

Research Progress on Ginger Germplasm Resources

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Abstract In this paper, the characteristics of ginger germplasm resources and the progress of breeding techniques are reviewed. Systematic breeding is still the mainstream method, and multiple excellent varieties such as the Yujiang series have been developed. The virus-free seedlings and tube ginger induction technology effectively solve the problem of seed degeneration. ⁶⁰Co-γ ray mutagenesis and colchicine induction provide important means for germplasm innovation. Currently, there is a shortage of drought resistant and disease resistant varieties, and the application of molecular breeding is lagging behind. In the future, efforts should be made to strengthen the screening of stress resistant germplasm, promote the application of molecular marker assisted breeding and gene editing technology in the genetic improvement of ginger, and provide technological support for the breeding of specialized varieties.

Key words Ginger, Germplasm resources, Breeding technology, Virus-free seedling, Mutation breeding

0 Introduction

Zingiber officinale Roscoe is a perennial herbaceous plant of *Zingiber*, *Zingiberaceae*. It is a typical medicinal and edible crop, and is widely used in traditional medicine, food processing, and seasoning fields. Traditional medicine believes that ginger has the effects of relieving external coldness, warming the spleen and stomach, stopping vomiting, resolving phlegm, and stopping cough^[1]. Its medicinal value has been systematically recorded in ancient Chinese literature. In the *Treatise on Cold Damage Disorders*, ginger is used as an adjunctive medicine, which can work together with *Ramulus Cinnamomi* and *Ephedrae Herba* to relieve muscle and dispel wind cold^[2]. The *Records of Famous Physicians* clearly states that ginger can "eliminate wind evil, harmonize cold and heat, nasal congestion, and stop vomiting"^[3]. The *Analects* also has a description of its consumption that "ginger cannot be removed from the dining table, but it should be eaten in moderation". Ginger can be consumed fresh or processed into ginger tea, ginger soup, and other products, with both nutritional and health benefits.

In recent years, multiple advances have been made in ginger breeding research. Through gene sequencing and genetic analysis, researchers have preliminarily analyzed the genomic characteristics of ginger^[4] and located a number of key genes and genetic loci that regulate important agronomic traits^[5], laying the foundation for revealing the molecular mechanisms of trait formation.

Breeding technology is the core means to increase ginger yield, improve quality, and enhance stress resistance. Ginger is an asexual reproductive crop, and its genetic characteristics can be effectively improved through screening of excellent parents and targeted breeding. At the same time, in-depth research on the growth and development laws of ginger can also provide scientific

basis for its standardized cultivation and management.

1 Industry characteristics

1.1 Rich variety resources and wide planting areas The cultivation history of ginger in China has lasted for more than two thousand years, and the rich and diverse natural conditions have nurtured over a hundred excellent local varieties such as Shandong ginger^[6], Sichuan Zhugen ginger^[7], Anhui Tongling white ginger^[8], Longhui tiger claw ginger^[9], and Taiwan fat ginger. These local varieties have been formed through long-term cultivation, domestication, and artificial breeding, with significant differences in traits. Their diversification has also promoted the development of cultivation modes from open field and plastic film covering to facility cultivation such as small and medium-sized arch sheds and large arch sheds^[10].

The main production areas of ginger in China include Shandong Province in the north, as well as provinces in the south such as Sichuan, Guangxi, Fujian, and Hunan^[11]. According to the survey data of the national characteristic vegetable industry technology system, the ginger planting area in Shandong Province is about 70 000 ha, accounting for more than 30% of the total area in China; the annual output is about 4 million t, accounting for 45% of the total national output, and the industrial scale ranks first in China^[12].

1.2 Medicinal and edible spice vegetable, and efficient industries for rural revitalization Ginger is a global cash crop with the value of seasoning, vegetable, medicine and essence oil extraction, and is planted in more than 50 countries and regions. It is not only a characteristic and efficient industry under the rural revitalization strategy, but also a pillar industry in some production areas. Ginger has a medicinal history of over three thousand years, hundreds of years earlier than the *Shennong's Classic of Materia Medica*^[13]. Traditional medicine believes that it has the functions of warming yang for dispelling cold, resolving surface and dispelling coldness, and promoting blood circulation, which can alleviate the discomfort caused by wind-cold common cold. On

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the edible level, ginger can be eaten fresh, cooked for seasoning, or processed into products such as candied fruits and sauces.

1.3 Long product value chain and significant trade fluctuations

The entire ginger industry chain covers planting, harvesting and storage, utilization of active substances, and development of health products. The value chain covers multiple links such as agricultural production, distribution and sales, and deep processing, all of which jointly affect product quality and market competitiveness^[14].

