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Research Progress on Fog Cultivation Technology for Potato Seed Production

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Abstract : The market demand for potato seed (minituber) is increasing with the progression and expansion of the potato industry, and the potato seed degeneration has become one of the important factors to restrict the yield and quality of potatoes in the actual development of potato industry. In recent years, the aeroponic cultivation of potato seed has the advantages of high yield and high efficiency as a newly developed virus-free production technology, which effectively solves the problems of soil-borne diseases and continuous cropping obstacles during the potato seed production, as well as opens up a new way for the scalization of potato seed production. In this thesis, the key points of potato seed aeroponic technology, the facility intelligentization development, the core nutrient solution and cultivation management and methods of automatic control of supply system were elaborated, the current problems and application prospects of this technology are summarized based on personal production experience, aimed to provide some foundations for the production as well as practical guidance of potato seed aeroponics cultivation.
Keywords: Potato; Mini-tubers; Aeroponics production technology；Research progress

Introduction

1. Current Status of Potato Seed Industry Development

1.1 Strategic Significance of the Potato Industry in National Economic and Social Development

As the world's fourth most important grain and vegetable dual-use crop, potatoes have become a major alternative crop for agricultural restructuring due to the cold resistance, drought resistance, and adaptability. In 2016, the Potato Staple Development Strategy Seminar extensively discussed the strategic significance, development ideas, objectives and approaches for promoting potato staple development. The development of potatoes as staples is not only an important measure to deeply implement the central government's policies on promoting agricultural restructuring, transformation of methods and sustainable development, but also has significant implications for ensuring China's food security, optimizing planting structures, increasing farmers' income, promoting sustainable agricultural development, alleviating resource and environmental pressures, and improving residents' dietary structure[1]. Since then, China has continuously implemented the potato staple development strategy with scientific and technological innovation as the guide, striving to promote coordinated development of potatoes and grains to meet the new nutritional and health requirements of the people for staple food consumption.

According to data from the National Bureau of Statistics, China ranks first in the world in terms of potato cultivation area. In 2021, China's potato planting area was approximately 4.606 million hectares which decreased of 1.08%, and the potato production was 18.309 million tons which increased of 1.81% compared to the previous year. Potato consumption for food is increasing, with processed consumption growing rapidly at an average annual rate of 1.3%. It is expected to reach 111.4 million tons by 2029, with an average annual growth rate of 0.6%[2]. As the potato industry continues to upgrade, China's international competitiveness in potatoes will further strengthen, with exports growing at an average annual rate of 1.5% and trade surplus expanding[3]. The development prospects are broad.

1.2 Importance and Current Status of Potato Seed

Potato seed (mini-tubers) refers to the first-generation seed potatoes with uniform size and good appearance grown from detoxified tissue culture seedlings through seedling refining, transplanting, and protective ground isolation. The descendants produced through mini-tuber production are favored by a large number of growers due to their high disease resistance, high yield, uniformity, and good commercial traits. Currently, in practical production, the issue of potato seeds is prominent, becoming one of the important factors to affect yield and quality and urgent problems to be solved for the industrialization of China's potato industry. The main characteristics are as follows: Firstly, there is a wide variety of seed potatoes without a dominant variety adapted to market needs[4]. Secondly, the seed potato characteristics are severely degraded and accompany with many diseases, especially widespread diseases transmitted by seed potatoes such as wilt,

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ring rot, blackleg, scab, and viral diseases, resulting in large disease areas, high incidence rates, and serious damage. Seventy percent of fields showed varying degrees of disease symptoms, with disease incidence rates reaching over 40% to 70% in severely affected areas. Thirdly, there are too many planting generations and multiple sources of seed potatoes, and they are not high-quality seed potatoes that have been detoxified or purified.

In summary, solving the problem of potato seed production requires market demand-oriented approaches, with active cooperation among the "technology + enterprise + market" triad and coordinate with stakeholders. Only by forming a community of shared interests in industrial development can high-quality seed potatoes be provided for production practices, continuously promoting the healthy development of the potato industry.

