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Research Progress on High-efficiency Cultivation Techniques of Blueberry and Its Development Potential in Under-forest Economy

Haineng LIN[1,2], Yuzhen YU[1,2], Hubo JIANG[3], Ting ZHANG[4]*

1. Guangxi Research Center for New Fertilizers in Forestry, Nanning 530003, China; 2. Guangxi Huawote Group Co., Ltd., Nanning 530003, China; 3. Guangxi Zhuang Autonomous Region Forestry Research Institute, Nanning 530002, China; 4. Guangxi State-owned Qipo Forest Farm, Nanning 530225, China

Abstract Through literature analysis and case study, the introduction history, variety selection (high bush, half high bush, low bush) and regional cultivation techniques of blueberry in China were summarized, and the practical effects of precision cultivation (water and fertilizer integration, wild planting) and under-forest economic model (forest-blueberry-fungus system, ecological tourism) were evaluated. It provided a technical reference for expanding the planting scale of blueberry and improving the fruit quality.

Key words Blueberry, High-efficiency cultivation techniques, Under-forest economy, Rural revitalization

0 Introduction

Blueberry is a deciduous shrub of *Vaccinium*, Ericaceae[1]. Its fruit is blue or black purple, so it is named "blue berry". It is native to eastern Canada, eastern and southern United States. Its fruit is rich in anthocyanins, vitamin C and other antioxidant substances[2]. It not only has high nutritional value, but also has significant effects in preventing brain nerve aging, enhancing body immunity, improving vision and alleviating eye fatigue. It is one of the five healthy fruits recommended by the World Food and Agriculture Organization[3-4]. Because blueberry is a shrub with small fruit, compared with other large-scale fruit trees, its demand for soil nutrients and exogenous nutrients is lower, and the nutrient output from fruit harvest is also less. So blueberry is regarded as a resource-saving fruit tree. In addition, blueberry berries have both rich nutrition and health characteristics. With the rapid development of social economy and the continuous improvement of people's consumption level, the market demand for blueberry is gradually increasing, showing a broad market prospect[5]. At present, blueberry, a new fruit, has attracted the attention of the government, enterprises and society, and is gradually developing into a worldwide fruit tree[6].

With the enhancement of people's awareness of health care and the improvement of social production and consumption capacity, blueberry has attracted much attention because of its unique health attributes[7]. Besides, blueberry planting technology is also constantly innovated[8]. Nowadays, the application of greenhouse cultivation, drip irrigation and other technologies has significantly improved the yield and fruit quality of blueberry. With the help of intensive management, blueberry diseases and pests have been effectively controlled. In addition, the quality of blueberry was further optimized by imitating the wild cultivation mode and planting in the natural environment such as mountains and woodlands. In order to better meet the market demand, blueberry industry clusters integrating planting bases, processing plants and sales channels have been formed in some regions, and a complete industrial chain is built, which enhances the added value of products and market competitiveness. At present, Chinese blueberry has been successfully exported to the United States, the European Union, the Pacific region and other countries and regions. With the gradual expansion of the influence of Chinese blueberry brand and the continuous development of the international market, blueberry as a cash crop has a broad development prospect[9-10]. This paper reviewed the development status of blueberry cultivation technology in China, in order to provide technical reference for expanding blueberry planting scale and improving fruit quality.

1 Development status of blueberry cultivation technology

The utilization and introduction of blueberry resources in China began in the 1980s, and it was first introduced and studied by Jilin Agricultural University. Subsequently, Nanjing Institute of Botany of Chinese Academy of Sciences, College of Forestry of Beihua University, Shandong Fruit Tree Research Institute and other research institutions introduced and cultivated blueberry varieties suitable for growth in China. The early research content mainly focused on variety introduction, cultivation technology, seedling technology and other fields, which laid the foundation for the industrial production of blueberry in China. Affected by climate conditions, the research focus in different regions is different. Due to the cold climate in Northeast China, the core of research is the development and utilization of wild blueberry resources and the introduction, breeding and cultivation of cold resistant blueberry varieties. It is necessary to focus on the introduction and cultivation of cold resistant varieties to ensure the normal growth and harvest of blueberry. Blueberry varieties from the southeast and south of the United States are mainly introduced in East China, such as Richu, Duke, Xilai, Lanfeng and other

