Research on the Construction and Promotion Application of Green Production Technology System for Curly Leaf Vegetable

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Abstract: *Curly leaf vegetable is a nutritious cruciferous specialty vegetable with significant economic benefits. Its vitamin C content is as high as 2.5 times that of kiwifruit, and it has strong adaptability. In the Yangtze River Basin, it can be cultivated twice a year, with a harvesting period of up to 8 months, and the output value can reach 20,000 to 30,000 yuan per 667 square meters. Based on production practice and literature research, this paper systematically summarizes the key technologies for green production of curly leaf vegetable, including intensive seedling cultivation, balanced fertilization, integrated water and fertilizer management, green prevention and control of diseases and pests, and standardized harvesting and preservation, so as to form a set of local production technical standards suitable for Hubei Province and similar ecological zones, in order to promote the development of the leafy vegetable industry towards a green, efficient, and sustainable direction.*

Keywords: *curly leaf vegetable; green production; standardization; Hubei Province; cultivation techniques; disease and pest control; harvesting and preservation.*

1. Introduction

As a new type of health-promoting vegetable, curly leaf vegetable is rich in vitamin C, folic acid, and various minerals, and features antioxidant properties and good storage and transportation tolerance, which conform to the trend of modern healthy diets. Hubei Province is located in the middle and lower reaches of the Yangtze River, and its climate is suitable for spring and autumn cultivation of curly leaf vegetable, showing great development potential. However, the current planting scale is still limited due to reasons including the lack of popularized techniques, low standardization, and insufficient mastery of green production techniques by growers. Therefore, constructing and promoting a green production technology system for curly leaf vegetable is of great significance for enhancing industrial competitiveness and promoting rural revitalization. This paper, based on recent planting practices and technical summaries, systematically elaborates the technical pathways for green production of curly leaf vegetable, in order to provide technical support for the industrialized development of curly leaf vegetable in Hubei Province and surrounding areas.

2. Biological Characteristics and Industrial Value of Curly Leaf Vegetable

2.1 Biological Characteristics

Curly leaf vegetable is a variety of Brassica oleracea in the family Brassicaceae. Its plant morphology is characterized by curled and wrinkled leaves, dark green leaf color, and crisp and tender leaf texture. In terms of physiological ecology, curly leaf vegetable prefers a cool and mild climate, with an optimal temperature range for photosynthesis of 15–25°C. It is sensitive to high-temperature stress; growth is retarded and lignification intensifies when the temperature exceeds 30°C. The crop has a relatively strong tolerance to low temperatures; mature plants can withstand short-term low temperatures of about –5°C. In the Yangtze River Basin, it can be grown in open fields over winter, effectively extending the growing period. Curly leaf vegetable adapts to a wide range of soils, with sandy loam soil of pH 6.0–7.5, rich in organic matter and well-drained, being the most suitable. Its root system is shallow and consists mainly of fibrous roots, with moderate absorptive capacity; therefore, it requires high uniformity and continuity in water and nutrient supply. In addition, curly leaf vegetable is a long-day crop, but it is not sensitive to photoperiod during the vegetative growth stage, making it suitable for both spring and autumn cultivation and endowing it with considerable flexibility in production scheduling.

2.2 Industrial Value

The nutritional composition of curly leaf vegetable has distinctive features. It is rich in vitamin C, folic acid, dietary fiber, and mineral elements such as potassium, calcium, and iron. Among these, the vitamin C content is at a relatively high level among leafy vegetables, conferring good antioxidant and immune-regulating functions, which align with modern consumers' demand for functional vegetables. In terms of processing and consumption attributes, curly leaf vegetable can be consumed fresh in salads, hotpot dishes, or stir-fries, and can also serve as raw material for further processing such as quick-freezing and dehydration, offering diverse product forms and strong market adaptability. In terms of planting economic benefits, curly leaf vegetable has a short growth cycle and a high multiple cropping index, with a yield per unit area superior to that of ordinary leafy vegetables. Moreover, its storage and transportation tolerance reduces post-harvest losses, which is conducive to extending the supply chain. At present, in suitable planting areas such as Hubei Province, curly leaf vegetable has initially formed a large-scale production pattern, becoming an important instrument for optimizing the vegetable industrial structure and enhancing land output efficiency, and it holds positive practical significance for promoting quality improvement and efficiency enhancement in crop production and increasing farmers' income[1].

3. Green Production Technology System

3.1 Intensive Seedling Cultivation Technology

Seedling cultivation is the foundational step in curly leaf vegetable production. Green seedling cultivation emphasizes environmental friendliness and healthy seedling development.