China's ginger trade fluctuates greatly, mainly due to production fluctuations, disorderly competition in the industry, and human factors^[15]. With the development of modern food industry and advanced processing technology, health and leisure products such as ginger tea, ginger jerky, and ginger juice drinks have been launched one after another^[10, 16]. In the international market, there is a strong demand for ginger in Asia, North America, and Europe, and the diversification of export markets helps to enhance the international competitiveness of ginger industry in China^[17].

2 Breeding technology

2.1 Systematic selection and breeding Ginger cultivars are difficult to flower and bear fruit, and the cultivation of high-quality varieties has been mainly based on clonal breeding for a long time. Among them, systematic breeding based on natural variation of field populations is the most mature and effective technical path^[18–19]. The technical process of this method is to collect local germplasm resources from multiple sources, conduct comprehensive identification of target traits such as yield, quality, and stress resistance, screen excellent strains based on breeding objectives, verify trait stability through years of multi-point regional experiments, finally select qualified varieties and promote their application^[18–19].

At present, multiple excellent main varieties have been selected and bred through this method in China. Jinchang ginger has been continuously screened and bred for 5 years, with stable heritability and strong disease resistance, and its yield increased by 25.6% compared to Changyi ginger^[20]. Fujian "Golden Ginger" has been selected and bred from individual plants for many years, with a yield increase of 22% compared to the local control, and it has both high quality and disease resistance characteristics^[21]. "Xiaolin Huangjiang No. 1" has high resistance to ginger blast disease and moderate resistance to ginger white star disease, with a growth period of about 209 d, and an increase in yield of 41.4%–51.7% compared to the control variety^[22]. The Yujiang series varieties (Yujiang No. 1-4) selected by Chongqing University of Arts and Sciences have shown good high yield and disease resistance, with Yujiang No. 1 increasing yield by 16.33% compared to Zhugen ginger^[23–26].

2.1.1 Cultivation of virus-free seedlings. The research on the cultivation technology of virus-free ginger seedlings in China began in 2002. After more than 20 years of development, a relatively mature technical system has been formed in detoxification technology, rapid

propagation, nutrient regulation, and ploidy mutagenesis^[27–30].

Long-term asexual reproduction of ginger can easily lead to species degeneration, and the plant can accumulate pathogens such as *Ralstonia solanacearum*, *Pythium myriotylum*, cucumber mosaic virus (CMV), tobacco mosaic virus (TMV), etc., causing various soil borne diseases. In severe cases, it can reduce production by 30% to 80%, which is a key bottleneck restricting industrial development^[28, 31]. The cultivation technology of virus-free seedlings based on plant tissue culture can effectively remove pathogens and viruses, restore variety and quality, significantly improve yield and quality, and reduce the application of chemical pesticides, which is the core technical approach for green production of ginger^[28, 31]. At present, the virus-free derivative varieties have been applied in production, such as "Changjiang No. 1", which is a tetraploid variety selected from the somaclonal variants in the virus-free plants of Wuling yellow ginger, and has multiple resistances such as resistance to ginger blast disease, aphid mites, and drought^[32].

2.1.2 Tube ginger induction technology. The tube ginger induction technology is based on virus-free tissue culture seedlings, and induces the formation of micro rhizomes by regulating environmental and nutritional conditions, which can effectively shorten the breeding cycle of high-quality ginger varieties. Relevant research has been gradually carried out since 2002.

Sucrose is the core regulatory factor for induction of tuber ginger. Existing studies have shown that sucrose concentrations ranging from 8% to 10% (80–110 g/L) have the best induction effect^[33–35]. In terms of hormone regulation, 6-BA has an inhibitory effect on the formation of tuber ginger, while NAA and PP333 can synergistically promote induction. The optimal medium formula is MS + 1.0 mg/L of NAA + 0.2 mg/L of PP333 + 8% sucrose^[33–34]. The induction effect of gibberellin (GA) on rhizomes is superior to KT and NAA^[35]. Research on light quality regulation shows that green and red light can significantly promote the height growth of test tube seedlings, blue light can increase the reproductive coefficient, and yellow light has a weaker effect on growth^[36].

2.2 Physical mutagenesis breeding ⁶⁰Co-γ radiation mutagenesis breeding is one of the core technologies for cultivating new varieties of ginger. The conventional process is to use the main variety as the mutagenesis material, conduct trait identification and screening in the M₁ and M₂ generations after treatment, and comprehensively evaluate indicators such as yield, quality, disease resistance, and stress resistance through multiple generations of breeding and multi-point experiments. Finally, a stable strain that meets the target is selected and promoted for application^[18].