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Haineng LIN, senior engineer, master's degree, research fields: chemical engineering. * Corresponding author. Ting ZHANG, senior engineer, master's degree, research fields: forest management.

world-famous germplasm resources. These varieties adapt to high temperature and humidity environment, and fit the climate characteristics of East China. In addition, domestic institutions have carried out more than 40 years of breeding work on more than 100 blueberry varieties introduced from abroad. Through screening, breeding and selection, a large number of varieties suitable for China's climatic conditions, site environment and planting mode have been successfully cultivated and gradually promoted. These studies have not only promoted the progress of blueberry planting technology and variety diversification in China, provided farmers with more planting options, but also brought more high-quality products to consumers. At present, the planting area of blueberry in China has exceeded 69 000 ha, and China has become the world's largest blueberry producer. The planting area covers 26 provinces (cities), and the cultivation methods include greenhouse cultivation and open field cultivation. Among them, more than 56% of domestic blueberries are used for processing, while the output of Guizhou, Liaoning, Shandong, Sichuan and Yunnan accounts for 76.8% of the total output of China[11-13].

With the continuous progress of science and technology, the cultivation technology of blueberry is increasingly improved, which provides a solid support for improving the yield and quality of blueberry. However, in the actual production, there are still some problems such as improper variety selection, poor soil and improper water management, which restrict the development of blueberry industry[14]. At present, there are three main planting varieties of blueberry in China. According to the characteristics of plant height and cold resistance, it is divided into high bush, half-high bush and low bush blueberry. The introduction and promotion should be combined with the climatic conditions of different planting areas. Among them, the high bush blueberry plants can reach about 2 m after mature, and can tolerate −30 ℃ of low temperature, with good adaptability in temperate and cold temperate regions; the plant height of half-high bush blueberry is mostly 1.0–1.5 m, which is more suitable for extremely low temperature environment and suitable for cultivation in northern China; the low bush blueberry has short plants and strong cold resistance, which is suitable for planting in cold regions[15].

2 Cultivation techniques of blueberry

2.1 Selection of planting time Planting time is the key factor for blueberry planting. Generally, the humidity is high before germination in early spring, and planting at this time is conducive to the safe growth of blueberry seedlings. In the tropical and subtropical climate regions of southern China, due to the long duration of high temperature, the planting time is usually selected in winter (December to next March) to reduce the adverse effects of high temperature on blueberry seedlings. It should be handled flexibly according to soil conditions when planting: if the soil is sticky, the soil aeration and organic matter content can be enhanced by ploughing or adding organic matter such as sawdust and rice husk decomposition, to ensure drainage and air permeability and promote root growth. After planting, root-fixed water should be poured thoroughly. In areas with less rainfall, water retaining agent can be applied appropriately to prevent drought. In addition, in order to better maintain blueberry seedlings, the cultivation land should be equipped with sprinkler irrigation or drip irrigation equipment[16-17].

2.2 Selection and planting of cultivation garden As an indicator of measuring soil acidity and alkalinity, pH reflects the concentration of H^+ in soil. For blueberry growth, acidic soil with pH of 4.5–5.5 is the most suitable. If the soil pH exceeds this range, it needs to be adjusted. It can release H^+ by adding sulfur powder or aluminum sulfate powder to the soil, and reduce the soil pH. H^+ can be neutralized by adding lime, and the pH of soil is improved. It is worth noting that it is necessary to fully plough to promote the full mixing of soil and regulator after adjusting the pH of soil, so as to achieve the best effect. In addition, blueberry is suitable for planting in sandy or loamy soil, which has loose physical structure and good drainage performance. At the same time, the planting area should have appropriate rainfall to ensure that the soil is wet without ponding, and should be equipped with water and fertilizer integration facilities to ensure the water supply capacity of soil[18].

