



Virus-Free Sweet Potato Industry: Development Status and Production Suggestions

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Abstract: Sweet potato (*Ipomoea batatas* L.) is an important food, feed, and industrial raw material and new energy crop. Its rich nutritional value and health effects are increasingly being recognized by consumers, and the demand is increasing. However, due to the continuous cultivation of sweet potato over many years, the degeneration of seedlings and the accumulation of viral diseases are important factors affecting the yield and quality of sweet potatoes. This article provides an overview and analysis of the types and hazards of sweet potato virus diseases, the advantages of virus-free sweet potatoes, the scale of virus-free sweet potato cultivation, sweet potato stem tip virus-free production technology, its development status, and the existing problems. Combined with the development of the sweet potato industry across China, relevant development suggestions are proposed to provide a reference for promoting the healthy, stable, sustainable, high-quality, and efficient development of the sweet potato industry.

Keywords: sweet potato; virus-free; development status; production; industry



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1. Introduction

Sweet potato (*Ipomoea batatas* L.), a Convolvulaceae plant, is an annual or perennial herbaceous vine. It is known as a nutritionally balanced food and has many effects on preventing diabetes, cholesterol, cardiovascular disease, and so on [1–5]. Due to the continuous cropping of sweet potatoes for many years and the influence of environmental factors, the quality traits of seedlings have been gradually lost, their growth rate is decreasing, and they even gradually die, resulting in the continuous degeneration of seedlings and the accumulation of viral diseases, which are important factors affecting sweet potato yield and quality. At present, more than 30 species of sweet potato viruses produced by continuous cropping have been reported worldwide, and more than 20 species of sweet potato viruses have been reported in China [6]. The morphology and transmission routes of the virus are shown in Table 1. The main viruses that have a great influence on sweet potato production are sweet potato leaf curl viruses (SPLCV), sweet potato chlorotic stunt virus (SPCSV), and sweet potato feathery mottle virus (SPFMV). Co-infection of sweet potato chlorotic stunt virus (SPCSV) with sweet potato feathery mottle virus (SPFMV) results in sweet potato virus disease (SPVD) [7–9]. These virus species not only infect separately, but they also infect cooperatively, forming co-diseases and causing serious harm to sweet potato production. The quality and yield of sweet potato has decreased due to these viruses. Sweet potato yields can fall by more than 20%, with severe declines of 50% [10–12]. The application of virus-free sweet potato seedlings in production can effectively control the

occurrence of soil-borne diseases, has the advantages of a fast growth rate, a large seedling size, a large branch number, strong stress resistance, and a high commodity rate, and can increase the economic benefits of sweet potato production. Therefore, sweet potato virus-free technology is an effective way to prevent and control virus infestation, restore variety diversity, and improve sweet potato yield and quality [13].

Table 1. Common sweet potato virus names, particle morphological characteristics, and transmission.

Virus Species	Particle Morphology	Mode of Virus Transmission
Sweet potato feathery mottle virus (SPFMV)	Bent long rod-shaped length 830–850 nm	Mechanical and aphid transmission
Sweet potato latent virus (SPLV)	Bent long rod-shaped length 700–750 nm	Mechanical and root spreading
Sweet potato yellow dwarf virus (SPYDV)	Long rod-shaped length 750 nm	Mechanical and whitefly transmission
Sweet potato vein clearing virus (SPVCV)	Filamentous length 850 nm	Whitefly transmission