3.1.1 Seedling Cultivation for the Autumn Crop

Sowing is conducted from late July to mid-August, using 72-cell or 105-cell plug trays. The substrate should be loose, water-retentive, and free from pest eggs and pathogenic microorganisms. After sowing, cover the seeds with soil to a depth of 1–2 cm; excessive thickness hinders emergence, while insufficient thickness causes lodging. During the seedling stage, management focuses on moisture retention, cooling, and disease prevention. Water in the morning and evening, and supplement with 0.2% balanced water-soluble fertilizer as a top dressing. The main diseases to prevent are damping-off and downy mildew; it is recommended to apply 70% carbendazim wettable powder at an 800-fold dilution for prevention. For pests such as flea beetles, 20% acetamiprid at a 1500-fold dilution can be used. Physical control measures such as insect-proof nets and yellow sticky traps are encouraged to reduce the use of chemical pesticides.

3.1.2 Seedling Cultivation for Early Spring Crop

Sowing is conducted in December, using a multi-layer insulation system consisting of a greenhouse, heating cables, and thermal blankets to maintain the temperature at 20–25°C. After emergence, the plastic film should be removed promptly for ventilation to prevent diseases caused by high temperature and high humidity. Watering should be done with warm water at 10–20°C to avoid chilling injury to the roots. The main disease to prevent is downy mildew, for which a 500-fold dilution of 64% oxadixyl·mancozeb can be applied as a preventive measure. Generally, no chemical application is needed during the seedling stage, as the emphasis is placed on environmental regulation.

3.2 Scientific Fertilization Technology

Under the green production mode, fertilization management for curly leaf vegetable follows the principle of "organic fertilizer as the base, chemical fertilizer as a supplement, and coordinated regulation of trace elements," aiming to achieve the dual goals of high yield and quality of the crop and continuous improvement of soil fertility. According to the nutrient uptake patterns of curly leaf vegetable, it has a high demand for nitrogen throughout the entire growth period, and is sensitive to phosphorus, potassium, and trace elements such as boron and zinc. Boron deficiency tends to cause leaf curling and malformation, as well as necrosis of the central leaves, while zinc deficiency affects the development of growing points. Therefore, the fertilization system should ensure a balanced supply of both macronutrients and micronutrients.

3.2.1 Basal Fertilizer Application

In combination with land preparation, apply 400–600 kg of well-rotted chicken manure per 667 m^2, together with 30–50 kg of compound fertilizer ($N:P_2O_5:K_2O$ = 16:16:16). The application of organic manure not only provides slow-release nutrients but also improves soil aggregate structure and enhances water and nutrient retention capacity. Given the sensitivity of curly leaf vegetable to boron and zinc, incorporate 0.75–1.0 kg of granular boron fertilizer and 0.25–0.5 kg of zinc fertilizer into the basal fertilizer to prevent physiological disorders. In addition, apply 50 kg of superphosphate every two years to supplement calcium nutrition, which can effectively improve leaf texture and disease resistance.

3.2.2 Topdressing Strategy

After transplanting, when 2–3 new leaves have emerged, 10–15 kg of urea is applied per 667 m^2 to promote rapid establishment of vegetative growth. After the crop enters the vigorous growth period, balanced water-soluble fertilizer ($N:P_2O_5:K_2O$ = 20:20:20) is supplemented in a split application with small amounts at multiple times, based on plant vigor and leaf color changes, so as to avoid excessive nitrogen that may cause tender leaves and reduced resistance. In the middle and late stages, functional fertilizers containing amino acids or humic acids can be applied as foliar sprays to enhance leaf stress tolerance.

3.2.3 Approaches for Efficiency Enhancement

The integrated water and fertilizer management technology is fully promoted, through which soluble fertilizers are precisely delivered to the root zone via drip irrigation systems on demand, achieving synchronization of water and nutrients as well as spatiotemporal coupling. This technology can improve fertilizer use efficiency by more than 20%, reduce surface runoff and leaching losses of nitrogen and phosphorus, and significantly lower the risk of non-point source pollution. Meanwhile, it is recommended to combine this approach with soil testing and formulated fertilization, dynamically adjusting the fertilization plan based on the baseline nutrient content of the soil, so as to upgrade the fertilization management of curly leaf vegetable towards precision, reduction, and green development[2].

3.3 Rational Irrigation and Water Management

Curly leaf vegetable has a shallow root distribution and moderate water absorption capacity, and its growth and development are relatively sensitive to soil moisture conditions. In production, it is necessary to follow the principle of "moisture promotes growth, while waterlogging prevention protects roots" to establish a water management system that synergistically optimizes water-saving irrigation and field drainage, thereby achieving an organic integration of water supply–demand balance and root-zone environmental regulation.

