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Technical Bottlenecks and Innovative Development Recommendations for Rubber Tree Breeding in China: Postprint

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Abstract

Superior rubber tree varieties constitute the core element for ensuring stable production and supply security of natural rubber. China's rubber cultivation zones are situated on the northern margin of the tropics, constituting non-traditional rubber cultivation areas where climatic conditions are less favorable than those in traditional Southeast Asian rubber cultivation regions. Consequently, planted rubber trees frequently suffer from low-temperature cold damage and diseases, creating an urgent demand for high-yield, stress-resistant varieties in production. The primary causes for the paucity of high-yield, stress-resistant rubber tree varieties include: the highly heterozygous genome, prolonged juvenile phase, and cross-pollination characteristics of rubber trees, which hinder the pyramiding of high-yield and stress-resistance traits; and the low efficiency of selection methods in rubber tree breeding, characterized by small hybrid segregation populations and dependence on long-term field evaluation. Recommendations: apply the concept of whole-genome selection breeding, expeditiously establish high-generation seed orchards for rubber trees to achieve multi-trait pyramiding; establish dedicated technical support positions to continuously expand breeding population scale, and create an efficient rubber tree breeding technology system.

Full Text

Preamble

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Abstract

Superior varieties of rubber trees are crucial elements in achieving stable production and supply of natural rubber. In China, rubber tree planting areas are situated at the northern edge of the world's tropical zone and thus belong to non-traditional rubber tree planting areas with climatic conditions inferior to the traditional ones in Southeast Asia. The planted rubber trees are frequently damaged by low temperatures and diseases. Therefore, an urgent need in natural rubber production is to develop varieties with high-yield potential and strong stress-tolerance. The scarcity of such varieties is mainly ascribed to the highly heterozygous genome, a long juvenile period, and highly cross-pollination, making it difficult to integrate high-yielding traits and stress-tolerant traits. Furthermore, breeding selection efficiency is quite low, mainly due to the small size of hybrid segregant populations and long-term field work in the identification and selection of superior varieties. To address these challenges, it is recommended to apply the concept of genomic selection breeding to establish an efficient rubber tree breeding technology system. This can be achieved by establishing a high-generation rubber tree seed orchard to continuously expand the breeding population size and realize multi-trait integration. By doing so, new and improved varieties of rubber trees can be developed with high-yield potential and strong stress-tolerance, ensuring stable production and supply of natural rubber in non-traditional planting areas like China.

Keywords: rubber tree cultivars with high-yield potential and stress-tolerance, genomic selection breeding, high-generation seed orchard, breeding population size

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1 The Lack of High-Yield Stress-Resistant Varieties is a Major Bottleneck for China's Natural Rubber Industry Development

During the Korean War period in the 1950s, imperialist countries led by the United States imposed a comprehensive economic blockade and material embargo on China, which included natural rubber. Natural rubber is a strategic material, alongside steel, coal, and petroleum, as the four major industrial raw materials. Since 98% of natural rubber used worldwide comes from the rubber tree (*Hevea brasiliensis* Muell. Arg.), to solve the "bottleneck" problem of natural rubber supply, under the leadership of the Party Central Committee, senior scientists and various forces worked together to breed a batch of rubber tree varieties adapted to China's non-traditional rubber planting areas, and successfully established large-scale rubber plantations in China's high-latitude regions. This

created a miracle in the history of global rubber cultivation, achieving basic self-sufficiency and supply security of natural rubber in China, and providing rich genetic resources for subsequent breeding of stress-resistant high-yield varieties.

With the rapid development of China's automobile industry and international trade, the demand for natural rubber has continued to increase. In 2022, China's annual consumption of natural rubber approached 6 million tons, accounting for 42% of global natural rubber production[1]. However, China's natural rubber production in 2022 was only 850,000 tons, with a self-sufficiency rate of less than 15%, far below the 30% international supply security line[2]. Against the backdrop of the current unprecedented global changes in a century, the international trade environment for natural rubber is unstable and supply risks are increasing. To ensure the security of natural rubber supply and promote the high-quality development of the natural rubber industry, China urgently needs to innovate rubber tree breeding technologies, improve breeding efficiency, and cultivate new superior varieties with independent intellectual property rights that are suitable for different ecological zones in China's tropical regions, with high yield and multiple resistances, thereby increasing the yield per unit area of natural rubber and enhancing China's natural rubber supply capacity.

