 2005, 2008; Zhai et al., 2005; Zhai and Zhao, 2007). However, there are few reports published in English that contain detailed information about this industry. Based on data collected over 30 years by our research group and presented in a large number of Chinese publications, this paper aims to review the major historical events, status, potential problems and prospects concerning the development of the apple industry in China. This review paper will not only provide basic information about Chinese apple production, but it is also critical in establishing a reference for the sustainable development of the Chinese apple industry.

Major Developmental Stages of Apple Industry in China

China has a long history of 2000 years of apple production. However, apple production was negligible before the formation of the People's Republic of China in 1949 (Fu and Du, 1994; Lu and Jia, 1999). The Chinese apple industry experienced four development stages and the major cultivars, cultivation technologies, regions and production

[1] College of Resources and Environment, and College of Horticulture, Northwest A&F University, Yangling, Shaanxi 712100, People's Republic of China
[2] College of Horticulture, Northwest A&F University, Yangling, Shaanxi, People's Republic of China
[3] College of Agricultural Economics, Northwest A&F University, Yangling, Shaanxi 712100, People's Republic of China
[4] To whom reprint requests should be addressed; e-mail: hamny62@gmail.com (MYH), wyz689@hotmail.com (YZW), or xuexihuo@nwsuaf.edu.cn (XXH)

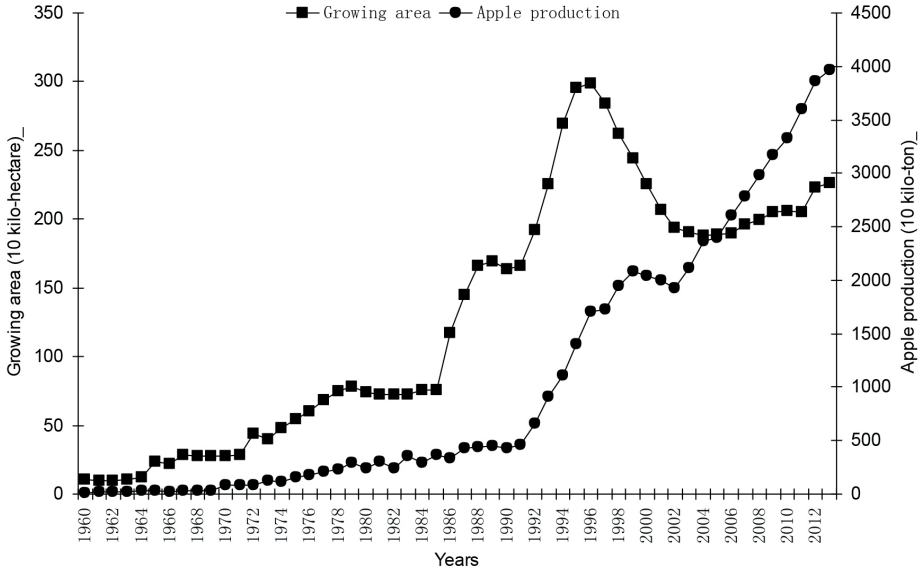

Fig. 1: Apple production and planted areas in China (1960-2013, data from FAO).

scale were distinct within each of these four stages (Fu and Du, 1994; Guo et al., 2003; Zhai et al., 2007).

Stage I (from the Han dynasty to 1949). Three major apple landraces were used in the imperial gardens of the Han dynasty (0-300 B.C) (Fu and Du, 1994; Lu and Jia, 1999). Chinese historical literature records that apples (*Malus spp.*) were grown in Northwest China, particularly in the Hexi Corridor in the 3rd century (Fu and Du, 1994; Lu and Jia, 1999).

The modern cultivated apple (*Malus ×domestica* Borkh.) was introduced into China in the late 19th century, mainly from European countries and the United States (Lu and Jia, 1999). The introduced apple cultivars were first tested and grown in Yantai, Shandong province (Lu and Jia, 1999). Cultivars with small fruit and mainly grown in the Northeast provinces of Liaoning and Jilin, were introduced from the former Soviet Union and the Middle East (Lu and Jia, 1999). Later, the Qindao, Chengdu, Hunming and Yili regions introduced a number of apple cultivars for testing and production from foreign countries (Lu and Jia, 1999). Before 1949, apple cultivars were mainly grown on the Jiaodong Peninsula, Xinjiang and in the northwest of the Yunnan-Guizhou Plateau. However, total apple production was low in this period (Lu and Jia, 1999).

