Current Situation and Prospect of Walnut Industry in China

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Abstract. Walnut is one of the four major nuts in the world. China is one of the origins and distribution centers of genus *Juglans*. Walnut plays an important role in China's non-wood forest industry, which is of great significance to the national grain and oil security, farmers' income increase, life quality improvement, and ecological environment construction. On the basis of reviewing the three fields of germplasm resources and breeding, cultivation technologies, and walnut processing and utilization that China's walnut industry focuses on, this paper puts forward suggestions on the outstanding problems faced by the current industry, in order to provide references for the decision-making of relevant departments.

1 Introduction

Juglans *regia* L. is a deciduous woody perennial with important economic value, which was most widely cultivated in temperate regions [1]. The total output value of Walnut in the world exceeds 18 billion dollars, and the main producers are China, US, Iran, Turkey, Mexico, Chile, and Ukraine. Walnuts are rich in protein, oil, amino acids, vitamins, essential minerals, and other nutrients. Long-term consumption of walnuts can prevent cardiovascular disease and reduce cholesterol. It is precisely because of its high nutritional and medicinal value that walnut has been included in the list of priority plants by the Food and Agriculture Organization of the United Nations [2]. China is one of the origin centers of walnut, and also the country with the largest cultivation area and yield. As a woody oil-bearing plant with strategic significance in China, it has played an important role in ensuring national grain and oil security, increasing farmers' income, and realizing rural revitalization.

At present, the research on walnut industry in China mainly focuses on the following aspects: 1) screening and breeding of excellent walnut germplasm resources; 2) cultivation management measures; 3) walnut processing and utilization. This paper reviews and summarizes the three fields of the industrial chain from the source to the end, in order to show the current situation of China's walnut industry more comprehensively and provide references for sustainable industrial development.

2 Geographical distribution and regional yield of Walnut in China

Walnuts are widely distributed in China, ranging from Nyalam County (N 28"06') in Tibet to Bole County (N 44"54') in Xinjiang (spanning 16"08' north-south latitude) and from Tashkurgan County (E 75"15') in Xinjiang to Dandong City (E 124"21') in Liaoning (spanning 49"06' East-West longitude) [3]. According to the geographic, climatic, and soil components, it could be divided into four important cultivation zones[4,5]: 1) the northwest area (Xinjiang, Shaanxi, Gansu, Qinghai and Ningxia) dominated by aridisols and desert soils with cold desert climate and hot semi-arid climate; 2) the southwest area (Yunnan, Sichuan, Guizhou, and Chongqing) dominated by iron-rich soil, vertisols and anthrosols; 3) the lower Yellow river area and the Bohai Bay area (Henan, Hebei, Shanxi, Shandong, Liaoning, and Beijing) dominated by semi-alfisols and semi-aquatic soils with dry-winter subtropical climate and hot semi-arid climate; 4) the central area (Hubei, Anhui, and Hunan) dominated by anthrosols and ferralsols with humid subtropical climate.

As stated in China Statistical Yearbook 2020[6], the walnut yield of China continued to increase from 1.28 million tons in 2010 to 4.17 million tons in 2017, fell to 3.82 million tons in 2018, and reached a new high of 4.80 million tons in 2020 (Fig. 1). The southwest and northwest regions are the traditional walnut production areas in China, accounting for 46.56% and 36.06% of the total national yield respectively. The walnut yield of Yunnan and Xinjiang alone reached 2.66 million tons, accounting for 55.40% of the country's total yield. The lower Yellow River and the Bohai Bay area are also important walnut producing areas, contributing to 13.89% of the total national yield. The walnut yield in Central China is 0.14 million tons, accounting for 2.91% of the national total yield. The walnut yields in various areas of China in 2020 were shown in Fig. 2.

