

Integration of Cultivation Techniques and Innovation of Production Models for Specialty Vegetable: Broccoli

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Abstract: With the rapid development of modern agriculture and the growing consumer demand for high-quality, healthy food, the importance of specialty vegetable broccoli in the market continues to increase. However, traditional cultivation models and production methods face numerous challenges in meeting market demands, improving yield, and ensuring quality. This study, based on an analysis of the current status of broccoli cultivation and industry development, proposes the integrated innovation of broccoli cultivation techniques and optimizes production models. By innovating quality seedling technology, optimizing transplanting and planting processes, and integrating pest and disease management with nutrient management techniques, the production efficiency and quality of broccoli are further enhanced. Additionally, by combining precision planting in smart agriculture with green circular production models, sustainable production pathways are explored, providing strong support for the development of the broccoli industry. The results indicate that integrated innovative cultivation techniques and production models can effectively improve broccoli yield and market competitiveness, with promising potential for broader regional application in the future.

Keywords: Broccoli; Integrated Cultivation Techniques; Production Model Innovation; Smart Agriculture; Green Circular Production

Introduction

As a specialty vegetable, broccoli is widely welcomed in the market due to its rich nutritional content and strong adaptability. In recent years, with the popularization of healthy eating concepts, the market demand for broccoli has significantly increased. However, traditional cultivation techniques and production models have certain limitations in addressing increasingly complex market demands, such as low production efficiency, difficulties in pest and disease management, and resource waste. Therefore, exploring an efficient and sustainable integrated cultivation plan and innovative production model for broccoli is of great significance for enhancing the competitiveness of the broccoli industry and achieving rural revitalization. This study aims to integrate modern agricultural technologies, innovate the cultivation techniques and production models for broccoli, and address the technological bottlenecks in traditional production to improve efficiency and quality. Specifically, the research focuses on technological innovations in key aspects such as broccoli seedling raising, planting, and pest and disease management, proposing precision planting and green circular production models based on smart agriculture to achieve sustainable development in the broccoli industry.

1. Current Status of Broccoli Cultivation and Industry Development

1.1 Diversity of Broccoli Varietals and Regional Distribution

Broccoli, an important variant of cauliflower, boasts rich varietal resources, wide adaptability, and high economic and nutritional value. Globally, broccoli varieties exhibit diversity, primarily in aspects such as color, shape, and maturity. Commonly seen broccoli varieties in domestic and international markets include traditional white broccoli, purple broccoli, and green Romanesco. This diversity satisfies the varied demands of different consumer groups for specialty vegetables.

In terms of regional distribution, broccoli cultivation shows significant geographical characteristics,

mainly limited by climate conditions and soil types. The primary cultivation areas for broccoli in China are concentrated in southern and coastal regions, such as Guangdong, Fujian, and Zhejiang provinces, where the climate is warm and humid, conducive to broccoli growth. Additionally, some northern provinces, such as Shandong and Hebei, have gradually established seasonal planting patterns to meet national market demands. In the international market, Italy, Spain, and France are major broccoli-producing countries, supplying not only their domestic markets but also exporting high-quality broccoli varieties globally. With advancements in agricultural technology and the promotion of greenhouse cultivation techniques, the regional cultivation pattern of broccoli is gradually expanding to more areas, further enhancing its market competitiveness^[1].

1.2 Current Status of the Broccoli Industry Chain and Market Demand Analysis

The broccoli industry chain encompasses several links, including seedling raising, cultivation, processing, and sales, involving the coordinated development of agriculture, food processing, and circulation service industries. Currently, the broccoli industry chain is relatively well-developed, particularly with significant progress in intensive cultivation and intelligent management. As consumer demand for healthy food increases, broccoli, recognized as a low-calorie, high-fiber healthy vegetable, is highly favored in the market, with demand growing year by year. According to relevant market research data, the annual growth rate of broccoli market demand has maintained above 5% in recent years, especially in large domestic and international cities, where the market demand for green, pollution-free broccoli shows a steady upward trend.