Stage II (the 1950s and 1960s). The primary objective of the Chinese apple industry in this period was to increase yield per hectare (Gao et al., 2011; Guo et al., 2003). Apple breeding programs were also strengthened. Fourteen cultivars, including 'Bayuesu', 'Cuihong', 'Fuhong', 'Fujin', 'Guoshuai', 'Honghua', 'Hongsheng', 'Jiefang', 'Jinhong', 'Yingqiu', and 'Youyi', were released by Chinese apple breeding institutes during this time. The cultivars, 'Green Banana', 'Huangkui', 'Jiguan', 'Jonathan', 'Ralls Janet', 'Red Delicious', 'Wojin', and 'Zhuguang', were mainly used for apple production (Gao et al., 2011; Guo et al., 2003; Zhai et al., 2007) and Beijing, Heibei, Shanxi, Inner Mongolia, Liaoning, and Anhui were the major apple producing regions in China during this period (Gao et al., 2011; Guo et al., 2003).

Stage III (in 1960s and 1970s). The primary objective of the Chinese apple industry in this period was to improve the appearance and overall quality of fruit (e.g., fruit color and size) (Gao et al., 2011; Guo et al., 2003). Fifteen apple cultivars were bred by Chinese apple breeders during this period, among which the most popular were 'Cuiping', 'Liaofu', 'Qinguan', 'Qinguang', 'Qiujin', 'Shengli', 'Xianghong', 'Xiangyanghong', 'Yanfeng', and 'Yanhongmi'. However, 'Qinguan', 'Red Delicious', 'Red Ralls Janet', and 'Starking Delicious', were the major cultivars used for apple production. 'Qinguan' was the most important cultivar grown in Northwest China at that time with the total planted area of this cultivar being 150,000 ha at the end of the 1970s (Gao et al., 2011; Guo et al., 2003; Zhai et al., 2007).

Stage IV (from 1980s until the present). The primary objective during this stage was to improve overall fruit quality for both appearance and internal fruit traits (Gao et al., 2011; Guo et al., 2003; Zhai et al., 2007). About forty apple cultivars were bred by Chinese breeders during this stage. Some of these were widely used for apple production in certain regions of China, e.g. 'Changhong', 'Fucui', 'Fushuai', 'Hanguang', 'Hongbaoshi', 'Huaguan', 'Huashuai', 'Jinyu', 'Liquan Fuji Spur', 'Ningfeng', 'Ningjin', 'Ningsu', 'Xiushui', 'Yanfu 1-6', and 'Yan Gala 1-2' (Gao et al., 2011; Guo et al., 2003; Zhai et al., 2007). However, 'Fuji' is currently the most import cultivar, accounting for 75% of total apple production. Other introduced cultivars (e.g. 'Fujiki 1', 'New Jonathan', 'Red Gala', 'Sansa' and 'Tsugaruhime') have also been planted (Gao et al., 2011; Guo et al., 2003; Zhai et al., 2007).

The planted area increased continuously from 1961 to 1996 and reached 3.1 m ha in 1996 (Gao et al., 2011; Guo et al., 2003; Zhai et al., 2007). However, between 1997 and 2001, the planted area decreased. This was due to growers ceasing production in unsuitable regions. Apple production, nonetheless, was almost constant over that time (Fig. 1). The planted area in the regions most suitable for growing apples increased rapidly after 1997, as apple growers were able to obtain high profits from apple production in these regions (Fig.1) (Wang and Li, 2003).

In 2001, the planted area and production of apples reached to 2.1 m ha and 20.0 m tonnes, accounting for a quarter of the total area and a third of total production of all fruit crops in China, respectively (Wang and Li, 2003). From 2008 to 2012, the planted area continued to increase, at an average annual rate of 4%. The planted area and production reached to 2.2 m ha and 39.0 m tonnes, respectively, in 2012 (Yang et al., 2012).