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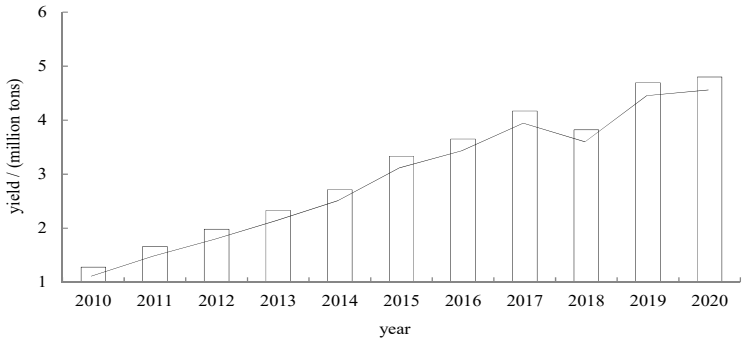

Fig. 1. Annual yield of Walnut in China from 2010 to 2020

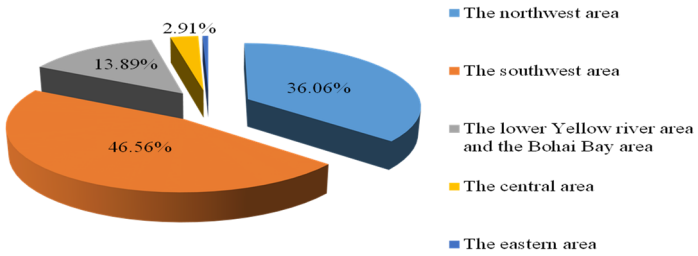

Fig. 2. Walnut yield in various areas of China in 2020

3 Walnut germplasm resources and breeding

3.1 Walnut germplasm resources

Relevant scientific research institutions in China have been carrying out a copious amount of work in investigating, collecting, and preserving of walnut germplasm resources. In 2014, a nationwide investigation was completed and a preliminary database of walnut genetic resources was established [7]. Based on the comprehensive investigation, the national and local walnut germplasm resources protection and utilization platforms had been established to collect and conserve varieties (clones), excellent individual plants, and special germplasm resources.

Climate and geographical environments vary in different regions of China, resulting in high genetic diversity levels of walnut. According to the previous researches [3,8-17], the dry weights of nuts and kernels in China ranged from 3.5 to 35.0 g, and 1.8 to 13.8 g, respectively; the kernel yield was 10.2% to 74.3%; and the shell thickness was 0.2 to 2.7 mm.

3.2 Walnut breeding

3.2.1 Cross breeding.

Walnut cross breeding in China started in the middle and late 1960s, with early-fruiting, high yield and quality as the main breeding goals. At present, multi-resistance (cold resistance, disease, and pest resistance) has also been included in the breeding goals.

Xinjiang walnut has the characteristics of early-fruiting and high yield, which was often used in the breeding of corresponding traits; however, it has the problems of premature aging and poor disease resistance. Walnut distributed in Northwest and North China has good nut quality (big nuts, thin shells, and high kernel yield) and good disease resistance, which can be used in breeding for resistance improvement, but they are not resistant to waterlogging. Juglans sigillata Dode from Southwest China has high temperature resistance and good quality, but they are not resistant to droughts and low temperatures. Juglans mandshurica Maxim in northern China has excellent cold and drought resistance, and is often used for cold resistance breeding. Juglans hopeiensis Hu is a hybrid of Juglans regia and Juglans mandshurica, which could be used as walnut rootstock. Juglans cathayensis Dode is widely distributed in China and has superior stress resistance, which mainly cultivated as walnut rootstock.

The hybrid walnut varieties ‘Xiangling’ (‘shangsong 6 hao’×‘Aksu 9 hao’), ‘Luguang’ (‘Xinjiang kakazi’×‘shangsong 6 hao’), ‘Luxiang’ (‘shangsong 6 hao’×‘Xinzaofeng’), ‘Yuanlin’ (‘Yuanfeng’×‘Chandler’), ‘Daixiang’ (‘Liaohe 1 hao’×‘Xiangling’) with early-fruiting, high yield and quality were bred by Shandong institute of pomology. Liaoning institute of economic forestry also used Xinjiang early-fruiting walnut as parent and bred ‘Liaoning’ series varieties, such as ‘Liaoning 1 hao’. The Chinese academy of forestry has created 'Zhonglin' series varieties through cross breeding with Shanxi local walnuts as their parents. For improving the resistance and nut quality, interspecific hybridization also has attracted much attention. Liaoning institute of economic forestry bred 'Hanfeng' by crossing 'xinzhipi' with Juglans cordiformis. Yunnan academy of forestry and grassland has bred 'Yunxin' and 'Yunlin' series varieties by crossing Xinjiang early-fruiting walnuts and Juglans sigllata[18].