2.3 Field management

2.3.1 Soil management. In order to improve soil structure and aeration, organic fertilizer, rice husk, bark and other materials can be added to the soil. In terms of soil drainage, because blueberry likes to be wet but avoid ponding, perlite and vermiculite should be added to the planting soil to enhance the soil drainage capacity. In addition, blueberry growth needs adequate nutrition and regular fertilization. Organic fertilizer and chemical fertilizer can be applied, but the amount of fertilization should be strictly controlled to prevent excessive fertilization. After planting and during the growth period of blueberry, weeds and miscellaneous shrub should also be removed manually to avoid competing with blueberry for nutrients[19].

2.3.2 Water management. Compared with other fruit trees, blueberry needs less water, and excessive irrigation is easy to cause root rot. Therefore, it is necessary to reasonably determine the irrigation frequency and water volume according to the soil type and climate conditions, and it is appropriate to keep the soil moist without ponding for each irrigation. Because blueberry is not tolerant of excessive moisture, ponding will cause the root to decay due to hypoxia. So perlite, vermiculite and other materials are often added to the soil to improve the soil drainage performance when planting. In addition, blueberry has different water requirements at different growth stages. At the beginning of growth, sufficient water is helpful to promote bud germination and leaf extension. During the growth and development period, the soil should be kept moist. During the fruit growth period, the amount of irrigation should be increased to ensure sufficient soil moisture, so as to improve the fruit quality and yield. In terms of water quality, blueberry is suitable to use pure water. Hard water, salt water or water

containing harmful chemicals will have a negative impact on their growth. In arid environment, silica gel, bentonite and other hygroscopic agents can be added to the soil to maintain soil moisture and help blueberry growth. To sum up, the water management of blueberry needs to comprehensively consider soil type, climate conditions, growth stage, water quality and other factors, and adjust flexibly. Through reasonable irrigation and drainage, maintaining soil water balance, and using moisture absorbent, it can create a good growth environment for blueberry[20-22].

2.3.3 Fertilization management. Fertilization method and amount of blueberry should be determined according to different growth stages and soil conditions, mainly including the following. Before planting, organic fertilizer can be applied to the soil to provide long-term and stable nutrients for blueberry. Generally, 500 g of organic fertilizer is required for each blueberry tree. During the growth period of blueberry, topdressing should be carried out according to its growth needs, and the mixed fertilizer with the ratio of nitrogen, phosphorus and potassium as 1∶1∶1 is appropriate. In addition to applying base fertilizer in the growing season, water-soluble fertilizer and trace elements should be applied after blueberry enter the nutritional period. Specific to each growth stage: in the early growth stage, proper application of nitrogen fertilizer can promote the growth of branches and leaves; before the flowering stage, it is conducive to flower bud differentiation and flowering by increasing the application of phosphorus fertilizer; at the fruiting stage, the application of potassium fertilizer can promote fruit development and improve quality. In addition, trace elements and nutrients can also be supplemented by foliar fertilizer during the growth of blueberry. It is generally sprayed every two weeks, which can significantly improve the yield and quality of blueberry[23].

2.4 Pruning technology Reasonable pruning can effectively promote the growth of blueberry and improve the yield and quality. After the young trees are planted, they should be properly pruned in time to create a good growth space for the tree and promote its healthy development by removing thin and weak branches, diseased and dead branches, dense branches, *etc.* For mature trees, the core goal of pruning is to maintain the tree shape and ensure the fruiting. When pruning, it is necessary to keep the fruiting branches and flowering branches, and clean up the diseased and weak branches and dense branches, so as to improve the ventilation and light transmission conditions of the crown. With the increase of blueberry age, the fruiting ability gradually declines. At this time, it is necessary to carry out renewal and pruning, timely remove the old branches, stimulate the germination of new branches, and restore the tree vigor. Blueberry is usually pruned in spring and autumn. Spring pruning can promote the growth of branches and increase the rate of flowering and fruiting; autumn pruning can optimize the tree shape and promote flower bud differentiation.