The apple industry in areas around the Bohai Gulf has declined in the past two decades. However, it has rapidly increased in the Loess Plateau, for example, in the provinces of Gansu, Shaanxi and Shanxi (Han, 2010). The best regions on the Loess Plateau for apple production are found to be the areas with an altitude of 800-1200 m, extending to an altitude of 1300 -1500 m. These areas include Jingning, Zhuanglang, and Qingyang in the Gansu province. At present, Gansu province has become the area with the greatest potential and it has the fastest development of apple production (Han, 2010).

The Major Apple Production Regions in China

In total, 25 provinces are involved with apple production in China. These provinces can be categorized into five major regions according to ecological conditions, scale of apple production and cultivar composition (Fig. 2) (Han 2010; Li 2012; Liu 2005). The two most important regions are the Loess Plateau and the Bohai Gulf (Figs. 3 and 4) (Du et al., 2006; Han, 2010; Li and Li, 2006; Zhai et al., 2007). The provinces of Shaanxi, Shandong, Shanxi and Gusu are the most important for apple production (Han, 2010; Zhai et al., 2007). Seven and six superior ecological conditions, respectively, within the Loess Plateau and the Bohai Gulf region, meet international criteria required for the

Fig. 2: Schematic map representing the five major regions for apple production in China (2014). R1, the Loess Plateau Region; R2, the Bohai Gulf Region; R3, the Ancient Yellow River Course Basin Region; R4, the Northeast and Northwest Cool Region; R5, the Southwest Plateau Temperate Region. Source map from: http://afe.easia.columbia.edu/china/geog/maps.htm#1b.

production of high quality apples (Moser and Raffaelli, 2012). In contrast, only five superior ecological conditions within Washington State meet these requirements (Tian, 2004). Thus, the Loess Plateau has been regarded as one of the most superior and suitable regions for apple production in the world (Han, 2010; Tian, 2004; Zhai et al., 2007). Over the past decade, development of the Chinese apple industry has shown a common trend (Fig. 4): a relative reduction in the Bohai Gulf region and a rapid expansion in the Loess Plateau, especially to the western areas and to the higher altitudes in the north of the Loess Plateau (Han, 2010; Li, 2012; Zhai et al., 2007).

The Loess Plateau Region (R1). The Loess Plateau extends widely from the Taihang Mountains in the east, the Qinling Mountains in the south, the Ningxia Plain in the north and west to Guide county in Qinghai province, Jue county in Gansu province and the Yili valley in Xinjiang. Most of Shaanxi province is located in the center of the Loess Plateau (Wu, 1998). The most important apple counties in Shaanxi include Luochuan, Baishui, and Qianxian (Han, 2010). The most important areas for apple production in the Northern Hemisphere have a latitude of 33 to 39° and an altitude of 800 to 1200 m (Fan, 2011; Han, 2010; Li, 2012; Zhai et al., 2007;). The Weibei District (North to the Weihe River) is located in the Loess Plateau with the latitude of 34°11″ to 36°20″ and an elevation of 1000 to 2000 m in the northwest and 600 to 900 m in the southeast. This district is regarded as one of the most superior areas for apple production in China (Han, 2010; Tian, 2004; Zhai et al., 2007).

The Loess Plateau has a topography mainly consisting of cliff-edged plains, ridges and valleys. The major type of soil is a loess with soil thickness of 50 – 80 m. It is rich in potassium, magnesium, calcium, zinc, selenium and other nutritional elements. Soil oxygen concentration is 10-15% and pH value is 5.5–6.7 (Hou, 2008; Wu, 1998), which are

both suitable for apple root growth. Most of the areas in this region do not have irrigation systems and apple production depends on natural precipitation. It has a temperate climate, with an annual average temperature of 7.0 to 13.3°C, a lowest temperature of –2.7 to –7.0°C in January, an absolute lowest temperature of –16.0 to –25°C, an absolute highest temperature of 36 to 42.5°C, a frost-free period of 180 to 220 days, an annual effective accumulated temperature of 2500-4123°C, a sunshine period of 1900 to 2536 h, an average annual precipitation of 525 to 730 mm, and a drought degree of 1.03 to 1.54 (Hou, 2008; Wu, 1998).