2. Potato Seed Fog Cultivation Technology

2.1 Research Progress on Potato Seed Fog Cultivation Technology

In recent years, significant research progress has been made in potato seed production, with fog cultivation technology for potato seeds demonstrating technical advantages and being recognized as one of the best methods for seed potato production[5]. This technology represents a novel cultivation method where plants are grown in a relatively enclosed device, with their roots exposed inside the apparatus[6,7]. Nutrient solution is sprayed onto the roots through the fogging device to provide the necessary water and nutrients for plant growth, constituting a soilless cultivation technique. It does not require soil or substrate for plant growth; instead, it creates an artificial crop growing environment, effectively resolving the contradictions between "water-air-nutrients" in traditional soil cultivation. This allows the crop roots to be in the most suitable environmental conditions, avoiding soil-borne pathogens and viruses, thereby significantly increasing the quality and yield of seed potatoes. Moreover, this technology is not limited by site or seasonal factors which can easily achieve year-round production.

In 1996, South Korea first successfully conducted trials on the detoxification of potato seeds using fog cultivation. Subsequently, the fog cultivation technology for seed potatoes was gradually matured.China firstly introduced this technology from South Korea in 1997 and successfully conducted trials at the Potato Research Institute of Heilongjiang Academy of Agricultural Sciences [8]. The multi-provinces (autonomous regions), such as Jilin, Tibet, Yunnan, Gansu, Sichuan, Inner Mongolia, and others successively introduced this technology and carried out related experimental research. Although China started relatively late in this technology, the market development prospects were promising. In recent years, research on intelligent automatic control systems, core nutrient solutions, and their supply systems has increased. Regions such as Chengdu, Zhuanglang, Diqing, Hohhot, and others have successfully introduced fog cultivation technology for the production of potato seeds and achieved good results [9].

2.2 Fog Cultivation System

The fog cultivation model integrated biotechnology, engineering technology, and intelligent computer control technology, mainly including fog cultivation systems, nutrient solution supply systems, and intelligent control systems. The working principle was shown in the diagram (Figure 1). As early as 1990, China's use of fogging facilities was in the semi-automatic stage. With the development of the Internet of Things and information technology, the automatic control systems have been successfully applied in mist cultivation production. Relevant parameters have been further optimized, achieving automatic adjustment/supply of nutrient solutions and high-efficiency intelligence[10]. In terms of fogging regulation, Man Junlong[11] used fluid dynamic ultrasonic fogging nozzles to achieve directional spraying, making the fog droplet clusters more uniform within the radiation range of the conical rectifying hood, with a larger diffusion range, longer spraying distance, and longer mist floating time. In terms of intelligent control, Zhang Zhefeng[12] applied key technologies for automatic monitoring of nutrient solution supply to vegetable mist cultivation, utilizing fuzzy neural network control algorithms to analyze collected information. Local control and remote control were effectively combined to achieve automatic adjustment and supply of nutrient solutions. Lakhiar[13] introduced smart sensor technology to monitor and control basic parameters of fog cultivation systems, enabling automated management of potato seed fog cultivation technology and providing data support for optimization and upgrading.