3.2.2 Rootstock breeding.

Improving the multi-resistance of walnut is the main goal of rootstock breeding. At present, Juglans and Pterocarya are mainly used for walnut rootstocks.

Juglans regia rootstock showed excellent grafting affinity and a high graft survival rate, but it cold and waterlogging resistance were poor. Juglans mandshurica is cold and barren tolerant, however, the grafting affinity is unsatisfactory in the late growth stage as rootstock. Juglans sieboldiana and Juglans cordiformis could be used as rootstocks for dwarfing walnut trees. Juglans nigra has strong resistance (drought resistance, cold resistance, and disease resistance), strong adaptability to an adverse environment, and good grafting affinity. Pterocarya stenoptera has good waterlogging resistance, strong disease resistance, and moderate drought resistance, but as a rootstock, it has affinity differences due to different walnut varieties. Previous studies [19, 20] showed that Pterocarya stenoptera has excellent resistance to walnut blight and good grafting affinity with walnut varieties 'Tulare' and 'Vina', but it is incompatible with 'Chandler'.

4 Walnut cultivation

4.1 Training and Pruning

Central leader shape and open center shape are commonly used in walnut orchards, which are suitable for dense planting, and sparse planting or intercropping gardens respectively [21]. In order to avoid excessive branches consuming a large amount of nutrients and affecting the reproductive growth, and to optimize the light interception throughout the canopy, it is necessary to prune at regular intervals. Spring pruning is suitable for overgrown plants, which is conducive to controlling tree vitality and promoting early harvest. Summer pruning is aimed to remove the overly dense and weak branches in the canopy, shorten the long branches and retain some side branches, and promote the sprouting in the next year. Autumn pruning (from mid-September to early November) mainly aims to maintain proper light interception and distribution in the canopy by removing dense branches and shading branches. Winter pruning does little damage to the tree, so the optimization of tree shape could be carried out in winter. Winter pruning could effectively promote flower bud formation and yield improvement.

4.2 Water and fertilizer management

Walnut trees are sensitive to soil moisture; while low soil moisture content will affect fruit setting, too much water will cause the leaves to fall off early. Previous studies [22] showed that in order to meet the needs of high yield, sufficient irrigation should be carried out thrice, that is, before sprouting, after flowering, and after harvest but before soil freezing.

At present, the fertilization measures of walnut garden are mainly divided into organic fertilization, chemical fertilization, and foliar fertilization. Generally, organic fertilizer is applied after walnut harvest in autumn. As a quick acting fertilizer, chemical fertilizer is generally applied in the sprouting stage, young fruit stage, and shell hardening stage. Foliar fertilizer has the advantage of high efficiency, which could be sprayed when element deficiency occurs [22]. Walnut has different demand for mineral elements in different growth and development stages. It has a large demand for N, P, K, Fe, Mn, Zn, Cu and Mg in flowering stage; Ca, Mg and B in shell hardening stage; and Mg in fruit ripening stage [23]. The application of K, Ca and Mg fertilizers could increase the nut weight, while the appropriate application of P fertilizer can increase the crude fat content [24].