'Fuji' and 'Qinguan' are the two main cultivars, accounting for 80% and 10% of the apple production in this region, respectively (Table 1). Other cultivars account for less than 10% of production (Han 2010). The most important rootstocks used in this region are seedlings from wild species, e.g. *M. sieversii* and *M. baccata* (Wan et al., 2011). Dwarfing rootstocks used in this region are responsible for less than 10% of the planted area and the most widely used are M.26, SH series and M7. In recent years, the apple industry in Gansu province has increased rapidly, reaching ~ 0.3 million hectares in 2012 (Han and Li, 2008). The planted area and production in the Loess Plateau accounted for 52% of the total area and 45% of total apple production in China in 2011 (Han and Li, 2012).

Areas with an altitude of over 1000 m on the Loess Plateau confer conditions that produce the highest quality apples within the overall region. Conditions with an extensive temperature differential between day and night, sufficient sunlight and high ultraviolet radiation in this region facilitate production of high quality apples with an attractive appearance, bright color, good shape, high sugar content, a balanced ratio of sugar to acidity, with a juicy and strong flavor in the fruit flesh. Disadvantages in this region include insufficient water for irrigation and uneven distribution of rainfall throughout the year, which affect fruit growth and result in relatively small fruit in some years (Han, 2010; Tian, 2004).

The Bohai Gulf Region (R2). This region is located around the Bohai Gulf at a latitude of 36 to 40°, extending across South Liaoning, West Liaoning, South Hebei, Beijing, Tianjin, and most of the Shandong province (Li, 2011; Wu, 1998). It has a temperate climate with the annual average temperature of 9 to 13°C, an average temperature of – 3 to –11°C in January, an absolute minimum temperature lower than – 26°C, an average temperature of 20°C from April to October, a frost-free period of 131-220 days, an annual precipitation of 500-700 mm and sunshine of over 2500 h (Wu, 1998). Most of soil is a brown forest soil, which is suitable for growing apple trees (Fan, 2011).

The Bohai Gulf Region is the second largest apple producer among the five major regions in China (Han, 2010). The planted area was about 240,000 ha in 2009 (Han, 2010). The major cultivars are 'Fuji' and 'Jonagold', accounting for more than 90% of apple production in this region (Table 1) (Yan et al.,

Table 1: The major apple cultivars grown in the five regions of China.

	Five apple growing regions												
	R1		R2		R3			R4			R5		
Major cultivars	Fuji	Qinguan	Fuji	Jonagold	Jonathan	Starking Delicious	Red Delicious	Fuji	Golden Delicious	Starking Delicious	Fuji	Golden Delicious	Starking Delicious
Total production within region (m tonnes)	10.53	2.40	10.45	0.20	0.06	1.25	0.38	3.58	0.13	0.02	0.35	0.06	0.09
Average fruit diameter (mm)	73	78	76	75	70	78	76	71	70	74	71	69	73

Note: R1, the Loess Region; R2, the Bohai Gulf Region; R3, the Ancient Yellow River Course B asin Region; R4, the Northeast and Northwest Cool Region; R5, the Southwest Plateau Temperate Region.

2010). The most important rootstocks were seedlings from wild species, e.g. *M. baccata, M. sieversii* and 'Pingyitiancha' (*M. hupehensis*) (Han, 2010). Dwarfing rootstocks used in this region represent less than 10% of the total planted area and the most widely used are M.26 and M.9. The planted area and production in this region accounted for 32% and 38%, respectively of the total area and total production in China in 2008 (Han, 2010). Advantages in this region include a strong base of technical support, a quick shift from traditional technologies to modern production systems, a ready acceptance of new cultivars by growers, and a relatively high rate of transfer of high production technologies to growers (Han, 2010). The appearance and overall quality of fruit from this region are among the highest ranked in the country (Han, 2010). Low temperatures in winter often cause damage to trees and the early occurrence of frost often affects the normal defoliation of apple trees in this region (Han, 2010; Wu, 1998).

The Ancient Yellow River Course Basin Region (R3). This region is located in the south of the North China Plain. It is located between the Yellow River and the Huaihe River, with a longitude of 113 to 120° (Lu, 1980; Sheng et al., 1982; Wu, 1998). It extends from Zhengzhou in Henan province in the west to Binhai in Jiangsu province in the east, covering the four provinces of Henan, Anhui, Shandong and Jiangsu (Sheng et al., 1982).