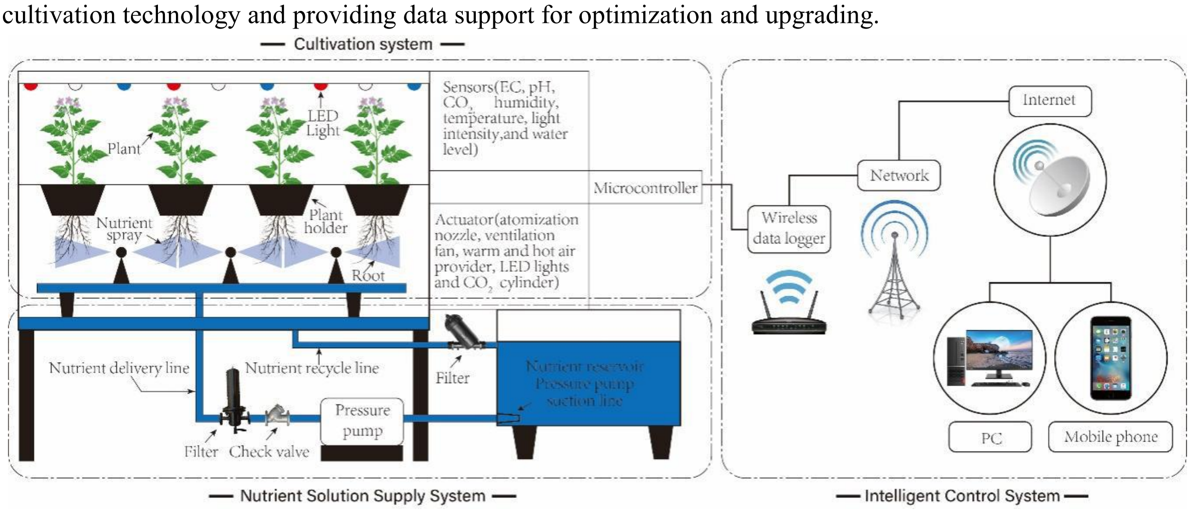

Figure 1 The working principal diagram of improved aeroponics planting system

Table 1 Basic monitoring and control parameters in aeroponic planting system

Parameters	Common value	Other requirements
Parameters of spray system	The spray/aerosol/droplet sizes range from 10 to 100 micrometers for high-pressure, 5 to 50 micrometers for low-pressure, and 5 to 25 micrometers for ultrasonic atomizers.	Atomization Nozzle
Growing medium	Planting Trough	Planting Trough Box
The desirable pH of the nutrient solution	The pH value varies according to the planted species (Onion 6.0-7.0, Cucumber 5.8-6.0, Carrot 5.8-6.4, Spinach 5.5-6.6, and Potato 5.0-6.0).	pH Meter
Desirable EC of the nutrient solution.	The EC value varies according to the planted species (Onion 1.4-1.8, Cucumber 1.7-2.2, Carrot 1.6-2.0, Spinach 1.8-2.3, Lettuce 0.8-1.2, Tomato 2.0-5.0, and Potato 2.0-2.5 $ds\cdot m^{-1}$).	EC Meter
Humidity	Provide 100% available moisture.	Humidity Meter
Temperature	Optimal temperature: 15°C - 25°C, should not exceed 30°C, and should be below 4°C.	Temperature Meter
The light inside the box	Keep the light inside the cultivation box sufficiently dark to provide a dark environment for root growth.	Shading, fully avoid light
Atomization time	Depends on the growth stage of the variety.	Timed Manual Operation System
Atomization interval time	Depends on the growth stage of the variety.	Timed Manual Operation System

2.3 Nutrient solution components and supply systems

In 1840, German chemist Liebig proposed the theory of plant mineral nutrition, laying the foundation for modern hydroponics theory. From 1859 to 1865, German scientists Sachs and Knop conducted precise experiments on hydroponics and formulated the world's first nutrient solution formula, marking the beginning of hydroponic technology research[14]. Scientists discovered that plants require about 17 essential elements, including 9 major elements: C, H, O, N, P, K, Ca, Mg, S, which account for more than 0.1% of the plant's dry weight; and 8 trace elements: Mo, Cu, Zn, Mn, Fe, B, Cl, Ni, which account for less than 0.01% of the plant's dry weight. Currently, scientists have developed many nutrient solution formulas, among which the Hoagland nutrient solution, Murashige and Skoog (MS) solution, and International Rice Research Institute nutrient solution are suitable for most plants and are widely used in agricultural production[15]. The basic components are detailed in Tables 2 and 3."