3.3.1 Irrigation Strategy and Precise Water Regulation

Differentiated irrigation is implemented according to the water demand characteristics at different growth stages. At the seedling stage, the root system is not yet well developed, so the relative water content of the topsoil layer should be maintained at 70%–80% to promote root penetration and vigorous seedling growth. After transplanting and seedling establishment, the crop enters the vigorous vegetative growth period, during which transpiration and soil evaporation increase. At this stage, the soil relative water content should be maintained at 65%–75% after each irrigation, and supplemental irrigation should be applied when the surface soil becomes slightly dry (at an interval of approximately 3–5 days) to avoid drought stress that may cause leaf aging and increased cellulose content. In terms of irrigation methods, traditional flood irrigation is abandoned, and drip irrigation or micro-sprinkler irrigation is fully adopted. Drip irrigation delivers water directly to the root zone, reducing surface evaporation and deep percolation; micro-sprinkler irrigation also provides humidification and cooling effects, making it particularly suitable for high-temperature seasons or protected cultivation environments. Both methods can significantly reduce air humidity and suppress the occurrence of foliar diseases.

3.3.2 Drainage and Waterlogging Reduction and Soil Aeration Assurance

Curly leaf vegetable is extremely sensitive to waterlogging stress. Excessive soil water saturation can lead to root hypoxia and accumulation of harmful substances from anaerobic respiration, which in turn induces root rot and plant wilting. For fields in areas with concentrated rainfall or with a high water table, a cultivation system of deep furrows and high ridges should be implemented. The specific specifications are as follows: ridge height of 20–25 cm, ridge surface width of 80–100 cm, and furrow width of 30–40 cm, forming a "three-ditch" drainage network (consisting of field ditches, middle ditches, and surrounding ditches) to ensure that there is no standing water in the field after rain and that subsurface waterlogging can percolate downward. In addition, it is recommended to combine soil moisture monitoring equipment or simple tensiometers to guide irrigation decisions in real time and avoid blind watering. Through a management model of "controlling surface moisture and replenishing subsurface water, combining drainage and irrigation," the dynamic balance of water, air, and heat in the root zone can be maintained, thereby creating a suitable water and ecological environment for high quality and high yield of curly leaf vegetable.

3.4 Field Comprehensive Management

Rational planting density and population structure regulation: Based on the plant spread and light utilization characteristics of curly leaf vegetable, a wide-ridge and narrow-furrow planting pattern is adopted. The ridge width is 1.2 m, row spacing is 50 cm, and plant spacing is 35–40 cm (for the spring crop, as temperatures rise quickly and the vegetative growth period is shortened, the spacing can be appropriately reduced to 30–35 cm), with 2,700–3,200 plants planted per 667 m^2. This density configuration not only ensures sufficient nutritional area for each individual plant but also creates a reasonable population leaf area index, which facilitates canopy ventilation and light penetration, reduces inter-plant humidity, and minimizes disease occurrence, while simultaneously achieving efficient utilization of land resources.

3.4.1 Soil Cultivation and Ecological Weed Regulation

After transplanting and seedling establishment, and before canopy closure, shallow hoeing and soil loosening are carried out twice at a depth of 3–5 cm to break soil compaction, improve rhizosphere aeration, and simultaneously remove germinated weeds. Care should be taken during loosening operations to avoid damaging the root system. Weed management prioritizes a combination of manual pulling and intertillage weeding, with strict control over the use of chemical herbicides. Once the plants enter the vigorous growth period and the leaves have fully closed the canopy, the dense canopy effectively shades the soil surface, inhibiting weed seed germination and growth, thereby creating an ecological regulation effect of "suppressing weeds with the crop canopy" and consequently reducing labor and chemical inputs.

3.4.2 Green Prevention and Control Technology System for Diseases and Pests

Following the plant protection policy of "prevention first, integrated control," a green prevention and control system is established, with agricultural control as the foundation, physical and biological controls as the dominant measures, and chemical control as a supplement. Agricultural control adopts measures such as crop rotation, field sanitation, and ridge cultivation to reduce the source populations of pathogens and pests. Physical control includes hanging yellow sticky traps to trap and kill aphids and whiteflies, setting up sex pheromone traps to attract and kill adult diamondback moths, and covering with insect-proof nets to block pest invasion. Biological control employs microbial or botanical agents such as Bacillus thuringiensis and azadirachtin. For the major diseases including black embryo disease, soft rot, and downy mildew, low-toxicity fungicides such as 70% carbendazim or 64% oxadixyl·mancozeb are applied alternately at the early stage of disease incidence. For pests such as diamondback moth, aphids, and whiteflies, highly effective and low-risk insecticides such as 3% emamectin benzoate or 60 g/L spinetoram are recommended. All chemical control measures must strictly comply with the pre-harvest interval, and application records should be established to ensure that pesticide residues in the products meet green food standards, thereby achieving the integration of yield, quality, and ecological safety.