Natural conditions (precipitation, radiation and temperature) belong in the transitional zone between warm temperate and temperate climates with relative dry weather and a relatively rapid increase of temperature in spring, high moisture and hot weather in summer, and dry, cool weather in the fall but providing sufficient sunlight for apple growth (Han, 2010; Wu, 1998). Extensive temperature variation among years in this region is due to its transitional zone and a large plain resulting in a ready exchange of air currents between locations, and different intensities and onset times of monsoons among years (Sheng et al., 1982; Wu, 1998). This region has a typical continental climate with an annual average temperature around 14.0°C, average temperatures of 27°C in July and –0.5°C in January, and an average frost-free period of 210 days (Sheng et al., 1982; Wu, 1998).

Most of the soil is a fluvo-aquic soil with a high concentration of $CaCO_3$ (7%), alkaline conditions (pH 8–9), a low concentration of organic matter (0.5% in the top soil), low nitrogen, low rapidly available phosphorus, with sandy soil in the top soil and clay mixed with sand in the lower layers (Sheng et al., 1982; Wu, 1998).

Apple production in this region accounts for ~7% of total apple production in China (Han, 2010). The major cultivars are 'Jonathan', 'Ralls Janet', 'Red Delicious', and 'Starking Delicious'. The most important rootstocks are seedlings from wild species, e.g. *M. baccata* and *M. sieversii*. The most widely used dwarfing rootstocks are M.26 and M.9 (Han, 2010).

The Northeast and Northwest Cool Region (R4). This region extends across Southwest Jilin, Northwest Liaoning, the Hexi Corridor, Hamid, Tarim Basin and the Yili District of Xinjiang, most counties along the Huangshui River downstream of Qinghai, and the Lhasa and Shigatse Districts of Tibet (Lu, 1980; Wu, 1998). This region has a cool temperate climate with an annual average temperature of 7–8°C, an average temperature in the coldest month lower than –14°C, an absolute minimum temperature of –30°C, and an average frost-free period of 130–137.5 days (Lu, 1980; Wu, 1998). It has drought periods and windy conditions exist in most areas of this region. Only early- or mid-ripening cultivars with high abiotic endurance can be grown in most areas of this region due to the harsh conditions (Han, 2010). Apple production in this region accounted for 5-8% of total production in China in 2008. 'Fuji', 'Golden Delicious', 'Ralls Janet', and 'Starking Delicious' are the major cultivars in this region

(Table 1). Genotypes with high cold hardiness from the seedlings of wild species, e.g. *M. baccata* and *M. sieversii*, are mainly used as rootstocks (Han, 2010).

The cultivar 'Hanfu' is a hybrid from the cross between 'Dongguang' and 'Fuji' bred by Prof. Huai-yu Li at Shenyang Agriculture University. It has been identified amongst local cultivars as having the greatest cold hardiness but with high fruit quality and high productivity (Li and Qiao, 1998). The planted area for this cultivar has reached about 30,000 ha and it is mainly grown in Liaoning and Shengyang provinces in the northeast of China.

The Southwest Plateau Temperate Region (R5). This region is located in the center of the Yunnan-Guizhou Plateau with a geographical distribution ranging west to downstream of the Tibet Brahmaputra River including southern counties of Qamdo, north to the South Liangshan Mountains including the counties of Xichang in West Sichuan, and east to the Baise District of Guangxi province. Low latitude and high altitude are its typical geo-ecological features. Most apples are grown within an altitude of 1500 –3000 m (Lu, 1980; Wu, 1998). This region has a temperate and plateau climate with the annual average temperature of 9–13°C, an average temperature of 2–9°C in January and 18–22°C in July, an average temperature of 20°C from June to August, a frost-free period of 144–218 days, an annual precipitation of 800–1000 mm and annual sunshine of over 2000 h (Lu, 1980; Wu, 1998). The low variation of annual average temperature is due to its high altitude. Apple production in this region is characterized by early fruiting, early ripening and high fruit quality, most likely due to the relatively long winter dormancy period, sufficient sunlight and high radiation for apple growth (Lu, 1980; Wu, 1998). Early- or mid-ripening cultivars are suitable in the southwest of this region covering the northeast of Yunnan province. However, the major cultivars are mid- or late-ripening, including 'Golden Delicious', 'Fuji' and 'Starking Delicious'. Most trees are standard-sized and grown on seedlings from wild species, e.g. *M. baccata* and *M. sieversii*, as rootstocks (Han, 2010).