Table 2 Formula of Hoagland nutrient solution and three modified nutrient solution

Reagents	Hoagland nutrient solution（mg/L）	Modified nutrient solution I（mg/L）	Modified nutrient solution II（mg/L）	Modified nutrient solution III（mg/L）
$Ca(NO_3)_2\cdot 4H_2O$	708.45	1180.75	945	945
KNO_3	1020	506	607	506
NH_4NO_3	—	—	—	80
$NH_4H_2PO_4$	230	—	115	—
KH_2PO_4	—	136	—	136
MgSO4	239.3	241	241	241
FeNaEDTA	—	—	36.7	36.7
$FeSO_4\cdot 7H_2O$	0.07	—	—	—
KI	—	—	0.83	0.83
H_3BO_3	2.86	2.86	6.2	6.2
$MnSO_4\cdot H_2O$	—	—	16.9	16.9

$MnCl_2 \cdot 4H_2O$	1.81	1.81	—	—
$ZnSO_4 \cdot 7H_2O$	—	0.22	8.6	8.6
$Na_2MoO_4 \cdot 2H_2O$	—	—	0.25	0.25
$H_2MoO_4 \cdot H_2O$	0.09	0.02	—	—
$CuSO_4 \cdot 5H_2O$	—	0.08	0.025	0.025
$CoCl_2 \cdot 6H_2O$	—	—	0.025	0.025

Table 3 Formula of Kimura B nutrient solution and International Rice Research Institute nutrient solution

Reagents	Kimura B nutrient solution（mg/L）	International Rice Research Institute nutrient solution（mg/L）
$(NH_4)_2SO_4$	48.2	—
NH_4NO_3	—	114.25
K_2SO_4	15.9	89.25
$MgSO_4 \cdot 7H_2O$	135.1	405.0
KNO_3	18.5	—
Ca（NO_3）$_2 \cdot 4H_2O$	86.4	—
$CaCl_2$	—	110.75
KH_2PO_4	24.8	—
$NaH_2PO_4 \cdot 2H_2O$	—	50.38
Na_2EDTA	7.45	—
$FeSO_4 \cdot 7H_2O$	5.57	—
$FeCl_3 \cdot 6H_2O$	—	9.63
$MnCl_2 \cdot 4H_2O$	1.81	1.88
$ZnSO_4 \cdot 7H_2O$	0.22	0.04
$CuSO_4 \cdot 5H_2O$	0.08	0.04
H_3BO_3	2.86	1.17
$H_2MoO_4 \cdot H_2O$	0.09	—
$(NH_4)6Mo_7O_{24} \cdot 4H_2O$	—	0.09
Citric acid (monohydrate)	—	14.87