2. Development Status of the Virus-Free Sweet Potato Industry

2.1. Planting Scale of Virus-Free Sweet Potato

According to the data of the Food and Agriculture Organization of the United Nations (FAO), the 108 countries and regions with sweet potato are mainly distributed in Asia, Africa, North America, South America, and Oceania. Asia and Africa are the main planting continents for sweet potato. In 2021, China’s sweet potato planting area was about 2.206 million hectares, making it the largest sweet potato planting country in the world, accounting for 29.80% of the world’s planting area, and the output value accounts for 53.80% of the world’s total output. At present, the main potato-producing countries in Africa include Egypt, Kenya, Sudan, South Africa, and so on, among which Kenya has gradually become one of the main production areas of this crop. Due to its long-term tuber cultivation, the seedling degeneration is serious, which has a strong impact on its quality and yield. It is an important step to revitalize the sweet potato industry to solve the degeneration problem caused by long-term asexual reproduction and eliminate the harm of virus diseases. With large-scale planting, the average yield per hectare of virus-free sweet potato can be increased by 20% to 40% [14,15]. Sweet potato detoxification is a new economic growth point for achieving high-yield, efficient, and high-quality agricultural development, and it is also an urgent problem to be solved in current agricultural production. It is expected that between 2024 and 2026, the detoxification area of sweet potato will account for about two-thirds of the total area of China, which will play a positive role in increasing the income of sweet potato farmers and developing the sweet potato economy [16–18].

2.2. Main Cultivars of Virus-Free Sweet Potato

Virus-free sweet potato varieties can be divided into three types: the fresh food type, the starch type, and the processed type. At present, the fresh food type is the most popular in the market and is the main planting for virus-free sweet potato varieties. Popular sweet potato varieties in the USA include the ‘Beauregard’, ‘Garnet’, and ‘9408’ sweet potato. The American ‘9048’ sweet potato has dark green and small leaves, with short stem nodes, spindle-shaped potato pieces, red skin, white pulp, large and neat potato pieces, and high resistance to root rot, black spot, nematodes, and other diseases and pests. The main varieties of sweet potato in New Zealand include ‘Owairaka’ and ‘Toka’, of which ‘Beauregard’ is the sweetest. Popular varieties of African sweet potato include ‘orange sweet potato’, which is also rich in vitamins, and ‘Tanzania’, which is high in starch [19–22].

At present, there are more than 70 common sweet potato varieties in China, and the coverage rate of excellent new varieties has reached 85%. The main varieties are prominent and diversified. Three series of high-quality virus-free sweet potato varieties have been screened and constructed, including high-quality baking varieties 'Yanshu 25' and 'Pushu 32', high-quality cooking varieties 'Jishu 26' and 'Xinxiang', early maturity and high yield varieties 'Longshu 9', etc. Among them, 'Pushu 32' has an excellent taste, a high growth rate, a good stable yield, medium storage, and medium resistance to early blight disease. 'Yanshu 25' has good germination, a medium-long vine, a potato spindle shape, a light peel, and an orange meat; the potato concentration and potato block size are uniform, a single plant produces five potatoes, and the large and medium potato rate is high [23–25].

2.3. Production Method for Virus-Free Seed Potato

The application of shoot tip meristem culture detoxification technology is a main technique to solve the decrease in the excellent seed quality of sweet potato. After Nielsen in the United States obtained virus-free sweet potato seedlings for the first time in 1960, the virus-free technology for the sweet potato shoot tip developed rapidly. After that, various agricultural countries also began to use the tissue culture technology of the sweet potato shoot tip to carry out the large-scale production of virus-free sweet potato seedlings.

The meristem tip culture methodology consists of the following steps: First, one selects the sweet potato with strong growth, cuts the leaves, and then cuts them into several small segments with one axillary bud or terminal bud (Figure 1). Explants are sterilized with 75% C_2H_6O for 30 s, followed by 0.1% $HgCl_2$ for 10 min. Then, the sterilized explants are placed under a dissecting microscope, and the large young leaves on the terminal or axillary buds are peeled off. The shoot apical meristem with one to two leaf primordia is cut from 0.3 to 0.5 mm (Figures 2 and 3) and quickly inoculated into the prepared medium.



Figure 1. Shoot tip selection of virus-free material.



Figure 2. Virus-free subculture of sweet potato for 30 days.



Figure 3. Sweet potato was incubated for 15 days by virus-free rooting.