Major Technologies and Tree Systems Used in China

The major tree systems. Approximately 87 - 90% of apple trees in China are of standard size (Han, 2010). Wild species of *M. sieversii*, *M. baccata*, *M. prunifolia*, and *M. hupehensis* ('Pingyitiancha') have mostly been used as rootstocks (Wan et al., 2011). Because seedlings are used for rootstocks, genetic segregation in the population often results in heterogeneity in vigor and height among trees within the population. Other disadvantages of this system include late onset of fruiting (long juvenility) and tall trees resulting in inefficient tree management. Other tree systems (<10%) include the use of wild species as rootstocks, dwarfing genotypes (mainly from M.26) and the use of interstems – often called 'semi-dwarfing' by Chinese growers.

Major Chinese apple rootstocks. M. sieversii is mainly distributed in the Yili District of Xinjiang around the Tianshan Mountains and in several states of Kyrgyzstan (Wan et al., 2011). This species has high genetic diversity and high biotic and abiotic resistances including drought resistance, cold hardiness, and resistance to a number of diseases and pests (Wan et al., 2011). It is a widely used species for apple rootstocks in China.

M. baccata is a widely distributed species in Shaanxi, Gansu, Shanxi, Hebei and the three provinces of Northeast China. Some genotypes in this species have been identified to have high cold hardiness and be able to survive at −50°C in winter. This species grows well in sandy soils. Its fibrously rooting ability has been observed to confer early fruiting and high productivity for most scion cultivars. This species cannot grow in high saline-alkaline soils, showing yellow chlorosis symptoms. It has low tolerance to waterlogging and root rots but moderate resistance

to drought. Grafting incompatibility with some cultivars is also a problem, showing an obvious "knot" at the graft interface. Seeds of *M. baccata* are relatively small and seedling emergence is low and weak. Early fruiting and high productivity can sometimes be associated with early senescence in the scions in trees grafted with this rootstock (Wan et al., 2011).

M. prunifolia is widely distributed in North China including the provinces of Shaanxi, Henan, Gansu, Shandong, and Liaoning. Seedlings of this species can produce strong main roots and young seedlings grow rapidly. The mature tree has a strong root system including strong lateral roots. It has strong endurance to drought, cold, waterlogging and saline-alkaline soils, root rots, woolly aphid, and crown gall. This species has good graft compatibility with most cultivars. Grafted trees grow strongly and have a long longevity. This species has high genetic diversity, thus superior genotypes adapted to local environmental and ecological conditions are available from local wild populations (Wang and Wang, 2008).

Most of the "SH series" are dwarfing rootstocks with resistance to drought (Yang et al., 2010). These rootstocks were bred by the Pomology Institute of the Shanxi Academy of Agricultural Sciences and are mainly used in Shanxi, Gansu, Hebei, Beijing, and Shaanxi (Yang et al., 2010). SH1 was derived from the cross 'Ralls Janet' × *M. honanensis.* This rootstock is adapted to the conditions of the Loess Plateau Region. It shows good graft compatibility with *M. baccata*, *M. micromalus* and most cultivars such as 'Fuji', 'Starking Delicious', and 'Red Delicious' when it is used as the interstem. The grafted trees grow strongly, with an early fruiting habit and long longevity. The performance of 'Fuji' trees grafted on SH1, such as fruit color, flavor, flesh texture and storability of fruit, was better than that on M.26 (Yang et al., 2010).

Major cultivation technologies. Major cultivation technologies used in China are different from those used in western countries.

Thinning - The most important cultivar grown in China is 'Fuji'. This cultivar is sensitive to chemical thinning application. Most flower and fruit thinning is fulfilled by manual labor in China. Thinning is performed twice, once at the time of loose-cluster to 'pop-corn' stages, the other one or two weeks after bloom.

Pollination - Most apple orchards are pollinated naturally by wind and bees. A few apples are pollinated artificially.

Irrigation - Over 70% of apple production in China is dependent on natural precipitation. The remaining orchards have irrigation systems, including furrow and drip.