Nutrient solution is a major source of plant nutrients and is also one of the key factors determining the success of potato fog cultivation . Wang Kexiu's [16]research on the effect of nitrogen levels on potato plant agronomic traits, dry matter content, and yield under fog cultivation conditions showed that nitrogen levels significantly affected the plant height, stem thickness, leaf number, leaf area, chlorophyll content, stolon number, total plant dry matter content, individual tuber number, and yield of potato varieties 'Chuan Yu 117' and 'Mira'. The optimal nitrogen concentration was 240 mg/L, and reasonable adjustment of the nitrogen-phosphorus-potassium ratio could achieve more ideal quantities and yields. Zhang Xiaoyong[17] studied the nutrient element requirements of potato plants at different growth stages and found that excessive nitrogen content could introduce chloride ions that were detrimental to potato tuber growth. Qiao Jianlei[18]and Oraby[19]optimized the Hoagland nutrient solution, finding that the potato yield was highest when the nitrogen: phosphorus: potassium ratio was 1.00:0.28:1.30, and the ratio of nitrogen: phosphorus: potassium of 1.00:0.28:1.29 was beneficial for later-stage plant growth and development . Zhao Chenxiao and He Wenshou's[20] research on the optimal calcium concentration for fogged potatoes showed that a Ca^{2+} concentration of 4.80 mol/L resulted in good nutrient absorption by plants, and appropriately increased the calcium concentration could improve plant growth and promoted the absorption of potassium and magnesium elements by plants. Bao Lei et al [21].studied the nutrient solution concentration and sprayed frequency at different growth stages and found that, at 30 days after planting, sprayed at 0.8 times the concentration of Hoagland nutrient solution with a 20-minute interval was conducive to the early-stage nutritional growth of potato plants; at 60 days after planting, sprayed at 1.0 times the concentration of Hoagland nutrient solution with a 25-minute interval was conducive to the reproductive growth and yield increase of later-stage potato plant. Additionally, treating with 1.0 times the concentration of Hoagland nutrient solution in the early stage of growth and 1.2 times the concentration in the later stage, with a 25-minute interval and 15-second sprayed, resulted in the best potato yield and tuber grading. Ding Fan[22]found that foliar application of foliar fertilizer could promote the absorption of nitrogen, phosphorus, and potassium by potato plants and increased the tuberization rate.Xu Shujuan[23]found that sprayed with ethephon during the flowering period could effectively increase the chlorophyll content of potato leaves, increase stomatal conductance, and intercellular CO_2 concentration, with the best effect observed at a concentration of 20 mg/L. Tang Daobin[24]found that light factor regulation could promote the early and abundant occurrence of potato leaflets, stolons, and tubers. The optimal combination was found to be 12 hours of daylight and a light intensity of 600 $\mu mol/m^2 \cdot s$.

2.4 Key Technical Points of Potato Seed Fog Cultivation

In potato seed fog cultivation, the average number of tubers per plant reaches 30-50, and can even exceed 100, significantly surpassing traditional substrate cultivation by over 20 times. Moreover, it boasts a high level of automation, leading to a significant reduction in production costs. The basic technical points and illustrative diagrams can be found in Figure 2."

Figure 2 The whole process of potato mini-tubers production in an aeroponic system and field planting example
Note: ①Rapid propagation of tissue culture seedlings; ②Provisional planting of tissue culture seedlings; ③Planting stock; ④Seedling growth initial stage; ⑤Seedling growth intermediate stage; ⑥Seedling growth late stages; ⑦Harvest and dry; ⑧Sorting and grading; ⑨Low temperature storage; ⑩Field demonstration.

2.4.1 Rapid Propagation of Tissue Culture Seedlings
Selected the high-quality potato seed tubers, performed shoot tip meristem culture for virus elimination, and conducted laboratory tissue culture rapid propagation after virus detection. Transplanted robust seedlings and strengthened process management after 20-30 days of tissue culture seedling growth.

2.4.2 Preparatory Work for Production Equipment
The main equipment consists of automatic nutrient solution spraying and cultivation troughs (beds). The cover boards of the cultivation beds were made of heat-insulating, light-proof, heat-absorbing, and deformation-resistant materials. The boards were drilled with holes of 15 cm (or 20 cm) × 15 cm (or 20 cm) size, with a diameter of 10 mm. The size of the nutrient solution pool (bucket) depended on the cultivation area (generally, an area of 1 m^2 can supply a cultivation area of 20 m^2). Equipped with stable power supply and emergency power supply equipment.

2.4.3 Pre-Planting Preparation
Preparation of Seedling Beds: The substrate was used for seedling preparation was always fresh and did not require sterilization. However, if the substrate for planting beds was old (1-2 years), it must be undergoing sterilization. You could use a strong acidic solution with a pH of around 4.0 to clean the substrate, allowing it to be soaked thoroughly in the acidic solution to eliminate harmful elements. After cleaning, rinsed once with clean water after 3-5 days. Once sterilization was complete, sprinkled an appropriate amount of compound fertilizer as basal dressing.
Preparation of Planting Seedlings: During the seedling preparation, placed the tissue culture seedlings at room temperature for 2 days after acclimatization, then cleaned the residual culture medium from the roots. Transplanting the seedlings at a spacing of 3 cm × 5 cm onto prepared beds of perlite, vermiculite, or sand.

