


Current situation and future outlook of production, processing and marketing in the celery industry

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Abstract

China is the largest vegetable-producing country in the world, with annual production accounting for more than 50% of the total world production. Celery is a major leafy vegetable and has rich nutritional and medicinal values. In recent years, celery production has been steadily developing in all parts of China under the environment of good operation of the overall vegetable industry market. Many concentrated and contiguous large-scale celery production areas are spread in both north and south of China. However, the current celery industry still needs improvement in the creation of an intensive production system, prevention of premature bolting, prevention and control of pests and diseases, development of deep processing products, marketing, brand protection, and other aspects. In the future, with the improvement of cultivation technology, the intensification of production is expected to be further improved. At the same time, it is necessary to solve the problems in celery production through the cooperation between scientific research institutions and production enterprises, to promote the rapid development of the celery industry.

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Introduction

Vegetables are one of the essential foods in people's daily diet as they can provide necessary nutrients for the human body including multiple vitamins and minerals^[1,2]. China is the largest vegetable-producing country in the world^[3]. According to the official statistics of the Food and Agriculture Organization of the United Nations (FAO: www.fao.org/faostat/zh/#data/QCL), the vegetable harvested area in 2022 was 2.35×10^7 hm² in China which accounted for 40.42% of the world. The average yield reached 2.63×10^5 hg/ha, contributing more than 50% of the world's production. Vegetables produced in China are exported all over the world and the exports value reached 15.50 billion US dollars in 2018. Vegetable industry occupies 10% of the agricultural land and contributes nearly 40% of the output value of the crop industry^[4–6]. As an important aspect of rural characteristic industries, the vegetable industry is an important approach to building characteristic industries and increasing farmers' income in many regions of China. According to estimates, vegetable production contributes nearly 274.35 US dollars to the per capita annual income of farmers in China, accounting for more than 10%. The vegetable industry has become one of the pillar industries of the agricultural and rural economy in China, plays an irreplaceable and vital role in the development of rural economies, employment of urban and rural labor force, and the balance of international agricultural trade^[7–9].

Celery (*Apium graveolens* L.) is a kind of vegetable crop with the same origin as medicine and food, which is rich in vitamins, carotenoid, protein, cellulose, and other nutrients, and has been widely cultivated around the world^[1,10–12]. Celery contains a variety of pharmacologically active substances and is a good source of flavonoids, volatile oil, and antioxidants with high medicinal value, which is widely used in the food and pharmaceutical industries^[13–15]. According to the data published in 'Socioeconomic Data and Applications Center (SEDAC)' (<https://sedac.ciesin.columbia.edu>), the celery planting area in 1989 was 9.70×10^4 hm² in China, accounting for 1.5% of the total vegetable planting area at that time and the total production was 3.81×10^6 t. By 2003, the planting area of celery increased to 5.43×10^5 hm² and the total production reached 1.80×10^7 t. In the following 10 years, the planting area of celery has been stable at about 5.50×10^5 hm², accounting for about 3% of the total vegetable planting area, and the total production of celery was about 2.5×10^7 t, ranking first in the world. In 2021, the export quantity of fresh and refrigerated celery in China was 2.42×10^4 t with a year-on-year growth of 2.6%. The exports amounted to 21.88 million US dollars with a year-on-year growth of 25.3%. At present, celery has become one of the main protected cultivated vegetables in China and is one of the major vegetables consumed by Chinese residents. In 2021, celery was listed as one of the 'top ten excellent germplasm resources' by the Ministry of Agriculture and Rural Affairs of

People's Republic of China (www.moa.gov.cn/xw/shipin/202111/t20211124_6382868.htm). Several celery cultivars led by 'Majiagou celery' have been listed as 'Protected Geographical Indication Products' in China^[16]. Therefore, the production of celery plays a very important role in vegetable production in China^[17]. This review mainly introduced the current situation of celery production, processing and marketing of celery, and looked forward to the future of celery industry, intending to provide new prospects for celery production.

Current status of celery production

Celery has a long cultivation history and a wide production area in China. At present, celery is grown in almost all provinces of China, there are more than 20 provinces with over 10,000 hm² planting area. In recent years, with the overall market of the Chinese vegetable industry running well, celery production has been developing steadily country wide. The celery planting area and output yield also show good development trends. Henan, Shandong, Jiangsu, Guangdong, Guangxi, Chongqing and Hebei provinces are the main planting areas, and there are many large-scale celery-producing areas in the north and south of China^[17].