1.1 China's Natural Rubber Supply-Demand Contradiction is Increasingly Prominent, with Extremely Low Self-Sufficiency Rate

China has designated natural rubber production protection zones covering an area of 1.2 million hectares (18 million mu). In 2022, the tapping area in China's rubber planting regions was approximately 790,000 hectares (11.85 million mu). Based on an annual production of 850,000 tons of natural rubber, the average yield per unit area in China is approximately 1,076 kg/ha (72 kg/mu). Due to the long economic lifespan of rubber trees and extremely slow variety replacement, the main varieties currently planted in China's rubber cultivation areas are still old introduced varieties, with only a small proportion of new varieties. In Yunnan's rubber planting areas, the main varieties are three old introduced varieties (GT1, RRIM600, and PR107) and two independently bred and promoted new varieties (Yunyan 77-2 and Yunyan 77-4). In Hainan's rubber planting areas, the main varieties are two old introduced varieties (RRIM600 and PR107) and one subsequently promoted new variety (Reyan 73397)[3].

1.2 There is Still Great Potential to Improve Natural Rubber Yield per Unit Area Through Variety Improvement

The yield of rubber trees is formed under tapping conditions. Unlike the "autonomously controllable" yields of grain, cotton, oil, and fruit crops, rubber yield is affected not only by natural environmental factors such as biotic and abiotic stresses, but also by factors such as tappers' skills, tapping systems, and market prices[4,5]. For example, before the reform of the state farm economic system, in first-generation rubber plantations of Category I rubber planting areas in Yunnan and Hainan, these old varieties achieved large-area dry rubber yields

exceeding 1,500 kg/ha (100 kg/mu), demonstrating that strict implementation of technical regulations for “management, maintenance, and tapping” can ensure rubber tree production and achieve high yields per unit area[5].

Like other economic crops, variety improvement remains the fundamental approach to increasing yield per unit area in production protection zones. Rubber tree domestication is still in its early stages, with few hybrid generations, and the genome heterozygosity of cultivated varieties is close to that of wild species[6]. Moreover, high-yield and stress-resistance traits have not been aggregated, leaving further potential for yield improvement. For example, trial planting at Yunnan Mengding Farm (Category I rubber planting area) showed that the new high-yield variety Reyan 8-79 achieved an average dry rubber yield of 7.1 kg/tree and 2,461.5 kg/ha (164.1 kg/mu) in its 4th tapping year. The earlier developed new variety Yunyan 77-4 yielded 2.1 kg/tree and 709.5 kg/ha (47.3 kg/mu), while the control old introduced variety GT1 yielded 1.8 kg/tree and 591 kg/ha (39.4 kg/mu)[7]. These results indicate that under specific planting conditions and management, Reyan 8-79’s average yield per tree and per unit area were approximately 3.4 times and 3.5 times those of Yunyan 77-4, and 3.9 times and 4.2 times those of GT1, respectively, demonstrating significant potential for improving yield per unit area through variety improvement. However, selection for yield traits still relies on long-term field yield measurement, while cold resistance traits are still evaluated using cold gradient sentinel nurseries. These methods not only consume substantial manpower, financial resources, and land, but also suffer from small selection scale and low efficiency, particularly in obtaining hybrid offspring that effectively combine high-yield and stress-resistance traits. Recently, researchers from the French Agricultural Research Centre for International Development (CIRAD) have begun studying the accuracy of genomic selection technology for predicting latex yield traits in rubber trees, but the results have been unsatisfactory due to the lack of scientific dissection of yield component traits[9].

2 Problems in Traditional Rubber Tree Breeding

2.1 Traditional Rubber Tree Breeding Has a Long Cycle and Low Efficiency, and Current Methods Cannot Effectively Combine High-Yield and Stress-Resistance Traits

After germplasm creation, rubber tree breeding undergoes nursery seedling comparison selection, field clone comparison selection, and regional adaptability evaluation, resulting in an extremely long selection cycle. Before 2018, China’s rubber tree breeding program consisted of: (1) nursery seedling comparison selection, starting trial tapping in the 3rd year after planting for 2 years, tapping 2 months per year and 15 taps per month; (2) field primary clone comparison selection, with 3 plots of 5 trees each, continuous tapping and yield measurement for 5 years after 8 years of planting; (3) field advanced clone comparison selection, with 3 plots of 50 trees each, continuous tapping and yield measurement for 5 years after 8 years of planting; and (4) regional adaptability evaluation, in

2 ecological zones with 2 test sites each, 3 plots of 100 trees per site, continuous tapping and yield measurement for 5 years after 8 years of planting. Consequently, the total breeding cycle from pollination to variety selection was 43 years, including a 30-year selection cycle and 13 years for regional adaptability evaluation[8].