In terms of the supply chain, the broccoli industry chain faces certain challenges. Firstly, there is a spatial asymmetry between production areas and market demand; broccoli grown in southern regions often requires long-distance transport to northern consumption markets, leading to high transportation costs. Secondly, there is insufficient technological advancement in the processing phase; further optimization is needed in cold chain transportation and preservation techniques to extend shelf life. Additionally, the brand awareness of domestic broccoli is low, and marketing efforts are inadequate, resulting in low product added value. These issues somewhat limit the further upgrading and expansion of the broccoli industry chain. Therefore, future development of the broccoli industry chain needs to seek breakthroughs in product fine management, market branding, and supply chain optimization.

1.3 Technological Bottlenecks and Challenges in Existing Cultivation Models

Currently, broccoli cultivation primarily employs open-field planting, while some regions are gradually introducing greenhouse and facility agriculture techniques. Although existing cultivation techniques can generally ensure normal growth and yield of broccoli, several technical bottlenecks and challenges remain in practice. Firstly, broccoli has high environmental requirements, especially sensitivity to temperature and moisture management; traditional open-field cultivation models struggle to effectively cope with climate change and extreme weather, resulting in significant yield fluctuations. Secondly, pest and disease management techniques are relatively outdated; broccoli is vulnerable to various pests and diseases such as downy mildew, powdery mildew, and aphids. Existing control methods primarily rely on chemical pesticides, which can lead to soil pollution and resistance issues with long-term use, while green control techniques have yet to be widely adopted^[2].

Moreover, water and fertilizer management in broccoli cultivation is a significant technical bottleneck. Traditional irrigation and fertilization methods lead to water resource waste and nutrient loss, which not only reduces production efficiency but also adversely affects the environment. Although precision fertilization and integrated water-fertilizer technology have achieved some success in certain areas, barriers such as high technical costs and low acceptance among farmers still hinder broader application. At the same time, the level of mechanization in broccoli production is low, particularly in transplanting and harvesting stages, which rely heavily on manual labor, increasing production costs and limiting the development of large-scale, intensive cultivation.

To address these technical challenges, the cultivation model for broccoli urgently needs to integrate modern agricultural technologies, exploring innovations in green pest and disease control, precision irrigation and fertilization, and intelligent temperature control, thereby overcoming the bottlenecks of traditional models, enhancing production efficiency and quality, and promoting sustainable development in the broccoli industry.

2. Integrated Innovation of Broccoli Cultivation Techniques

2.1 Innovation and Optimization of Quality Seedling Technology for Broccoli

The seedling stage is a critical phase in broccoli cultivation, directly impacting subsequent growth and yield. Traditional seedling methods mostly rely on open-field seedling raising and simple substrate formulations, leading to issues such as long seedling periods, poor disease resistance, and low survival rates. Therefore, innovating and optimizing seedling technology is crucial for improving seedling quality.

Firstly, substrate optimization forms the foundation for enhancing seedling quality. In modern seedling technology, substrate selection should focus on characteristics such as light weight, good aeration, and high organic matter content. Through experimental comparison, a suitable seedling substrate can be formulated based on broccoli's growth characteristics, such as using a mixed substrate of perlite, coconut coir, and organic fertilizer, which not only improves aeration but also enhances moisture retention, promoting robust root development of seedlings.

Secondly, the introduction of greenhouse seedling raising and temperature and humidity control technology significantly improves seedling efficiency. By utilizing modern greenhouse facilities along with intelligent temperature and humidity control systems, the seedling environment can be maintained under optimal conditions for broccoli growth, avoiding extreme weather impacts on seedlings and shortening the seedling period. Additionally, applying LED lighting technology to provide suitable light conditions during low-light periods can enhance photosynthesis in seedlings and increase survival rates.

Finally, the application of green pest and disease management technology is also a key focus of innovation in the seedling stage. Traditional chemical pesticide methods can lead to soil and environmental pollution; however, biological pesticides, microbial formulations, and physical control techniques, such as insect nets and yellow sticky traps, can effectively reduce the occurrence of pests and diseases, ensuring healthy seedling growth. By integrating these technologies, the quality of broccoli seedlings can be significantly enhanced, laying a solid foundation for subsequent cultivation.

2.2 Scientific and Rational Transplanting and Planting Techniques

Transplanting and planting serve as key links in broccoli cultivation, directly affecting root development and subsequent yield. Scientific and rational transplanting techniques not only ensure seedling survival rates but also promote early growth, laying the groundwork for high yields^[3].