Production and cultivation methods of celery

According to different cultivation facilities, the production and cultivation methods of celery can be divided into open-field cultivation and protected cultivation. Open field cultivation can be arranged in spring, summer, and autumn, mostly in spring and autumn. The facilities used in the cultivation of celery in protected areas include windbreak, cold frame, low tunnel, plastic greenhouses, improved medium tunnel, and solar greenhouses. Among them, the most used are plastic greenhouses and solar greenhouses^[18,19].

At present, the cultivation of celery mainly adopts the way of sowing and raising seedlings first and then field planting, which saves seeds and is convenient for seedling management. If properly dense planting, celery can grow into medium seedlings for harvesting and marketing generally at 60~70 d after planting, it takes longer for overwinter production. In recent years, this method has also been adopted in planting western celery cultivars in many areas, which greatly shortens the production cycle, makes cultivation easier, significantly reduces the use of pesticides, improves commodity quality and increases planting income. Therefore, it has been rapidly popularized and evolved into a new celery planting method^[17,20].

Open field cultivation

Open field cultivation is a traditional celery cultivation method, which is simple to operate at low cost, but it is greatly restricted by the region and season. At present, in addition to the southern region with better temperature conditions, many northern regions also carry out large-scale seasonal celery open-field production. For example, the Bashang plateau of Hebei province has made full use of its unique climatic conditions in recent years to plant open-field celery and harvest in July and August. It can fill the off-season market supply in Beijing, Shanghai, Guangzhou, and other regions^[19,21].

Plastic tunnel cultivation

Plastic tunnel cultivation mainly uses different specifications and sizes of plastic tunnels for celery production. It has many advantages including heat preservation, rain prevention, wind

protection, lower investment, and higher efficiency. Solar greenhouse cultivation has risen in recent years because of its low cost, good efficiency, simple technology, production and quality assurance, and it is increasingly common in the northern region. In Huanghuadian Town, Wuqing district, Tianjin province, winter celery cultivation has been realized in most of the solar greenhouses, whose products could be sold at a high price around the time of the Spring Festival^[19,20,22,23].

Gradual construction of an efficient whole industrial chain

Considering the fact that the planting and processing management level of celery is still relatively backward, the popularization ratio of simple and efficient cultivation technology systems is low, the degree of intensification and mechanization is not high. On the whole, a complete and effective planting, storage, and processing system has not been well formed. The phenomenon of celery concentrated on the market still exists in individual places, the price fluctuates greatly, and the loss rate during the process of picking, storage and transportation is high. There are differences in the production quality level of celery across China. For example, celery produced in some areas remains excessive pesticide residues and cannot be entered into domestic supermarkets or exported in large quantities. The celery produced in some areas is of good quality. Having said that the post-production technology such as grading and packaging is backward, which affects the grade and level of the products. Some celery planting areas are difficult to gain profit because the scale of intensive production is insufficient^[24–27]. The low informatization degree of the celery industry chain affects the sustainable development of the celery industry. The selection of excellent cultivars of celery, the creation of simple, safe and efficient production technology systems, the improvement of the mechanization level, the coordination and connection of preservation processing, the storage logistics and other technical innovation and integrated application of the celery industry chain need to be popularized^[28,29].

Prevention and control of premature bolting

Celery cultivation is more suitable for cool environments. Influenced by environmental conditions and its own genetic factors, it is susceptible to premature bolting in winter and spring cultivation, which leads to the quality decline. Premature bolting means that after celery seedlings grow 2~3 true leaves, flower buds form under the influence of low temperature in a certain stage and bolted under high temperature and long sunshine. Premature bolting will affect the growth of celery petioles, resulting in lower petiole yield, increased crude fiber content, reduced edible quality, and economic benefits. Premature bolting of celery generally occurs in celery planted in the overwintering period and spring, and the flower bud differentiation must be carried out. In the following three conditions, celery may occur premature bolting: first, the seedling must grow to a certain size, generally 2~3 true leaves; second, low temperature (below 10 °C); third, the low temperature should last for a certain time (about 10 d). Celery planted in spring has differentiated flower buds due to seedling cultivation at low temperatures, and grows in spring or early summer after planting. At this time, the temperature is high and the sunshine duration is long, so premature bolting is more likely to occur^[30–32].