In 2018, the technical regulations for this breeding program were revised[8], mainly in two aspects: (1) shortening the selection cycle by replacing the 13-year field primary clone comparison with a “small-scale clone comparison” similar to seedling comparison, reducing the selection time by 9 years; and (2) selecting target traits separately, conducting trials for high-yield and stress-resistance traits independently. However, selection for yield traits still relies on long-term field yield measurement, while cold resistance traits are still evaluated using cold gradient sentinel nurseries. These methods not only consume substantial manpower, financial resources, and land, but also suffer from small selection scale and low efficiency, particularly in obtaining hybrid offspring that effectively combine high-yield and stress-resistance traits. Recently, researchers from CIRAD have begun studying the accuracy of genomic selection technology for predicting latex yield traits in rubber trees, but the results have been unsatisfactory due to the lack of scientific dissection of yield component traits[9].

Rubber trees possess biological characteristics including a highly heterozygous genome, long juvenile period, cross-pollination, asynchronous flowering periods, self-incompatibility, and low seed set, which are unfavorable for achieving multi-trait integration breeding goals using traditional breeding or molecular design breeding methods. (1) Traditional breeding methods: These biological characteristics mean that aggregating superior allelic variations into a single individual requires constructing large-scale hybrid segregating populations and conducting extensive phenotypic identification work including trial tapping and yield measurement[10,11]. Natural rubber yield in rubber trees is formed under tapping conditions, featuring continuous harvesting and cumulative yield calculation, making yield component traits difficult to dissect. Yield measurement data are susceptible to environmental and human factors, resulting in low accuracy. Therefore, dissecting yield component traits and establishing corresponding evaluation techniques are urgent technical challenges to overcome. (2) Molecular design breeding methods: The biological characteristics of rubber trees make it impossible to construct recombinant inbred lines, and mining quantitative trait loci is extremely difficult, representing an international challenge in molecular breeding[6]. Even when mutants with extreme phenotypes are generated through mutagenesis breeding, it is difficult to locate the mutated genes[6,11,12]. Meanwhile, the most potentially applicable molecular modules are unknown, making molecular design breeding currently unfeasible. Therefore, for the time being, natural or artificial hybridization remains the important means for aggregating stress-resistance and high-yield traits in rubber trees. Innovating large-scale selection methods for rubber tree germplasm is a crucial scientific and technological problem that needs to be solved.

2.2 The Utilization of Rubber Tree Germplasm Resources in China Needs to be Strengthened

The rubber tree is native to the Amazon River basin in South America. China's existing rubber tree germplasm resources mainly include three categories: Wickham germplasm, pre-1981 non-Wickham germplasm, and 1981 IRRDB wild germplasm. Wickham germplasm originates from the 46 surviving seedlings that Henry Wickham collected from the Amazon River basin in 1876, shipped via London's Kew Garden to Sri Lanka, Indonesia, Malaysia, and Singapore. These germplasm and their hybrid offspring belong to Wickham germplasm, including commercially cultivated varieties such as PR107, GT1, RRIM600, Yunyan 77-4, and Reyan 73397[13]. The National Rubber Tree Germplasm Repository in Danzhou, Hainan, established in 1983, preserves approximately 6,000 accessions of *Hevea* germplasm, while the Jinghong Rubber Tree Germplasm Repository in Xishuangbanna, Yunnan, established in 2006 under the Ministry of Agriculture, preserves approximately 3,000 accessions[13-15]. Most germplasm in both repositories consists of 1981 IRRDB wild germplasm, mostly maintained in limited areas as propagation nurseries. Currently, both Wickham germplasm and 1981 IRRDB wild germplasm lack precise evaluation of yield and stress-resistance traits, severely restricting innovative utilization of these resources. It is necessary to strengthen genetic 基础研究 on trait-related genetics, dissect yield, cold resistance, and disease resistance component traits and establish corresponding evaluation techniques, construct universal and efficient somatic embryo regeneration and plant genetic transformation systems, identify key genes and signal transduction networks regulating superior trait expression, break through key core technologies for directional introduction of wild germplasm genetic resources, and thereby enrich and improve the genetic diversity of rubber tree varieties to provide superior genetic sources for germplasm creation.

