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REVIEW

Advances and prospects of super rice breeding in China

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Abstract

Super rice breeding in China has been very successful over the past 3 decades, and the Chinese government has made great efforts to support breeding and cultivation of both conventional and hybrid super rice. In this review, we focus on the progress in and potential of super rice breeding. After the establishment of the breeding theory and strategy of "generating an ideotype with strong heterosis through inter-subspecies hybridization, by using gene pyramiding to combine elite traits through composite-crossing to breed super rice varieties with both ideotype and strong hybrid vigor", a series of major breakthroughs have been achieved in both conventional and super hybrid rice breeding. A number of new genetic materials with ideotype have been created successfully, and the Ministry of Agriculture of China has approved 156 novel super rice varieties and combinations for commercialization. During the Developing the Super Rice Varieties Program, great attention has also been paid to the integration and demonstration of the rice production technology. Collaboration between industry and university researchers has led to technological innovations and initiation of a demonstration system for super hybrid rice. With widespread cultivation of super rice with higher quality and yield, as well as resistance or tolerance to abiotic or biotic stresses, the yield of rice production per unit has reached a new level. In addition to increased quality and yield, hybrid rice breeding has also led to improvements in many other agronomic traits, such as resistance to pests and diseases, resistance to lodging, and optimized light distribution in population. Achievements in super rice breeding and innovation in rice production have made major contributions to the progress in rice sciences and worldwide food security.

Keywords: super rice, super hybrid rice, ideotype, heterosis, breeding

Food security issues are the top priority for China's national economy and people's livelihood. Maintaining grain self-sufficiency in China has become harder as the population grows and arable land shrinks, so the pressure on food security is increasingly severe. A medium- and long-term development plan for national food security (2008–2020) suggested that China needs to produce additional 50 million tons of crop grains to meet the food supply for the increasing population by 2020. Rice is a dietary staple for more than half of China's population, so improving rice production is crucial for ensuring food security in China. In general, there are two ways to increase the grain output of rice: expanding planting areas and increasing grain yield per unit area. However, expanding the planting area for rice in China is unlikely, due to water restrictions and strong competition from corn. Therefore, the only way to increase rice production is to improve productivity of varieties in rice paddies through scientific and technological innovations. Historical experi-

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ence has shown that development of genetic resources in rice breeding is an effective way to increase the production potential of certain rice varieties. These genetic resources can be then used, in combination with development of new technologies, to improve rice yields. In the past, breeding of dwarf varieties and hybrid rice led to increased yields. In the 1980s, a concept of varieties with very high yield, called super rice, was proposed as a new breeding objective. Thirty years of breeding and studies in super rice has resulted in successful development of new germplasm resources, new varieties, and improved cultivation techniques. These significant breakthroughs have made contributions to both national food security in China and progress of rice science.

1. History of the super rice

Super rice is rice bred for super-high yield. In 1981, the Ministry of Agriculture, Forestry and Fisheries of Japan launched large-scale collaborative research projects to develop super-high-yield rice, along with improvement of cultivation techniques. This plan focused on breeding high yield varieties, and establishing a system of cultivation techniques to maximize potential of super-high-yield varieties. Over 15 years, implementation of the plan led to release of some super-high-yield varieties that produced 10 t of brown rice per hectare, an increase by 50% compared to the control variety Akihikari. By the late 1980s, the grain yield of some varieties, such as Chenxing, Aoyu 326, and Beilu 130, was close to 10 t ha^{-1}, but those super-high-yield varieties were not widely grown by farmers due to low seed setting rate, poor quality, and limited adaptability (Higashi 1987; Xu *et al*. 1990).

In 1989, the International Rice Research Institute (IRRI) launched a plan to breed for the new plant type (NPT) rice, with a goal of increasing yield by 20% compared to the existing high-yield varieties, or producing 13–15 t of grains per hectare. In 1994, at the Consultative Group on International Agricultural Research (CGIAR) meeting, IRRI announced that its NPT rice reached the yield of 12.5 t ha^{-1}, a 20% increase compared to the control variety. However, the NPT rice had a low rate of seed setting, poor grain filling, and weak resistance against brown planthopper. These unfavorable traits restricted widespread cultivation of the NPT rice. IRRI endeavored to improve those disadvantages, but failed to make substantial progress. Since the development of the NPT rice, the news media have repeatedly used the name super rice to report achievements in breeding this type of rice. Over years, the term of super rice has gradually become popular in super-high-yield rice breeding, and nowadays it is adopted widely in all kinds of news media (Chen *et al*. 2001).

In 1951, Prof. Yang Shouren's research group in Shenyang Agricultural University conducted inter-subspecies crossing between *indica* rice (Natehao) and *japonica* rice (Jiali). Since then, a series of inter-subspecies combinations were bred. In 1960, varieties named Liangyong 2 and Liangyong 3 were released successfully. In summarizing his breeding practices, Prof. Yang Shouren published the research papers that reported application of inter-subspecies hybrids for rice breeding (Yang and Zhao 1959; Yang *et al*. 1962; Yang 1987). In the 1970s, Prof. Yang Shouren's research group realized the importance of plant type in determining grain yield and introduced this trait into inter-subspecies hybrids (Yang 1977). And in the mid-1980s, the theories for breeding super-high-yield rice were gradually formed and the methods were developed. In 1987, Prof. Yang Shouren published a paper that discribed the theory of super rice breeding (Yang 1987). The theory, first developed by Shenyang Agricultural University Rice Research Institute (SAURRI), involved creating diversity by making inter-subspecies hybridization or crosses between geographically distant germplasms, and selecting the ideotype among individuals derived from multiple crosses and backcrosses to synthesize favorable genes and optimize trait balance (Chen *et al*. 1995; Yang *et al*. 1996). Between 1986 and 1995, super high yield rice breeding was included in the China National Key Science and Technology Projects.

In April of 1996, the Chinese State Council approved a proposal to conduct studies on super rice. In June of that year, a conference hosted by the Science and Technology Division of the Ministry of Agriculture of China was held at Shenyang Agricultural University. During the meeting, researchers decided to start a Super Rice Research Program in China. In October of 1996, the Ministry of Agriculture of China released the Dawn of the New Century Agricultural Program (China Super Rice Breeding-history, Current Situation and Development). This document further clarified the technology needed and the approach for breeding super rice, including super conventional rice and super hybrid rice. This project was implemented in three phases, and was designed to achieve 10.5, 12, and 13.5 t ha^{-1} in 2000, 2005, and 2010, respectively. By the end of 1997, Prof. Yuan Longping (China National Hybrid Rice Research and Development Centre) published a manuscript on "High-Yield Breeding for Super Hybrid Rice" and submitted this research to Premier Zhu Rongji in July, 1998 (Yuan 1977). In October of 1998, the Premier Fund Program Conference on Super Hybrid Rice Breeding was hosted by the Ministry of Agriculture of China in Changsha, which officially launched the project of "Super Hybrid Rice Breeding" that symbolized the start of super high-yield breeding for hybrid rice.

Coming into the 21st century, China's super rice research has bloomed in many aspects; the super rice can be *indica* or *japonica* varieties; the research departments have spread