The sweet potato stem tip regenerated seedlings are cultured in a medium for 50–60 days, with leaves growing to around five to six pieces (Figure 4). The main virus detection methods for sweet potato virus diseases currently include visual inspection, indicator plant detection, serological detection, biological methods, electron microscopy observation, and polymerase chain reaction technology and nucleic acid sequence amplification technology in molecular biology. After determining the plant traits, the virus-free seedlings are immediately domesticated and transplanted (Figures 5 and 6). The stem tip detoxification technology of sweet potato can significantly increase the yield of sweet potato and reduce the infection of diseases and pests.



Figure 4. Virus-free sweet potato seedlings were rooted and cultured for 45 days.



Figure 5. Virus-free sweet potato seedlings were transplanted for 30 days.



Figure 6. Sweet potato virus-free cultivation.

2.4. Current Situation of World Sweet Potato Production

According to the Food and Agriculture Organization of the United Nations database (FAO), the top 10 countries in the world for sweet potato production in 2021 were China, Malawi, Tanzania, Nigeria, Angola, Ethiopia, Indonesia, Rwanda, the United States, and Uganda. Among them, China's sweet potato production was 47.835 million tons, accounting for 53.6% of the world's total production (Figure 7) [26–28]; Malawi's sweet potato production was 7.45 million tons; Tanzania's sweet potato production was 4.992 million tons; Nigeria's sweet potato production was 3.943 million tons; sweet potato production in Indonesia was 1.649 million tons; sweet potato production in Rwanda was 1.329 million tons; sweet potato production in the United States was 1.309 million tons; and Uganda's sweet potato production was 1.267 million tons [29,30].



Figure 7. Harvest of healthy varieties of 'Yanshu 25' sweet potatoes in China.

3. Problems in the Development of the Virus-Free Sweet Potato Industry

3.1. The Virus-Free Sweet Potato Seedling Breeding System Is Not Perfect

The supply capacity of high-quality virus-free seed potato is insufficient. There is a lack of production and rapid propagation of virus-free sweet potato seedlings, with few professional production enterprises of virus-free sweet potato seedlings. At present, the existing virus-free tissue culture capacity and breeding base cannot meet the market

demand. The supply of sweet potato seedlings in the main producing areas mainly depends on cooperatives to buy from vendors, and farmers' self-propagation is common, leading to variety degeneration. At the same time, the quantity and quality of sweet potato seedlings per unit area are different due to technical irregularities, and the quality of sweet potato seedlings is difficult to guarantee. Virus-free sweet potato only removes the virus from the seed potato seedlings as much as possible, rather than making the sweet potato resistant to virus. In addition, the market for growing sweet potato seedlings is not standardized. Although some large enterprises have their own virus-free sweet potato technology, and the quality of sweet potato seedlings is relatively stable, small and medium-sized enterprises are more likely to breed sweet potato seedlings via the self-propagating and self-breeding of self-retaining seed sweet potatoes, resulting in frequent problems of plant diseases and pests, and cross-regional seed transfer leads to the spread of quarantine pests [31,32].

3.2. The Virus-Free Sweet Potato Planting Mechanization Degree Is Not High

With the acceleration of economic development and land circulation, the structure of agricultural management and the rural labor force has changed, and the production of sweet potato has gradually been dominated by new management subjects, such as large households and cooperatives. With the increase in labor costs, improving the degree of mechanization and light and simplified practical production technology has become an important way to reduce the labor costs and improve the production efficiency.

The production of sweet potato mainly includes three processes: seedling raising, transplanting, and harvesting. The main machinery required for the mechanization of sweet potato production includes a seedling machine, a cultivator, a rotary cultivator, harvester, a ridger, a transplanter, a vine cutting machine, and so on. In addition to cultivation, field management, and production, there is still a lack of suitable models for seedling raising, transplanting, cutting, and harvesting. In 2021, the comprehensive level of tillage and harvest mechanization of sweet potato in China was only 26%, compared with the comprehensive mechanization rates of wheat, corn, and rice in the same year, which were 97.29%, 90.00%, and 85.59%, respectively. The mechanization level of sweet potato production is relatively low, and its total output ranks fourth in terms of domestic food crops [33]. The mechanization level of sweet potato production is similar to the other industries across China and also faces the dilemma of a low comprehensive level. At present, only the mechanization levels of tilling, ridging, and field management are relatively high, the mechanization levels of seedling rearing, transplanting, vine cutting, and harvest are relatively low, and the related operations are largely completed by manual work [34–36].