3 Recommendations for Innovative Development of Rubber Tree Breeding in China

Compared with breeding technologies for staple crops such as rice and maize, rubber tree breeding technology development lags far behind, with modern science and technology barely entering the field of rubber tree breeding. This insufficient scientific and technological support seriously constrains the high-quality development of China's natural rubber industry. Traditional breeding methods often focus on hybridization and selection among high-yield varieties, lacking experimental designs for high-generation breeding and integrated breeding, leaving China's rubber tree industry facing the problem that "high-yield varieties are not cold-resistant, and cold-resistant varieties are not high-yield." Small-scale hybrid breeding methods, combined with insufficient investment and poor platforms, constrain the development of rubber tree breeding technology and make it difficult to ensure high-quality development of China's natural rubber industry. Currently, China has bred a batch of rubber tree varieties

with superior single traits, such as the high-yield variety Reyan 8-79 and the cold-resistant variety 93114, and has screened a batch of candidate germplasm showing disease resistance characteristics in rubber tree germplasm repositories[13-16]. Research institutions such as the Chinese Academy of Sciences have determined whole-genome sequences for some rubber tree germplasm[6,11,12], obtaining large amounts of genetic diversity data and plant trait data that provide foundational conditions for dissecting the genetic basis of superior phenotypes and identifying key genes, and can effectively support the research and development of rubber tree genomic selection breeding technology and high-generation integrated breeding.

3.1 Innovate Rubber Tree Breeding Selection Methods Based on the Concept of Genomic Selection

Conventional rubber tree breeding relies on continuous multi-year yield measurement work, resulting in low selection efficiency. Genomic selection breeding technology is a transformative technology for shortening the rubber tree breeding selection cycle. By establishing relationships between genome-wide genetic markers and traits related to rubber production, stress resistance, and disease resistance, it enables early genotype-based selection at the seedling stage. That is, using seedling genomic selection combined with nursery seedling comparison identification to replace traditional phenotypic selection methods of field primary clone comparison and field advanced clone comparison in mature trees, it is expected to shorten the rubber tree breeding selection cycle from 30 years (old breeding technical regulations) or 21 years (new breeding technical regulations) to 4 years. Based on this, three key areas of work should be emphasized:

- (1) Based on created and screened varieties with superior performance in single traits, aim for multi-trait integrated breeding and improving effective tapping tree numbers, increase investment in rubber tree breeding platforms and basic research. Further collect superior rubber tree germplasm resources and evaluate superior traits. Make full use of rubber tree varieties/germplasm with superior single traits, especially those producing high-quality natural rubber, to construct high-generation rubber tree seed orchards. Based on big data such as genomics and phenomics, combined with artificial intelligence deep learning models and other methods, develop genomic selection breeding technology and continuously optimize the genomic selection breeding technology platform, shorten trait selection cycles and expand selection scale, mine genetic markers regulating traits related to rubber production, cold resistance, and disease resistance, and achieve early genotype selection for rubber tree traits.
- (2) Relying on genetic engineering methods such as gene editing and overexpression genetic transformation, enhance the number of totipotent cells in rubber trees through artificial modification of genetic elements and synthetic genetic pathways, thereby using multiple methods for large-scale creation of new germplasm, while updating the reference population and

database of the genomic selection technology platform to accelerate the breeding of stress-resistant high-yield varieties. On the basis of overcoming trait selection bottlenecks, further break through basic research bottlenecks in functional verification of key rubber tree genes, dissect the genetic basis of superior traits such as stress resistance and identify key genes, and through technological innovation dissect key regulatory factors and signal pathways for high-quality rubber synthesis to accelerate the breeding of superior rubber tree varieties with stress-resistant, high-yield, and high-quality traits.

- (3) Strengthen research on new technologies such as early selection, integrated breeding, mutagenesis breeding, ploidy breeding, cell engineering breeding, molecular marker-assisted breeding, and transgenic breeding in rubber trees to construct a modern rubber tree breeding technology system. Combined with actual production conditions in China's rubber planting areas, further explore genetic molecular elements related to high yield and stress resistance, identify molecular modules with breeding value, and expand the scale of germplasm creation and breeding populations for selection.