To avoid premature bolting of celery, it is necessary to conduct good cultivation management. Particular attention should be paid to sowing and harvesting on time to avoid the influence of weather, and also to manage the temperature in the planting environment. Celery planted in protected areas during the overwintering period should be sown from early August to early September, and the harvest should be completed before late March to early April, to avoid sowing too late and growing too short. Celery planted in a protected area during spring should be sown from late January to early March and the best time to sow celery in open fields is in early April when it is sunny. Greenhouse seedlings need to cover the cold frame in advance and sowing should be carried out after the ground temperature of 10 °C in the cold frame reaches more than 10 °C. In the winter and spring seedling periods, attention should be paid to heat preservation. Low temperatures below 8 °C should be avoided at the seedling stage, the night temperature should be above 12 °C, and the daytime temperature should be 15~20 °C to prevent the seedlings from passing the vernalization stage. The harm of premature bolting can also be reduced by regular splitting of leaves. When celery grows to 70~80 cm high, split 1~3 outer leaves at a time, leaving 2~3 mature leaves. In the whole harvest period, each celery can split leaves 3~5 times and finally dig the whole plant at one time^[31,32].

Prevention and control of pests and diseases

With the expansion of the celery planting area and the increase of stubble numbers, root rot, and other diseases and insect pests caused by repeated cropping are increasingly serious. The limitation of climate conditions and abnormal changes of natural climate during installation cultivation aggravates the occurrence degree of diseases and insect pests. On the other hand, the safety control of vegetable production is more and more strict, and the requirements of disease and pest control measures are more and more standardized. These factors make the difficulty of celery disease and pest control significantly increased. The following factors have led to the susceptibility of diseases and pests: the lack of relevant planting techniques by agricultural workers, the use of celery cultivars with weak disease resistance in celery cultivation, the lack of seed treatment before planting, the lack of timely application of insecticides and fungicides before planting, poor planting management, close planting, irregular improvement and cleaning of soil and fields, and unreasonable fertilization and topdressing^[33,34].

The main control measures for celery diseases and insect pests include agricultural control, physical control, and chemical control. At present, most celery diseases and pests can only be effectively prevented and controlled by chemical methods. Using insecticides and fungicides using spraying, powder spraying and smoking is the common chemical control method. As of July 2020, 166 pesticides had been registered on celery, including 99 insecticides, 33 fungicides, and 34 plant growth regulators, in addition, 87 pesticides have been registered on leafy vegetables. A total of 33 kinds of active ingredients were registered in the registered pesticide products, 82.2% of which were registered before 2014.^[35] The active ingredients of most pesticides have been used for years, and pests have developed resistance to some pesticide products, resulting in ineffective control effects. At present, there is no

effective pesticide for control of leaf miners registered on celery. Farmers have limited available pesticides when diseases or pests occur, and it is difficult to realize drug rotation. Therefore, in the actual production of celery, the phenomenon of out-of-range drug use is common, which further increases the difficulty of prevention and control of pests and diseases, and the demand for antagonistic celery cultivars is also imminent^[36].

Processing products of celery

Celery has beneficial effects on a range of metabolic syndromes^[37]. Studies have shown that celery is a major source of natural antioxidants such as phenolic acids, flavonoids, flavanols, vitamin C, β -carotene and manganese, which are natural plant compounds that can reduce the activity of proinflammatory cytokines and thus prevent the occurrence of inflammation^[13–15]. Apigenin and other flavonoids are important pharmacological active substances in celery, which have the functions of reducing blood lipid, anti-diabetes, anti-hypertensive, and anti-cancer^[38–40]. Celery contains γ -terpinene, d-limonene, 2-hexenal, (E)- β -myrcene and other volatiles, and shows a unique aroma^[41]. The prospect of celery edible product development is broad. For example, probiotic-fermented celery juice can prevent obesity, intestinal disorders, and obesity-related metabolic disorders caused by high fat diet and can regulate gut microbiome, the volatile oil components in celery seeds have pharmacological effects such as reducing blood pressure, diuresis, increasing appetite and strengthening stomach^[42–44].