Existing research has clarified the dose effect and application value of ginger irradiation: low-dose irradiation can be used for storage and preservation. Wang Shoujing *et al.*^[37] found that doses of 150 and 250 Gy can inhibit ginger germination and improve storage and preservation rates, but can cause excessive loss of vitamin C and increase reducing sugar content in the early stages of

storage. Ren Qingsheng *et al.* [38] confirmed that 25–40 Gy of irradiation can effectively inhibit the germination of ginger during storage. At the molecular level, irradiation treatment can induce heritable variations in ginger rhizomes [39]. There are significant differences in the sensitivity of different varieties to γ rays. The critical radiation dose for the shoots and rhizomes of Laiwu ginger is 25 Gy, while that of Jinchang ginger is lower than 25 Gy [40]. In breeding practice, the variation range of the VM2 generation population after irradiation is relatively large, and some mutant strains in the VM2 generation exhibit trait degradation. However, after multiple generations of targeted selection, a high-quality and stable new ginger variety "Fuyu No. 1" has been successfully bred [41–42].

2.3 Chemical mutagenesis breeding Colchicine is the most commonly used agent for inducing chromosome doubling and creating tetraploid germplasm in ginger. The existing research has systematically optimized the technical parameters of *in vitro* induction: using 0.20% of colchicine liquid culture medium for 8 d resulted in the best effect, with mutation rate and survival rate reaching 42.86% and 70%, respectively [43]; adding 30 mg/L of colchicine to the culture medium for 5 d resulted in a mutation rate of up to 65%; when treated with 0.1% of colchicine through injection, soaking, and embedding methods, the mutation rates were 27.5%, 22.5%, and 47.5%, respectively [44]. Wang Xingcui *et al.* [45] further clarified the suitable range of concentration and treatment time: when the concentration of colchicine is 0.034%–0.187% and the treatment time is 4.91–15.62 d, the survival rate of adventitious shoot regeneration plants from ginger test tube seedlings can reach over 80%.

3 Research prospects for breeding technology

3.1 Cultivation of stress resistant superior varieties

3.1.1 Drought resistance. Frequent extreme drought often leads to reduced or even cease production of ginger, which has become a core abiotic stress that restricts the stable development of the industry. It is the fundamental way to alleviate the threat of drought, ensure production stability and planting efficiency, and boost farmers' confidence in planting by cultivating drought resistant varieties. Subsequent research requires the systematic collection of drought resistant germplasm resources (including wild germplasm and resistant local varieties). Combined with indoor physiological identification and field drought stress experiments, resistance performance is comprehensively evaluated, in order to provide material basis for drought resistant variety breeding.

3.1.2 Disease resistance. It is the most economical and environmentally friendly strategy for crop disease prevention and control by breeding and promoting disease resistant varieties. In the future, it is necessary to focus on cultivating new varieties with strong disease resistance, stable traits, and both high-quality and high-yield characteristics, in order to minimize the impact of diseases on ginger production and ensure the economic benefits of growers.

3.2 Development of intelligent breeding technology Molecular marker assisted breeding is based on the linkage relationship between molecular markers and target trait genes, and achieves trait targeted selection through marker detection. It has the advantages of fast and accurate selection, and is not affected by environmental conditions. It can reduce the large-scale phenotype screening of hybrid offspring, and achieve early selection of low heritability and difficult to determine traits by combining traditional breeding with molecular marker technology, thereby shortening the breeding cycle, improving selection accuracy, and reducing costs [46]. Meanwhile, the integrated analysis of large-scale genotype and phenotype data can uncover new functional genes and genetic loci, providing theoretical support for analyzing species genetic backgrounds and optimizing breeding objectives. The team from Chongqing University of Arts and Sciences has applied molecular marker technology to ginger genomics and phylogenetic analysis [47]. With the development of gene sequencing, functional genomics research, and high-throughput SNP typing technology, the application prospects of this technology in ginger breeding will be even broader.

4 Conclusions

Overall, there are still several key technological bottlenecks in the current field of ginger breeding: the genetic transformation system is not perfect, breakthroughs have not been made in sexual reproduction research, and the analysis of key functional genes for stress resistance and quality regulation is relatively lagging behind. But with the continuous advancement of related research, ginger breeding technology is expected to achieve important breakthroughs and gradually reduce dependence on foreign germplasm resources. By applying cutting-edge breeding techniques to create excellent new germplasm with independent intellectual property rights and carrying out industrial applications, the germplasm demand for ginger production in China can be effectively met. Future research needs to focus on two main directions: first, improving the molecular marker assisted breeding technology system; second, deepening the application research of directed genome selection and gene editing breeding.

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