3.3. Sweet Potato Storage Technology Still Needs to Be Improved

The science-informed storage of sweet potatoes is the core link to achieve the annual supply and ensure a stable and increased income, mainly including timely harvesting, preparation of storage cellars, timely entry into cellars, and management during storage. However, sweet potatoes themselves have a high moisture content, and the quality of the storage is greatly affected by the temperature, humidity, external environment, and human management factors. In the main producing areas, the loss rate of sweet potato in the storage process is mostly more than 10%, and the commercial, large-scale, and safe sweet potato storage technology still needs to be improved [37]. Due to the large investment in the construction of constant temperature storage and the high operating cost, the storage of sweet potato is mainly dominated by traditional natural ventilation cellars. The temperature of the cellars is greatly affected by the change in the external temperature. Due to the lack of automatic monitoring equipment, it is impossible to accurately grasp the real-time temperature, humidity, and gas (carbon dioxide) data in the cellar, and the sweet potato is prone to decay. Most sweet potatoes are not classified and dried before storage and are directly stored in a warehouse, which can easily introduce diseases into the sweet potato. In addition, overfilling of storage cellars can lead to hypoxia and moisture damage

during the storage of sweet potato chunks, making them susceptible to fungal and bacterial diseases, resulting in rotting during storage [38,39].

3.4. The Processing Capacity of Virus-Free Sweet Potato Is Not Sufficient

Sweet potato has a high nutritional value and rich starch, which can be processed into starch products, various snack foods, sugar products, health products, and so on. It is also rich in food fiber and has many health functions for the human body. It can also be used as an industrial raw material. Due to its huge value-added potential, sweet potato processing is the largest value-added link in the entire industry chain [40,41]. The supply of virus-free sweet potato products is mainly for fresh sweet potato, and locally processed starch, vermicelli, dried potato, and other processed products are less than 1% of the output [42,43]. Virus-free sweet potato processing enterprises are mainly based on primary products, such as crude starch, dried sweet potato, and vermicelli with low added value, the deep processing scale is small, and the application and development of other uses are few.

4. Countermeasures and Suggestions

4.1. Improve the Virus-Free Seed Potato and Improve the Seed Breeding Technology System

In the first place, it is important to accelerate the construction of large-scale virus-free seedling breeding bases. Here, it is important to support the development of a number of professional sweet potato seedling rearing organizations and establish a stable breeding and production base for sweet potato seedling. Further, it is important to encourage and support sweet potato seedling enterprises to participate in the construction of a virus-free rapid propagation system of sweet potato. It is also important to guide and support the establishment of a group of modern agricultural enterprises specializing in virus-free sweet potato seedlings, specializing in the production and sales of virus-free sweet potato seedlings. The quality and supply of high-quality sweet potato seedlings are obtained to promote sweet potato production.

Secondly, it is important to strengthen market supervision and testing technology research and development. This includes developing virus rapid detection technology and seed sweet potato quality early warning technology suitable for enterprises and new business entities and forming a virus-free seed sweet potato breeding technology system of “virus-free culture + virus detection + virus-free seed potato seedling production” [44].

Thirdly, it is important to strengthen the quality monitoring and early warning of seed sweet potato. To strengthen the monitoring of whitefly in the breeding field, one should investigate and detect the occurrence of whitefly and the virus carrying rate regularly, to provide an early warning for the quality of the seed sweet potato, according to the occurrence and virus carrying rate of whitefly. In addition, it is important to conduct investigations and sampling during the growth and harvest period of sweet potatoes, to detect the disease incidence, virus types, and virus carrying status of sweet potato plants in the field. When a virus is detected, regulatory authorities should promptly issue warnings on the quality of the sweet potatoes carrying the virus to prevent unqualified sweet potato seedlings from entering the market.