Environmental Management: Thorough sterilization of the entire planting environment (or greenhouse) in advance was essential. You can use formalin (fumigation) for one time, followed by disinfection with 84 disinfectant or mancozeb solution to keep the environment clean. After the tissue culture seedlings were transplanted, maintained the growth environment at a temperature of 15-25°C, humidity of 70%-80%, and a photoperiod of 15-20 hours to ensure the seedlings root well and grow for 10-15 days before transplanting them to the fog cultivation system for planting beds (or growth trays).

Sterilization of Fog Cultivation System: For new equipment systems, you can use mancozeb or formalin for sterilization. For old equipment systems, cleaning the planting boxes thoroughly before transplanting seedlings. Disinfecting the boxes with a 40% formalin solution diluted 200 times, an 800-fold potassium permanganate solution, or a 500-fold mancozeb solution, and repeated the cleaning for 2-3 times[24]. For the pipeline system, using a 200-fold acetic acid solution for operation for 6-8 hours, then rinsed with clean water for 2-3 times. Additionally, hang yellow boards evenly in the greenhouse to detect and control aphids and other pests promptly.

2.4.4 Post-Planting Management

Select tissue culture seedlings with a height of 10-15 cm and stem thickness about 2 mm. Cleaning the roots thoroughly and immersed them in a 100 mg/L NAA solution with a pH of 5.8-6.0 for 15 minutes. Using tweezers to gently hold the base of the seedling and insert it vertically into the planting hole, ensuring that the base of the seedling was exposed 2-3 cm and that 2-3 leaves were exposed from the planting hole[25].

Temperature, Humidity, and Light Management After Planting: Before the rooting, misted the foliage of the tissue culture seedlings in the morning and evening. Provide 13-15 hours of daylight with an illumination of ≥2,000 lux. Maintaining the nutrient solution temperature at 18-20°C and the environmental temperature around 25°C with a humidity of 70%-80%. After the rooting, the optimal environmental temperature should be maintained at 20-25°C with humidity at 70%-80%. During the reproductive growth stage, daytime temperatures should be kept at 23-24°C and nighttime temperatures at 10-14°C, with humidity maintained at 70%-80%[25]. After tuberization, avoid high temperatures as they may result in small and deformed mini-tubers. Adjust the temperature and humidity inside the greenhouse by opening shade nets, using water curtains, and ventilation fans to meet the growth requirements of potato plants[25].

Disease and Pest Control: When the stolons of the potato plants begin tuberization, pull down 3-5 nodes into the cultivation trough and disinfect them to ensure that the roots and stolons were completely under the planting board, ensuring unobstructed planting holes. At the beginning of tuberization, apply a preventive late blight fungicide every 7-10 days and promptly remove fallen tubers or debris from the box. For early blight, late blight, and bacterial diseases, apply a fungicide every 2 weeks or add an appropriate amount of broad-spectrum fungicide to the nutrient solution regularly. Once diseased plants are found, remove them immediately and treat with pesticides[25].