The timing of transplanting is critical. Based on broccoli's growth characteristics, transplanting should occur when seedlings reach 4-5 true leaves; at this stage, the root system is well-developed and can quickly adapt to the soil environment. Additionally, transplanting should avoid high temperatures or strong light conditions, ideally conducted in the morning or evening to reduce moisture evaporation from seedlings and increase survival rates. By appropriately scheduling transplanting times, staggered planting can also be achieved, extending the market supply period.

Determining planting density is another important aspect of transplanting. The planting density of broccoli should be optimized according to its spatial requirements and light conditions. Overly dense planting can lead to insufficient light for plants, negatively impacting photosynthesis, while sparse planting wastes land resources. Through experimental research, the optimal planting density for different broccoli varieties can be identified, ensuring adequate space for photosynthesis during the growing season, thereby enhancing yield and quality.

Moreover, water and fertilizer management techniques are particularly important in the early stages post-planting. By employing integrated water and fertilizer technology, precise irrigation and fertilization can be achieved, effectively reducing water waste and nutrient loss. The first 1-2 weeks after planting is a critical period for root recovery; rational water and fertilizer management can not only promote root growth but also provide sufficient nutrition for rapid growth in later stages.

2.3 Integrated Technology for Pest and Disease Control and Nutrient Management During the Growing Phase

Broccoli is susceptible to pests and diseases during the growing phase, particularly downy mildew, black spot disease, and aphids, which can severely impact yield and quality. Therefore, innovative integrated pest and disease control technology is essential for ensuring healthy broccoli growth. Additionally, the growing phase coincides with a period of high nutrient demand, and scientific nutrient

management directly affects yield and quality.

In terms of pest and disease control, the combination of biological control and green pesticides has become an important method in modern agriculture. Biological control techniques effectively manage pests and diseases by introducing natural enemies and applying microbial formulations. For example, using predatory natural enemies such as ladybugs to control aphids or spraying microbial pesticides to manage downy mildew can reduce chemical pesticide use and lower environmental pollution. Moreover, the application of plant protection drones in large-scale cultivation enables precise spraying of control agents, improving control effectiveness and reducing pesticide usage, achieving targeted pest and disease management^[4].

Regarding nutrient management, broccoli has high demands for nitrogen, phosphorus, potassium, and trace elements during the growing phase. Traditional fertilization methods often suffer from low fertilizer utilization and environmental pollution; thus, integrating precision fertilization technology is vital for improving nutrient management efficiency. Based on soil nutrient monitoring and analysis of crop growth conditions, precision fertilization technology can supply nutrients according to the needs of different growth stages, minimizing over-fertilization and nutrient loss. Furthermore, the application of integrated water and fertilizer systems allows for synchronized irrigation and fertilization, enhancing the efficiency of water and nutrient utilization, thereby meeting the growth demands of broccoli.

By organically combining pest and disease control with nutrient management technology, the broccoli growth cycle can be completed in a healthy environment, ensuring the achievement of high-quality and high-yield outcomes. This integrated management model not only enhances production efficiency but also reduces the negative environmental impact of agricultural production, providing reliable technical support for the sustainable cultivation of broccoli.

3. Innovation of Broccoli Production Models

3.1 Analysis of Limitations in Traditional Broccoli Production Models

Traditional broccoli production models primarily rely on open-field cultivation and small-scale family farms. While this model has lower initial investment and a long cultivation history, it reveals numerous limitations as modern agricultural demands continue to rise. Firstly, traditional production methods are highly dependent on the natural environment, with fluctuations in climate conditions significantly affecting broccoli yield and quality. Extreme weather events such as heavy rain, drought, and frost can lead to substantial yield reductions. Furthermore, open-field cultivation relies on chemical pesticides for pest and disease control, and prolonged use can cause environmental pollution, soil degradation, and excessive agricultural residues, which restrict the product's market competitiveness^[5].

Secondly, traditional production models typically employ manual management practices, relying on human labor for planting, fertilizing, irrigating, and harvesting. As labor costs gradually increase, production efficiency in traditional models remains difficult to improve, further escalating production costs and limiting the scale and intensification of the industry. Additionally, traditional production models often lack scientific and systematic management, with growers frequently relying on experience rather than precise management of soil, moisture, and nutrients. This can lead to resource waste and unstable output, adversely affecting the overall benefits and quality of broccoli.