3.5 Standardized Harvesting and Preservation Technology

The harvesting and postharvest handling of curly leaf vegetable directly affect its marketability, storage life, and terminal market value. Based on the physiological characteristics of its leaves, including high water content, vigorous respiratory metabolism, and susceptibility to water loss and wilting after harvest, it is necessary to establish an integrated standardized technical process that combines timely harvesting, rapid pre-cooling, precise storage, and cold chain circulation, so as to maximize the maintenance of product freshness and nutritional quality.

3.5.1 Harvesting Standards and Methods

For the stepwise harvesting mode, when the outer functional leaves of the plant reach 10–12 in number, 2–3 central tender leaves are harvested, with leaf length controlled at 10–12 cm, while retaining 8–10 robust outer leaves to maintain the plant's continuous photosynthetic capacity and regenerative growth. Harvesting is conducted every 2–3 days, which enables multiple batches of market supply and increases the total yield per plant. For the one-time harvesting mode, it is mostly carried out from late February to early March in spring, when the overall leaf length of the harvested plants reaches 10–15 cm. The intact petioles and tender leaves are retained, and the plants are bundled with leaves attached or packaged whole, which can significantly improve the uniformity of commercial appearance and the market price. Harvesting operations should preferably be conducted on sunny afternoons, when the dew on leaf surfaces has dried and field heat is relatively low, which is conducive to subsequent pre-cooling, storage, and transportation.

3.5.2 Postharvest Handling and Pre-cooling Process

After harvest, the produce should be transported to the processing site within 2 hours and immediately sorted to remove diseased leaves, yellow leaves, mechanically damaged leaves, and foreign matter. After sorting, forced-air pre-cooling or vacuum pre-cooling is applied to reduce the core temperature of the leaves to 4–5°C within 2–4 hours, rapidly removing field heat and inhibiting respiration and ethylene release. After pre-cooling is completed, packaging is carried out according to the requirements of the sales channel: for e-commerce or supermarket sales, polyethylene fresh-keeping bags with micro-perforations or directional breathable containers are recommended, with a net weight of approximately 250–500 g per bag, and ethylene absorbers or humidity control pads may be placed inside the bags; for wholesale in bulk, corrugated cartons lined with cling film are used, with 5–10 kg per carton[3].

3.5.3 Storage and Cold Chain Circulation

Packaged curly leaf vegetable should be temporarily stored in a cold storage, with the storage temperature strictly controlled at 4–5°C and the relative humidity maintained at 90%–95%. Under these conditions, the leaf water loss rate is significantly reduced, and the degradation of chlorophyll and the oxidation of vitamin C are slowed down, extending the shelf life to 30 days while keeping the acceptable product rate above 90%. If controlled atmosphere storage is adopted (with O_2 concentration at 2%–5% and CO_2 concentration at 3%–6%), the shelf life can be further extended to 40–45 days. After leaving the cold storage, refrigerated trucks should be used throughout transportation, with temperature fluctuations not exceeding ±1°C, ensuring an uninterrupted cold chain from the production area to the end consumers. This technical system is not only suitable for traditional wholesale channels but also provides quality assurance for long-distance and multi-node distribution on e-commerce platforms, significantly reducing logistics losses and enhancing the market supply capacity and brand premium potential of curly leaf vegetable.

4. Recommendations for Local Planting Standards in Hubei Province

4.1 Standardization of Cultivation Seasons

It is specified that the sowing period for the autumn crop ranges from July 25 to August 15. During this period, seedlings are raised with shading and cooling, utilizing shading nets and ventilation facilities to lower the seedbed temperature and prevent high-temperature injury to seedlings. The sowing period for the spring crop is in December, with transplanting carried out under greenhouse or plastic film mulching conditions in mid-to-late January, supplemented by insulation blankets or small arched tunnels for cold protection. By precisely defining the sowing and transplanting windows, extreme temperature stress is avoided, and the plants are ensured to complete their vegetative growth under suitable light and temperature conditions.