2.4.5 Nutrient Solution Preparation and Management

To achieve ideal yield and quality under suitable nutrient solution conditions, the nutrient solution is crucial for aeroponic cultivation of potato plants[26,27]. In recent years, research on the nutrient solution components for aeroponic production of virus-free potato seedlings has increased, with several patented inventions having significant representativeness and practical guidance. Based on the latest research results, the entire process of aeroponic cultivation of potato seedlings was divided into five stages by Hu Zhenxing[28]: rooting, seedling, tuber formation, tuber enlargement, and harvesting. Different nutrient solution formulas (components) were prepared for each stage to effectively promote the growth of aeroponically grown potato plants, increase tuberization rate, and increase single-tuber weight. The nutrient solution components and related materials are summarized and organized based on years of practical experience. During production, after the aeroponic device was started, water was sprayed for the first 1-3 days, and nutrient solution is sprayed starting from the 4th day. The spraying interval for rooting seedlings was set to 30 seconds/5-10 minutes, and after rooting, it was set to 30 seconds/10-20 minutes during the day and 30 seconds/30-40 minutes at night. pH of the nutrient solution was monitored and adjusted using HNO_3, concentrated H_2SO_4, or NaOH solution to maintain it at 5.5-6.0. The nutrient solution is changed every 2-3 weeks. See Table 6 for details.

Table 4 Nutrient solution formula for virus-free seed potato production in different growth periods

Reagents	Rooting period (mg/L)	Seedling period (mg/L)	Tuber formation period (mg/L)	Tuber expansion period (mg/L)	Harvesting period (mg/L)
NH_4NO_3	720~880	1 440~1760	1080~1320	864~1056	432~528
KH_2PO_4	428.4~523.6	856.8~1047.2	979.2~1 196.8	1 566~1 914	783~957
KNO_3	181.8~222.2	363.6~444.4	909.0~1 111.0	727.2~888.8	363.6~444.4
$MgSO_4\cdot 7H_2O$	277.2~338.8	553.5~676.5	553.5~676.5	442.8~541.2	442.8~541.2
$Ca(NO_3)_4\cdot 4H_2O$	318.6~389.4	637.2~778.8	637.2~778.8	637.2~778.8	637.2~778.8
Na_2-EDTA·$2H_2O$	37.3	37.3	37.3	37.3	37.3
$FeSO_4\cdot 7H_2O$	27.8	27.8	27.8	27.8	27.8
$MnSO_4\cdot 4H_2O$	22.3	22.3	22.3	22.3	22.3
H_3BO_3	6.2	6.2	6.2	6.2	6.2

$ZnSO_4 \cdot 7H_2O$	8.6	8.6	8.6	8.6	8.6
$CuSO_4 \cdot 5H_2O$	0.025	0.025	0.025	0.025	0.025
$Na_2MoO_4 \cdot 2H_2O$	0.25	0.25	0.25	0.25	0.25
$CoCl_2 \cdot 6H_2O$	0.025	0.025	0.025	0.025	0.025
KI	0.83	0.83	0.83	0.83	0.83

Table 5 Nutrient solution concentrations for virus-free seed potato production in different growth periods

Nutrient Information	Rooting period（mg/L）	Seedling Period（mg/L）	Tuber formation period（mg/L）	Tuber expansion period（mg/L）	Harvesting period（mg/L）
Total saline content	2026~2454	3951~4806	3951~4806	4260~5185	2760~3350
Nitrogen（N）	315.0~385.0	630.0~770.0	630.0~770.0	525.6~642.4	2555.6~312.4
Phosphorus（P）	98.1~119.9	195.3~238.7	195.3~238.7	223.2~272.8	139.5~170.5
Potassium（K）	193.5~236.5	386.1~471.9	386.1~471.9	631.8~772.2	491.4~600.6
Calcium（Ca）	54~66	108~132	108~132	108~132	108~132
Magnesium（Mg）	27~33	54~66	54~66	54~66	43.2~52.8
Sulfur（S）	36~44	72~88	72~88	72~88	57.6~70.4

Table 6 Nutrient solution supply parameters for virus-free seed potato production in different growth periods