Fruit bagging - Fruit bagging is applied to ~90% of apple fruit destined for fresh consumption in China (Han, 2010; Zhai at al., 2006). The bag is usually composed of two layers of paper (the inner and external papers). Apple bagging is often performed six weeks after bloom, either on sunny days or on cloudy days where there has not been any rain in the preceding two days. At 24 h before bagging, fungicides, particularly those for preventing *Botrytis cinerea* infection, are applied to the trees. The removal of bags is performed in three steps: taking off the external paper 11-13 days before harvest, complete removal of the bags two days later, and then turning the fruits around a week before harvest to capture more color on the reverse side of the fruit. The strategy of removing the two layers of the bags separately at different times, rather than at once, dramatically reduces the incidence of sunburn on the fruits. Reflecting films are often placed on the ground under the trees to increase coloration on the fruits after the removal of these bags (Fig. 4).

Fruit surface on the apples produced using this bagging technology is brighter, cleaner and more colorful than on fruit that have not been bagged. However, this technology has high cost due to the significant investment that is required in labor. Storability is reduced a little compared to that for non-bagged fruit.

Research System, Grower Size, Marketing System and Fruit Uses in China

Research and extension support system. The research and extension system for supporting apple production can be categorized into national (supported by the Ministry of Agriculture of China), provincial and county levels. There are two national institutes responsible for fruit research and breeding, one in Xingcheng and another in Zhengzhou. In the 25 provinces where there is major apple production, there are provincial fruit search institutes or agriculture universities that are assigned tasks mainly for apple research, breeding and extension for their provinces. County fruit bureaus focus on technical extension to growers in their counties but experts from provincial institutes or universities lead the extension work. At present, Northwest A&F University is the national leader for apple research, breeding and extension in China - Prof. Mingyu Han is the chief scientist leading this mission.

Grower size and marketing system. The apple production unit in China is mainly based on the family as the managing unit, rather than on company models or large family units. On average, each grower (family) owns and manages 0.5-1.0 ha of apple orchard (Han, 2010). A small amount (< 0.5%) of apple production is produced by big companies. Most of the fruit from family growers is sold by local grower associations or fruit companies. These organizations buy fruit from the growers, store this fruit for a period, and then sell it to Chinese markets or foreign countries. Fruit storage companies ship the fruit to wholesale markets then to retail or directly to supermarkets throughout the country.

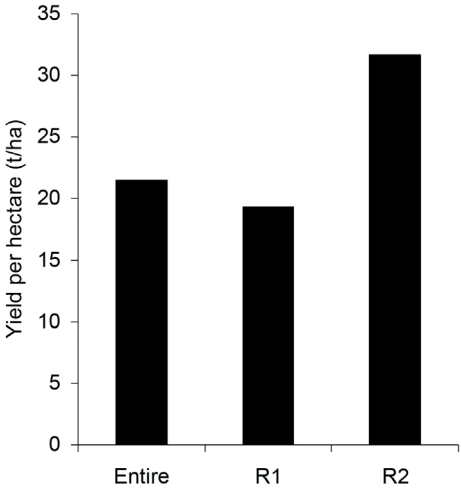

Fig. 3: Yield of fruiting trees for the entire Chinese apple industry and for two major regions in 2014 (data from http://www.china-apple.org/detail.jsp?id=2172). R1, the Loess Plateau Region; R2, the Bohai Gulf Region.

Fruit uses. About 75 - 85% of apples are used for fresh consumption in China (Han, 2010, Wu and Ma, 2009). Of these, 95% are sold to local Chinese markets (Wu and Ma, 2009; Zhai and Zhao, 2005). Only 3 - 5% of fresh fruit are exported, mainly to Russia and Southeast Asian countries (Han, 2010). About 70% of fresh fruit are stored in low temperature or controlled atmosphere storage systems for short or long term purposes. Trucks with low temperature storage systems are used for fruit shipping.

The remaining 15% of fruit are mainly used for processing into concentrated juice, chips or preserves (Ge et al., 2009; Han, 2010; Zhai and Zhao, 2005). The proportion of misshaped fruits of 'Fuji' apple is relatively high and these fruit have a low price if they are sold in fresh markets. Thus, most of these misshaped 'Fuji' fruit, which otherwise have high fruit quality, are used for juice processing. Juice quality, particularly taste quality from this cultivar, is relatively high because of the inherent high fruit quality of 'Fuji' apples. The concentrated apple juices are mainly exported (Han, 2010; Zhai and Zhao, 2005).