3.2 Precision Planting Models Based on Smart Agriculture

To address the limitations of traditional production models, precision planting based on smart agriculture has emerged. Precision planting integrates modern information technology with agricultural practices, achieving scientific and efficient broccoli production through comprehensive monitoring, analysis, and optimization of the entire production process. Firstly, the precision planting model employs technologies such as the Internet of Things, sensors, big data, and artificial intelligence to create a comprehensive monitoring system that collects real-time data on soil temperature and humidity, air quality, and crop growth conditions. Through data analysis, farmers can promptly understand broccoli's growth needs and implement targeted management measures according to the specific conditions at different stages.

The application of drone technology in precision planting offers significant advantages, especially in large-scale broccoli production. Drones can perform precise sowing, fertilization, irrigation, and pest control, greatly reducing labor input and enhancing production efficiency. Additionally, by utilizing

integrated smart water and fertilizer technology, water and nutrient supply can be scientifically adjusted according to real-time soil and plant needs, avoiding excessive irrigation and fertilization, thereby improving resource utilization and reducing environmental pollution.

The precision planting model based on smart agriculture not only enhances broccoli yield and quality but also improves controllability and sustainability in agricultural production. Through automated and intelligent management, labor costs and resource waste are minimized, optimizing production efficiency. More importantly, the precision planting model provides technological support for branding and standardized production of broccoli, helping growers transition from traditional agriculture to modern, efficient farming practices.

3.3 Construction of Green Circular Production Models

As the concept of sustainable development gains traction, green circular production models have become an essential direction for modern agricultural development. In broccoli cultivation, green circular production models emphasize the efficient utilization of resources and ecological production systems, achieving greening and sustainable development of broccoli production by reducing external inputs and enhancing resource recycling. Firstly, regarding fertilizer use, green circular production models advocate for the use of organic fertilizers and biological fertilizers to reduce reliance on chemical fertilizers, avoiding soil pollution and ecological imbalances. Organic fertilizers provide stable long-term nutrition for broccoli while improving soil structure and enhancing soil moisture and nutrient retention capacity, thus increasing the sustainable productivity of the soil^[6].

Secondly, the efficient utilization of water resources is a core aspect of green circular production models. By applying water-saving irrigation techniques such as drip irrigation and spray irrigation, broccoli production can significantly reduce water waste and achieve precise irrigation. Moreover, by integrating water and fertilizer technology, irrigation systems can simultaneously supply the water and nutrients required for plant growth, further enhancing resource utilization efficiency and minimizing environmental pollution from over-fertilization.

In terms of by-product utilization, green circular production models emphasize the comprehensive use of waste and by-products generated during broccoli production. For instance, broccoli stalks can be converted into organic fertilizers or animal feed through biodegradation technology, reintegrating into the agricultural production system and forming a closed-loop cycle. This not only reduces environmental pollution from waste but also improves resource utilization efficiency and lowers production costs. Furthermore, by introducing clean energy technologies such as solar energy and biomass energy, green circular production models can further reduce carbon emissions in agricultural production, achieving low-carbon cultivation of broccoli.

By constructing green circular production models, the production process of broccoli can realize a sustainable development path characterized by efficiency, ecology, and circularity. This model not only aligns with modern agricultural environmental requirements but also provides technological and conceptual support for the long-term development of agriculture, promoting the green upgrading of the broccoli industry and enhancing its market competitiveness.

Conclusion

This study analyzes the current state of broccoli cultivation and industrial development, proposing an integrated innovation plan for broccoli cultivation technology. This plan includes the optimization of key techniques such as seedling raising, transplanting, pest and disease control, and nutrient management, as well as innovative pathways for production models. The research indicates that by integrating modern agricultural technologies and smart agricultural methods, it is possible to effectively enhance broccoli yield and quality, reduce resource waste, and improve production efficiency. The implementation of precision planting models based on smart agriculture and green circular production models offers new approaches for the sustainable development of the broccoli industry. Future research directions should focus on further optimizing information management systems to enhance the technical level of precision planting, while also increasing the promotion of green production models to facilitate the ecological and efficient development of the broccoli industry.

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