When pruning, sharp tools should be used, such as scissors, handsaw, *etc.*, to reduce the risk of wound infection and branch splitting. Blueberry pruning should follow the principle of "light pruning, branch retention, ventilation and light transmission", to avoid excessive pruning and prevent tree weakness and damage to fruiting ability. In short, only by grasping the pruning time, selecting the right pruning tools, and strictly following the pruning principles, can we give full play to the role of pruning and achieve good growth, high quality and high yield of blueberry[24].

2.5 Prevention and control of diseases and pests In the prevention and control of blueberry diseases and pests, the strategy of "prevention first and comprehensive control" should be adhered to. The occurrence of diseases and pests can be effectively prevented by strengthening plant quarantine, keeping soil moist, rationally fertilizing, regularly removing weeds and fallen leaves, and selecting disease and pest resistant varieties. Once pests and diseases are found, targeted prevention and control measures should be taken quickly, and fungicides or insecticides should be sprayed reasonably for treatment[25].

2.5.1 Leaf spot disease. The disease mainly affects blueberry leaves. At the early stage of the disease, small red to brown spots appear on the leaves. At the later stage, the spots gradually expand and fuse into large spots. The diseased leaves should be removed in time, and fungicides such as mancozeb should be sprayed.

2.5.2 Stem canker. It mainly harms the stems and branches of blueberry. Red or brown disease spots appear in the early stage of the disease, and the disease spots expand in the later stage, which will lead to the stem and branch withering. Control measures include strengthening soil management, keeping soil moist, and spraying fungicides such as thiophanate methyl and zinc benzothiazole.

2.5.3 Aphids. Aphids will suck juice from blueberry leaves and twigs, resulting in curly leaves and poor growth of twigs. During the prevention and control, the fallen leaves and weeds should be cleared in time, and insecticides such as imidacloprid and pirimicarb should be sprayed.

2.5.4 Mites. Mites also feed on the juice of blueberry leaves and twigs, causing leaf chlorosis and twig growth retardation. Plant quarantine should be strengthened, and acaricide should be used for control.

2.5.5 Fruit borer. The fruit borer mainly harms the blueberry fruit, which will soften and rot. During the prevention and control, the fallen fruits and dead leaves should be cleaned in time, and pesticides such as dimethoate and trichlorfon can be sprayed.

3 Development prospects of blueberry in under-forest economy

3.1 Adaptive advantages of understory cultivation Blueberry is a shade tolerant shrub, and its ecological characteristics are highly compatible with the under-forest economic model. The research data showed that blueberry under 30% -50% shading environment could effectively alleviate the high temperature stress in summer and reduce the incidence of fruit sunburn. At the same

time, the naturally formed humus layer in the forest can stabilize the soil pH at 4.5 – 5.5, and ensure the content of soil organic matter ≥ 5%, significantly reducing the cost of soil improvement. Experiments under the forests of *Cunninghamia lanceolata* and *Phyllostachys edulis* in southern China and *Larix gmelinii* in northern China showed that the anthocyanin content of blueberry planted in the wild like way increased by 12% – 15% compared with open cultivation, and the incidence of diseases and pests decreased by more than 30%. In addition, the under-forest cultivation mode is especially suitable for ecologically fragile areas with slopes greater than 25°. It can not only realize the ecological benefits of soil and water conservation, but also create considerable economic benefits.

3.2 Innovation of compound business model

3.2.1 Forest-blueberry-fungus circulation system. Blueberry is planted under *Quercus* L. and other arbor layers, and acid tolerant edible fungi such as *Pleurotus citrinopileatus* is cultivated on the ground, to build a three-dimensional production mode. The experimental data of Sanming in Fujian Province show that this model can increase the income per unit area by 2.3 times. In addition, after returning the mushroom residue produced by edible fungus cultivation to the field, the content of soil available potassium increases by 40 mg/kg.