4.2. Strengthen the Mechanization of Virus-Free Sweet Potato Planting

By improving the planting technology of light and simple machinery, sweet potato production can be of high quality, light, simple, and efficient. Developing and promoting simple and practical sweet potato small rotary tillers, fertilizing machines, ridgers, excavators, etc., for tillage, fertilizing, ridging, harvesting, and other operations effectively reduces the labor intensity of sweet potato planting, improves the labor efficiency, further studies the “mechanization” operation of fresh potato varieties, and accelerates the process of mechanization promotion [45]. In addition, it is important to establish agricultural machinery and agricultural cooperation mechanisms, formulate large-scale and standardized agricultural technical regulations for sweet potato planting mechanization, and improve

and standardize planting patterns. One can gradually form a perfect new planting mode suitable for mechanical operations, and the sweet potato planting mode will gradually meet the requirements of mechanical operations. At the same time, it is important to continuously improve the suitability of sweet potato production equipment and sweet potato planting agronomics. Finally, it is important to create good conditions for equipment research and development.

4.3. Improve the Storage Level of Virus-Free Sweet Potato

In the production of sweet potato, the research and popularization of storage technology of sweet potato should be strengthened. This includes establishing standardized sweet potato storage cellars based on breeding and production bases. In addition, the study of the post-harvest preservation and anti-storage technology of instant fresh potato and post-harvest storage technology of different cultivars of sweet potato should be strengthened. The loss rate of sweet potato should be controlled within 10%, and the virus-free rate of sweet potato should also be guaranteed [46–48]. Further, one should support the construction of high-standard sweet potato storage and carry out science-informed transformation of sweet potato storage warehouses. The warehouses could be transformed through implementation of the following changes: equip them with intelligent ventilation control equipment for cold storage through modern information technology, achieve the real-time monitoring and automatic adjustment of the temperature, humidity, and other parameters of the storage environment, and improve the storage capacity and level of sweet potatoes.

4.4. Improve the Processing and Value-Added Ability of Virus-Free Sweet Potato

To begin with, it is important to cultivate characteristic brands. Based on geographical indications, one can build pollution-free, green, and organic brands (no pesticide residues, heavy metals, etc.), enhancing the popularity and influence of virus-free sweet potato local brands, such as ‘Shixia Sweet potato’. The sweet potato industry can increase the value of the product through the development of tourism (tasting and leisure experiences) and processed products (instant and convenience foods).

Furthermore, one should develop appropriate scale operations. Efforts should be made to support new business entities in the supply of high-quality seeds and seedlings, the demonstration and promotion of advanced production technology, the promotion of sales, and the improvement of post-harvest storage technology. At the same time, in view of the policy in China that restricts the development of processing enterprises, enhanced cooperation between existing sweet potato processors should be explored. By promoting the development of sweet potato industry, it can become an advantageous industry with certain popularity and competitiveness.

The third area is to extend the industrial chain and develop the sweet potato processing industry. In view of the policy restricting the development of processing enterprises, there should be an appropriate exploration of sweet potato processing enterprises’ cooperation channels. In the process of sweet potato processing, the risk of fresh sweet potato post-harvest sales should be reduced. By giving play to the advantages of processing on behalf of farmers, farmers can share the benefits brought by the increase in the processing of sweet potato and its added value. At the same time, to achieve the combination of agriculture and tourism management (agritourism), the following can be more actively developed: fresh sweet potato picking, park-like recreational spaces, farm share direct sales, and so on.

Finally, it is important to accelerate the construction of a social service system for sweet potato production. In the United States, Japan, and Western Europe, a relatively complete agricultural socialization service system for sweet potato production has been established. These services include the supply of agricultural machinery, fertilizers, pesticides, feed, and other agricultural means of production to agricultural producers, as well as agricultural credit and insurance services. The promotion of socialized services for sweet potato production is not limited to the improvement of planting technology but also includes subsidies

for small farmers and large-scale operating entities, as well as centralized subsidies for key production links [49,50].

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