3.2 Enhance High-Generation Rubber Tree Breeding

Natural rubber yield depends not only on the latex yield of individual rubber trees, but more importantly on the number of effective tapping trees in rubber plantations. Rubber tree germplasm resources are the gene pool for screening and breeding rubber tree varieties and the basic material for improving effective tapping tree numbers and creating stress-resistant high-yield new varieties. It is recommended to set improving effective tapping tree numbers as an important goal for rubber tree breeding technology development in the new era, focusing on two main aspects:

- (1) For collected rubber tree germplasm resources, systematically conduct identification and evaluation of traits such as tapping tolerance, cold resistance, and disease resistance based on previous surveys, and further conduct identification and evaluation of natural rubber yield component traits such as bark laticifer differentiation capacity and effective laticifer maintenance capacity, dissecting their genetic basis. On this foundation, use broader rubber tree germplasm resources to conduct high-generation breeding, create rubber tree primary seed orchards and high-generation seed orchards based on polycross mating designs, broaden the genetic background to improve effective tapping tree numbers, further comprehensively dissect natural rubber yield component traits and key regulatory factors, and achieve integrated breeding of stress-resistance and high-yield traits.
- (2) Use candidate superior germplasm obtained through traditional hybridization or genetic engineering to supplement or update parental trees in rubber tree high-generation seed orchards. On the basis of overcoming trait selection bottlenecks, further break through basic research bottlenecks in

functional verification of key rubber tree genes, dissect the genetic basis of superior traits such as stress resistance and identify key genes, and through technological innovation dissect key regulatory factors and signal pathways for high-quality rubber synthesis to accelerate the breeding of superior rubber tree varieties with stress-resistant, high-yield, and high-quality traits.

3.3 Establish a Standardized High-Throughput Phenotyping Platform for Rubber Trees

Every hybrid combination of high-yield and high-resistance germplasm may produce rubber tree germplasm with high yield and multiple resistances, but too small a selection scale may result in missing superior germplasm. Therefore, it is recommended to establish professional technical support positions to continuously expand the breeding population scale for genomic selection and accelerate the breeding of high-yield multi-resistant rubber tree varieties. It is suggested to use quantitative remote sensing from hyperspectral and high spatiotemporal resolution drones, combined with automatic phenology instruments and spore traps, to develop high-throughput phenotyping acquisition technology, reduce the workload and manual identification errors in evaluating traits related to rubber production and stress resistance, construct a standardized high-throughput phenotyping platform for rubber trees, and achieve rapid identification of rubber tree traits such as rubber production and stress resistance. Within the framework of genomic selection breeding technology, based on superior germplasm created through traditional hybridization and genetic engineering methods, integrate high-generation breeding and standardized high-throughput phenotyping technology to create a high-throughput integrated breeding technology system for rubber trees from experimental fields to laboratories and then to rubber planting areas.

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Footnotes:

State Council Guidance on Establishing Functional Zones for Grain Production and Protected Areas for Important Agricultural Products. (2017-04-10)[2023-12-18]. http://www.gov.cn/zhengce/content/2017-04/10/content_{5184613}.htm.

Rubber planting areas can be divided into three categories based on climate. Category I rubber planting areas refer to regions with an annual average temperature above 21°C, annual precipitation exceeding 1,200 mm, at least 9 months with monthly average temperature not lower than 18°C, average wind speed less than 2.0 m/s, and no more than 7 years from planting to tapping standard;

and where the lowest temperature in cold weather over the past 50 years is not lower than 0°C, average temperature not lower than 10°C, and rainy weather not exceeding 20 days.

First-generation rubber plantations refer to plantations formed by the first planting of rubber trees on land that has not previously been used for rubber cultivation. After replanting, subsequent plantations are called second-generation rubber plantations.

Dry rubber, also known as natural raw rubber or raw rubber, is the main primary product of natural rubber.

The 4th tapping year refers to the 4th year of the rubber tree's tapping period.

In 1981, member countries of the International Rubber Research and Development Board (IRRDB) collected wild rubber tree germplasm from the Amazon River basin.

Note: Figure translations are in progress. See original paper for figures.

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