3.2.2 Ecotourism complex. Relying on natural resources such as forest parks, an experiential farm featuring "flowers in spring and fruits in summer" could be built. The Yunfeng Mountain base in Miyun, Beijing is taken as the research object. By carrying out blueberry picking activities under the forest, the annual income of the surrounding home stay industry has increased by more than 2 million yuan.

3.2.3 Carbon sequestration value-added system. Using the synergistic effect of arbor and blueberry in carbon sink, it can apply for CCER certification. Preliminary estimates show that the annual carbon sequestration of mixed forest per hectare can reach 8.2 t, which is 18% higher than that of pure forest.

3.3 Direction of key technology breakthrough At present, blueberry under-forest cultivation needs to focus on overcoming three technical bottlenecks. First, light regulation. It requires the research and development of a dynamic shading system to achieve intelligent adjustment of canopy transmittance with the help of IOT sensors. The second is the construction of soil microbial community. By inoculating ectomycorrhizal fungi such as *Pisolithus tinctorius*, the survival rate of blueberry in barren forest land can be increased to more than 92%. The third is mechanized harvesting. The crawler type of under-forest harvester being tested by the Chinese Academy of Forestry Sciences has an operating efficiency of 0.3 ha/d, 15 times higher than that of manual harvesting.

3.4 Policy driven and industrial chain extension At the policy level, blueberry has been listed as a priority category in the *Development Plan of Under-forest Economy* issued by the National Forestry and Grass Administration in 2023, and a subsidy of 45 000 yuan/ha has been given to business entities with a contiguous planting area of more than 20 ha. In terms of industrial model, it is suggested to promote the tripartite cooperation mechanism of "state-owned forest farms + cooperatives + processing enterprises". The Leigong Mountain in Guizhou Province is taken as the research object. The local government has built a complete industrial chain from under-forest planting to freeze-dried powder processing, and the added value of products has increased by 40%. In the future, the brand influence can be improved by applying for geographical indication certification (such as "Changbai Mountain wild blueberry"). It is estimated that the scale of under-forest blueberry industry will exceed 5 billion yuan by 2030.

4 Conclusions

4.1 Mature variety regionalization technology system Through introduction, screening and independent breeding, China has built the planting modes of three blueberry categories, including high bush, half-high bush and low bush, which can adapt to different climatic zones. In particular, remarkable achievements have been made in the selection and breeding of cold resistant varieties in Northeast China and moisture tolerant varieties in East China, supporting 26 provinces (cities) in China to achieve differentiated production. Among them, the blueberry output of Guizhou and other four major producing provinces accounts for 76.8% of the total output of China.

4.2 Precision cultivation to improve industrial benefits The application of water and fertilizer integration, drip irrigation system and wild imitation cultivation technology increases blueberry yield by more than 30% and anthocyanin content by 12% – 15%. The standardized pruning technology based on the principle of "light cutting, branch retention, ventilation and light transmission" and the integrated disease and pest control strategy based on biological control effectively ensure the fruit quality. This has promoted 56% of domestic blueberry to enter the processing field, and the product exports cover Europe and the United States and other regions.

4.3 New path of under-forest economy development The research shows that the ecological and economic benefits of blueberry are more significant in the shading environment of 30% – 50%. The forest-blueberry-fungus circulation system can increase the income per unit area by 2.3 times; the annual carbon sequestration of carbon sink mixed forest reached 8.2 t/ha; breakthroughs in key technologies such as dynamic shading system and mycorrhizal inoculation have provided technical support for the promotion of blueberry planting in mountainous forest areas. Driven by policies, it is estimated that the scale of under-forest blueberry industry will exceed 5 billion yuan by 2030.

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and enterprises, thereby facilitating the efficient allocation of both educational and industrial resources. Thirdly, it is essential to enhance research focused on the brand development and market promotion of Guizhou products. This includes exploring more effective strategies for brand communication and market expansion, thereby improving the market competitiveness of these products. Fourthly, it is imperative to intensify research on cross-border e-commerce and international collaboration. This effort should involve the cultivation of professionals equipped with an international perspective and cross-cultural communication skills, ultimately promoting the sustainable development of Guizhou products in the global market.

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