According to the degree of processing, celery products can be divided into fresh vegetable products and deep processing products. Vegetables are mainly sold fresh. Deep processing products include celery dumplings, celery juice, celery tea, celery fruit cake, celery cookie, canned celery, pickled celery, dried celery, etc^[45–48]. At present, due to the low processing technology of celery, the market is still dominated by the sale of primary agricultural products, and the products sold have less added value. It is the general trend to develop the processing technology of celery products and extend the industrial chain.

Marketing of celery

Celery sales channels are relatively limited and the traditional sales methods are still dominant. This kind of slow and outdated traditional sales method is not conducive to the further development of high-quality celery cultivars with local characteristics. The network is a necessary condition for the development of e-commerce. Rural areas are the production centers of agricultural products, and the creation of the network of agricultural products is crucial for the development of agricultural products e-commerce. The development of e-commerce of agricultural products is conducive to broadening sales channels, strengthening the brand publicity of agricultural products, and improving the popularity of agricultural trademarks. At the same time, producers have the opportunity to reveal the historical and cultural connotation of local celery cultivars through different agricultural trademark information dissemination methods, so as to guide consumers to establish brand preferences of agricultural brands, and pay attention to

the cultural connotation of agricultural products brands and gradually cultivate brand loyalty^[47,49–52].

The sustainable development of the celery market requires the joint maintenance of manufacturers, sellers, consumers, local authorities, and so on. Counterfeiting is prominent in the market and brand protection is not strong. Currently, many celery manufacturers put the names of celery cultivars with local characteristics on the celery labels in the market to get greater benefits. It has affected the reputation of local specialty cultivars and reduced the loyalty of established brands. There is a necessity for relevant enterprises, sellers, and consumers to give full play to their indispensable role in product quality feedback, label use, and reports on fake and inferior products. Local authorities must attach importance to the cultivation and management of trademarks and formulate methods for trademark recognition. Manufacturers should distinguish packages according to the quality level of celery, coordinate packaging styles, colors, and patterns, and provide anti-counterfeiting marks^[49,50,53].

Future outlook of the celery industry

Establishment and optimization of energy-saving, high efficiency and simplified cultivation system

Celery production has the characteristics of simple cultivation, easy management, concentrated harvesting period, and low labor cost, so it is very suitable for intensive production and management. In recent years, some major celery-producing areas have carried out the promotion of the intensive production of celery, and many professional cooperatives or associations have emerged, which makes the production, circulation, and sales of celery coordinate with each other. The profit distribution is more guaranteed and more reasonable, and the advantages of intensive production and management gradually emerge. The intensive production of celery is conducive to the rapid promotion of new cultivars and technology, the relatively stable sale price of celery products, and the higher economic income of producers^[17,24,27]. It can be predicted that the intensive production level of celery will be further improved in China.

Strengthen the cooperation between scientific research institutions and production enterprises

It is important that celery scientific research is oriented towards production and in line with the celery industry. Researchers need to pay more attention to the development of celery industry and layout in advance, to provide help for celery genetic breeding through scientific research and innovation. At present, a celery germplasm resource nursery with a wide range of cultivars has been established in Suqian, Jiangsu Province by Suqian Research Institute of Nanjing Agricultural University (Fig. 1). In the future, scientific research institutions will speed up the creation of celery germplasm resources, strengthen the mining, protection, and utilization of celery excellent breeding materials, carry out the improvement and creation of celery breeding materials, and form the diversification, pluralism and differentiation of celery breeding characteristics. Scientific research work should be guided by market demand, focusing on the shortcomings in celery production, green and healthy food and simplified cultivation technology, and integrating enterprises for production service. Researchers need to make extensive use of the new technology of modern



Fig. 1 Celery germplasm resource nursery in Suqian Research Institute of Nanjing Agricultural University (Facility Horticulture Research Institute of Suqian), Nanjing, China.

celery breeding, combined with genome database and big data analysis to improve the accuracy of celery breeding goals, so as to build a celery genetic breeding research innovation platform, improve the celery genetic breeding research innovation ability.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Tan GF, Xiong AS; data collection: Liu PZ, Wang YH; data curation: Wang YH; formal analysis: Wang LX, Li MY; writing - original draft: Liu PZ; writing - review & editing: Liu H, Shu S, Xiong AS; supervision: Tan GF, Xiong AS. All authors reviewed the results and approved the final version of the manuscript.

Data availability

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

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Conflict of interest

The authors declare that they have no conflict of interest.

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