Growth period	Day/Spraying frequency（07:00-19:00）	Night/Spraying frequency（19:00-07:00）	Remark
Rooting period	During the first 1-3 days after planting, spray with water every 5-10 minutes for 30 seconds. Apply rooting nutrient solution from the 4th to the 7th day, spraying for 30 seconds every 10-20 minutes during the day and every 20-30 minutes at night.	During the first 1-3 days after planting, spray with water for 30 seconds every 5-10 minutes. Apply rooting nutrient solution from the 4th to the 7th day, spraying for 30 seconds every 10-20 minutes during the day and every 20-30 minutes at night.	Water mixed with rooting nutrient solution
Seedling period	40 s/10 min	40 s/20 min	Nutrient solution for seedling growth
Tuber formation period	40 s/20 min	30 s/30 min	Nutrient solution for tuber formation
Tuber expansion period	40 s/20 min	30 s/30 min	Nutrient solution for tuber enlargement
Harvesting period	40 s/30 min	30 s/1 h	Nutrient solution for the harvest period
2-3 days before harvest	30 s/1 h	30 s/2 h	Spraying with water
1 day before harvest	Stop spraying and proceed with water control measures.		

2.4.6 Harvesting and Storage

Early-maturing varieties have a relatively short growth period, and seeded potatoes can generally be harvested after about 60 days of growth, with tubers weighing between 3-5 grams being harvested. Harvesting was done in batches every 5-7 days, with a one-time harvest at the end of the growth period. Late-maturing varieties have a longer growth period, with tuber yields higher than early-maturing varieties, typically requiring 70-80 days of growth before harvesting. During harvesting, care should be taken to gently pick and place the potatoes to ensure uniform size and good commercial quality, with yields reaching over 50 tubers per plant. Before a one-time harvest, water was sprayed for 2-3 days to wash away salt from the potato skins. Spraying was stopped 1-2 days before harvesting, and water was controlled for 5-7 days to ensure remaining potatoes were harvested completely. After harvesting, the potatoes were washed clean, soaked in a 0.5% solution of both carbendazim and chlorothalonil for 10 seconds, spread on clean cotton cloth (avoiding stacking and exposure to sunlight), and air-dried to promote skin aging and reduce the rate of storage rot. After air-drying, another application of protective agents like carbendazim was sprayed, and after 1-2 days, the potatoes were graded by size, labeled, and sorted into low-temperature storage. For long-term storage, they were kept in a constant temperature chamber at 2-4°C with a humidity of 70-80% and a CO_2 concentration below 2.5 g/L.

3 Research Prospects

Potato seed tuber aeroponic production technology is one of the main directions for future virus-free seed potato breeding. In recent years, major potato-producing areas such as Inner Mongolia, Gansu Province, Ningxia, Southwest China, and Northeast China have carried out related work to establish "potato virus-free seed breeding bases." They have gradually formed an integrated potato industry development pattern of "introduction, breeding, propagation, promotion, addition, and sales," constructing an integrated potato industry system that includes potato breeding, virus-free rapid propagation, virus testing, original seeds, primary seeds, secondary seeds production, seed storage, seed marketing, and procurement processing. The application and innovative development of potato seed tuber aeroponic production technology will be of great significance in improving the potato seed tuber breeding system and enhancing the level of potato industry development.

Regarding the current research status and future directions of potato seed tuber aeroponic production technology, there are still some technical issues that need to be addressed urgently, including: (1) Research on intelligent and convenient production equipment: Continuously optimize and upgrade equipment devices to achieve modular installation, continuously reduce production costs, and truly realize the goals of strong operability and efficient intelligence; (2) Research on visualization of the aeroponic production process: Effectively integrate with disciplines such as network engineering technology and Internet of Things technology to achieve remote monitoring and operation control; (3) Research on nutrient solution formulation: Optimize and upgrade nutrient solution components to improve tuber yield and production; (4) Storage of aeroponically produced seed potatoes: Aeroponically produced potato seed tubers have high moisture content, easy rotting, and difficult storage characteristics. For easy management and loss reduction, utilize intelligent information technology to monitor and warn the storage cellar environment, real-time monitoring, and record of storage cellar environment data information.

These research directions will contribute to the continuous improvement and development of potato seed tuber aeroponic production technology, promoting the sustainable development of the potato industry.

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4. School enterprise cooperation project（RH2000000433）

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