A small proportion (<5%) of apple fruit is used for processing into apple vinegar, chips, wines and preserves (Han, 2010; Zhai and Zhao, 2005). In recent years, the volumes of these processed products have increased in China.

Fig. 4: Representative orchards in the two major apple production regions in China. Upper, R1, the Loess Plateau Region (Shaanxi); lower, R2, the Bohai Gulf Region (Shandong). Fruit quality in R1 is relatively high, but yield in R2 is higher. Reflective mulch and bagged fruit are evident in the photographs.

Roles of the Apple Industry in China

Increased farmer income. In China, most low-income people live in the countryside. The apple price is 2.5-3.0 fold that of the major cereal crops, such as wheat and corn, in local markets. Apple yield is 5-8 fold of these major cereals (Li, 2010). Although investment for apple production is relatively high, the net profit of apples is 5-7 fold that of cereals. Most of the areas are not suitable for the growth of cereal crops as they have low yields due to droughts. These areas are now currently planted with apple trees. Due to the rapid development of the apple industry in these areas over the past few decades, the living conditions of local farmers have dramatically improved and have been promoted (Li, 2010).

Geo-ecological improvement. The Loess Plateau is currently the most important apple producing region in China. The arid or semi-arid climates in this region resulted in a low rate of vegetation cover that resulted in serious soil erosion. An estimated 1.6 billion tonnes of sand and soil were flooded into the Yellow River every year in the1970s (Yu et al., 2007). It was reported that over 70% of the agricultural land in some counties in this region, such as Luochuan, Baishui, Xunyi, are now planted in apple trees and over 60% of the soil erosion has been reduced due to the strong rooting system of apple trees and the extensive nature of apple plantings in these areas. The humidity and precipitation in these counties has also increased by 30% because of improved ecological conditions due to the extensive apple plantings (Yang et al., 2010).

Multiple industries and job positions available. A number of industries have been established in the past few decades due to the development of the apple industry in China, e.g., manufacture of fruit bags and corrugated paper boxes, and production of fruit juice. Companies have also been established for fruit storage, shipping and sales, international fruit marketing, and so on. The apple industry and its relevant industry chains provide 20 to 25 m job positions guaranteeing a living for 35 to 40 m people in China (Han, 2010).

Problems and Challenges

Standard apple trees are currently mainly used in China. Compared to dwarf growing systems, the standard system has numerous disadvantages as described above (Wang et al., 2008). Fortunately, this problem has been recognised by both scientists and the government in China and they are seeking ways to solve this problem. For example, some Chi-

nese nurseries have imported a large number of high quality apple rootstocks from nurseries in European countries, particularly Italy, over the past two years to establish high quality, high density orchards in Shaanxi Province. In the next decade, the majority of Chinese apple growers are likely to use these modern apple systems.

There are currently only a few nursery companies in China that are able to produce high quality apple trees. Most apple trees from current nurseries carry a number of viruses, resulting in poor growth of trees, late fruiting and flowering, low yield and low fruit quality compared to high quality trees in western countries (Liu et al., 2012). The average yield of apples in China is very low, 19 – 31 $t \cdot ha^{-1}$ (Fig. 3), compared with that in Italy and France, 45 – 65 $t \cdot ha^{-1}$ (Han, 2010; Tian, 2004).

Small orchard sizes and the reality that most field work is carried out by hand-labor (particularly fruit thinning and bagging) means that production costs are relatively high. As labor costs are increasing worldwide, the Chinese apple production model is facing challenges, particularly from international competition. Development of apple industries in other countries, such as India and Brazil, is also introducing strong competition to Chinese apples both for local markets in China and internationally. The cost of apple production in these countries and in many western countries is relatively low (Liu et al., 2012).

A further problem in China is its cultivar composition as ~75% of apple production comes from 'Fuji'. However, this cultivar is very susceptible to diseases and abiotic stresses. This may impose a high risk or threat to this cultivar if one or a few destructive diseases develop within China (Liu et al., 2012).

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