4.3 Walnut diseases and insect pests

Diseases and insect pests are two important factors affecting the yield and quality of walnut. At present, more than 30 walnut diseases and 120 insect pests have been identified [21]. The most serious walnut diseases are black spot disease caused by Xanthomonas species, walnut canker disease caused by Cytospora species, and walnut anthracnose disease caused by Colletotrichum species. The walnut black spot disease is more serious in Shaanxi, Henan, Shandong, Hubei, Sichuan, and Chongqing, which will cause early fruit drop. The walnut anthracnose disease has occurred to varying degrees throughout the country, reducing the yield and quality of walnut. The more serious insect pests are *Atrijuglans hetauhei* Yang and *Batocera horsfieldi* (Hope). The *Atrijuglans hetauhei* Yang is widely distributed in Hebei, Henan, Shanxi, Shaanxi, Gansu, and Sichuan, and its larvae will eat the green husk and kernel. Longicorn pests occurring in Henan, Hebei, Shandong, Sichuan, and Chongqing can damage the trunk, causing walnut tree weakness, fruit drop and even crop failure. The following measures can effectively reduce the occurrence of diseases and insect pests: 1) keeping higher light interception in canopy and cleaning up the diseased branches and fruits in time; 2) adopting chemical control when diseases and pests are serious; 3) screening and breeding walnut varieties or rootstocks with disease and insect pest resistance.

5 Walnut processing

With the improvement of living standards, there is an increasing demand for high-quality walnut processing products. At present, the main walnut processing products include walnut oil, walnut protein products and some by-products.

Cold pressing is still the main method for producing walnut oil. The nutritional components of oil are well preserved, but the sensory quality needs to be improved. Some scholars [25] developed a novel process of producing fragrant walnut oil by Maillard reaction of enzymatic hydrolysate found in walnut meal. In addition, new processes of oil extraction, such as supercritical CO2 technology, are still being tried and improved for industrial production [26]. In order to prolong the storage period of walnut oil rich in unsaturated fatty acids (easy to be oxidized), some methods were used such as adding harmless natural plant antioxidants or applying

encapsulation behavior [27,28].

Walnut protein products mainly include walnut powder and walnut milk. Walnut powder is generally made from walnut meal by crushing, mixing, homogenizing, and spray drying, and it is widely used in protein beverage industry. Researchers have also developed a series of walnut milk products, such as skimmed walnut milk, compound walnut milk, and walnut yogurt, which meets the different taste of consumers. The preparation of walnut polypeptide products with different physiological activities (oxidation resistance, blood pressure reduction, blood glucose reduction, fatigue resistance, immune enhancement, etc.) has become a hot spot in the field of walnut protein development [29]. Walnut harvesting and processing can generate byproducts such as green husk, seed shell, and other wastes. If these wastes could be reasonably processed and utilized, it will further enhance the added value of walnuts. Green husk contains juglone, flavonoids, polyphenols and other components with anti-tumor activities, which can be used in the research and development of anticancer drugs [30]. Green husk could also be used as raw materials to produce plant-derived pesticides [31]. The seed shell contains lignin (38.05%), cellulose (30.88%) and hemicellulose (27.26%), which could be used for the preparation of high-end activated carbon [7].

6 Conclusions

Although China ranks first worldwide in terms of walnut cultivation area and yield, there are still some problems that restrict the further development of the walnut industry, mainly as follows: 1) The walnut yield per unit area is low and the improved walnut varieties are lacking; 2) Due to the lack of advanced cultivation and management technologies, the yield and quality of walnuts are unstable; 3) The post-harvest and processing technologies need to be improved; 4) The walnut industrial chain is short and related products need to be further developed.

To enhance the competitiveness of China's walnut industry in the world, the following suggestions were proposed: 1) The country could strengthen the guidance of walnut product positioning to realize product differentiation; 2) The adoption of improved walnut varieties should be promoted; 3) Improved varieties should be planted in the suitable area, and the planting scale should be appropriate; 4) In appropriate areas, mechanized, lightened and simplified, and patterned cultivation manners should be adopted to realize labor-saving management and walnut high-efficient production; 5) It is necessary to improve the innovation and achievement transformation ability throughout the whole industrial chain from the source (breeding, planting) to the terminal (processing); 6) Solve the problem of insufficient funds for relevant enterprises and farmers, and finally realize the sustainable development of the industry by supporting potential enterprises.

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