4.2 Soil and Environmental Requirements

Fields with a pH of 6.0–7.5, organic matter content ≥ 2.0%, and a texture of sandy loam or light loam should be selected. The terrain should be flat with convenient irrigation and drainage, and the fields should be located far from industrial and mining enterprises and pollution sources. The irrigation water quality must comply with GB 5084 "Farmland Irrigation Water Quality Standard," and the soil heavy metal content must not exceed the risk screening values stipulated in GB 15618, with testing conducted every two years. The previous crop should be a non-cruciferous vegetable, and the rotation cycle should be no less than three years.

4.3 Specifications for Pesticide and Fertilizer Use

The standards NY/T 393 and NY/T 394 shall be strictly implemented. The use of highly toxic and high-residue pesticides is prohibited, and priority shall be given to microbial agents, botanical pesticides, and bio-organic fertilizers. Chemical pesticides shall not be applied more than twice per growing season, and their use must be alternated. A fertilizer use record shall be established, and the proportion of commercial organic fertilizer in the total nitrogen input shall not be less than 50%.

4.4 Production Record and Traceability System

The growers shall establish electronic or paper field records, detailing the dates of sowing and transplanting, the sources and quantities of inputs (fertilizers, pesticides, and seedlings), field agronomic operations, harvest batches, test reports, and sales destinations, so as to achieve full traceability throughout the entire process. The records shall be kept for no less than two years. The use of QR code traceability labels is encouraged, allowing consumers to scan the code to access information on production origin and test results, thereby enhancing market trust.

4.5 Technical Training and Demonstration Extension

Relying on agricultural cooperatives, leading enterprises, and grassroots agricultural technology extension agencies, a number of core demonstration bases for green production of curly leaf vegetable shall be established, with each base covering no less than 3.3 hectares per county, and equipped with unified technical signage and field operation procedures. Organized technical training on standardization shall be conducted no less than twice annually, adopting a combination model of theoretical lectures, field observations, and on-site guidance, with a focus on training new agricultural business entities and large-scale growers. Meanwhile, user-friendly operation manuals shall be compiled to ensure that the technology is implemented correctly without deviation.

5. Recommendations and Prospects for Industrial Promotion

5.1 Policy Support

It is recommended that the provincial agricultural competent authorities include curly leaf vegetable in the local specialty vegetable catalog, and provide special financial support for improved seed subsidies, subsidies for green prevention and control materials, and water-saving irrigation infrastructure construction, while establishing transparent and standardized procedures for subsidy distribution. At the same time, exploration should be made to incorporate curly leaf vegetable into the local specialty agricultural product insurance catalog, covering natural risks and market price fluctuation risks, so as to stabilize growers' expectations. Local governments are encouraged to coordinate agricultural, financial, and commerce departments to form a linkage mechanism and jointly promote the healthy development of the curly leaf vegetable industry.

5.2 Scientific and Technological Support

Strengthening cooperation with agricultural research institutes and universities is recommended to carry out research on breeding for disease resistance (especially against black embryo disease and soft rot) in curly leaf vegetable, studies on mechanization-friendly cultivation modes, and integration of intelligent water and fertilizer management technologies. A collaborative innovation platform integrating industry, universities, research institutions, and extension services shall be established to accelerate the transformation of scientific and technological achievements into frontline production. The development of simplified harvesting equipment is encouraged to reduce labor dependence. Meanwhile, a real-time monitoring and intelligent decision-making system for the growing environment based on the Internet of Things should be constructed to enable precision management and remote technical guidance, thereby enhancing the contribution rate of science and technology.

5.3 Market Cultivation

In addition to fresh sales, the deep-processing product chain of curly leaf vegetable should be actively developed, including quick-frozen curly leaf vegetable, dehydrated vegetable powder, blended fruit and vegetable juice, and functional health foods, and special channels such as catering, aviation, and military supply should be expanded. Relying on e-commerce platforms and livestreaming sales, a regional public brand should be built to enhance brand premium. At the same time, curly leaf vegetable should be promoted to be included in school nutrition meals and the community fresh produce supply chain, so as to build diversified and stable market outlets.

6. Conclusion

The green production technology system for curly leaf vegetable integrates intensive seedling cultivation, balanced fertilization, water-saving irrigation, green prevention and control, and standardized harvesting, with significant dual ecological and economic benefits. Promoting this technology in Hubei Province can effectively improve the yield and quality of curly leaf vegetable, enhance market competitiveness, and promote the development of the leafy vegetable industry towards green, standardized, and branded directions, thereby providing strong support for rural revitalization and sustainable agricultural development.

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