Sci. Bull. (2015) 60(6):657–660
DOI 10.1007/s11434-015-0755-6

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News & Views

Yuan Longping: hybrid rice is on the way to fulfilling its potential

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Published online: 1 March 2015

2014 was a banner year for Yuan Longping, "the father of hybrid rice", and his team. The yield of "super rice" hit a new record of 1,026.7 kg per mu (about 15.4 t per ha), which represents an earlier than expected achievement of their target of 1,000 kg per mu.

Although born in Beijing, Yuan has lived most of his life in coastal regions along the Yangtze River. He spent a large part of his adolescence in Chongqing and several of his high school years in Wuhan; as an adult, he is resided in Hunan, where he began his pursuit of hybrid rice in the 1960s.

It thus seems natural that Yuan has chosen to focus on rice, a Chinese staple crop commonly planted in the southern part of the country—including the Yangtze River area where water resources are relatively abundant.

Yuan has stressed the importance of choosing the proper direction in scientific research: "For me, hybridizing rice has been the correct pathway. In spite of difficulties and frustrations, I knew that success would knock on my door one day."

Time has proven him correct. Hybrid rice has earned him fame and numerous prizes. From his point of view, however, continuous breakthroughs in hybrid rice breeding are what give him the greatest motivation and satisfaction. And at the age of 84, he has no plans to retire in the near future. "Work makes me happy, and I feel relaxed in the rice field," he said with a smile. "We're 90 % certain to increase rice production to 16 t per ha in 3 years."

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In a recent interview with *Science Bulletin* (*Sci Bull*) at the China National Hybrid Rice Research and Development Center in Changsha, Yuan shared his opinions and his research strategy for hybrid rice, which he hopes will accelerate the worldwide spread of hybrid rice and end hunger.

Getting connected to hybrid rice

Sci Bull Why did you choose to research hybrid rice in the 1960s? We know that you once studied other crops such as sweet potato.

Yuan After graduating from university, I was assigned to teach at an agricultural college in Hunan Province. At first, I spent 2 years studying sweet potato. I gradually realized, however, that rice was the staple food of China, especially in southern China and that the government was more likely to support and fund rice breeding research.

A series of natural disasters and the "Great Leap Forward" then plunged China into a major famine. Food scarcity caused many people to starve to death. During the years of the famine, food was more precious and expensive than gold, and hunger was like a monster, endangering the lives of thousands of people.

That's why I finally decided to switch to the research and development of improved rice breeding. In 1961, I happened to find a natural hybrid rice plant with more plumper grains than ordinary ones. Greatly encouraged, I collected the seeds of this plant, sowed them in the field, and carefully nurtured them until harvest. Unfortunately, the result was disappointing: Few plants had their parents' excellent qualities. As I sat on the ridge of the rice field observing the crop, an idea suddenly came into my mind: Hybrid vigor exists, but pure rice lines cannot show segregation of characters in their offspring.

Since then, I've devoted myself to research on hybrid rice that is aimed to enhance its output based on a simple logical principle: Superior species always have hybrid vigor, rice included.

Sci Bull Was this principle widely accepted in China at the time?

Yuan No. Many experts had doubts about rice hybrid vigor, while others said that rice was a self-pollinating crop and had no hybrid advantage. From 1964 to 1973, we tried to cultivate stable and high-yielding hybrid rice species.

We began by using existing, mutated male sterile rice individuals to create hybrid rice lines, but could not secure 100 % sterility of the propagating material, which is crucial for high output of hybrid rice. To overcome this obstacle, we began to search for a distant hybridization pathway using wild rice to cross-breed with cultivated rice. We eventually found a wild rice species called "Wild Abortive" in 1970 in Hainan. This species served as the foundation of the successful three-line (male sterile line, maintainer line and restorer line) hybrid rice breeding system in 1973. The hybrid rice species yielded 20 % more per unit compared with common ones.

Sci Bull Why do three-line hybrid species have higher yields than common ones?

Yuan This is difficult to explain. Hybrid vigor is a globally common phenomenon: One uses parents with different genetic makeups to construct a hybrid with its unknown internal biological mechanism so far, which enhances its viability and thus generates hybrid vigor. This vigor is what boosts the yields of hybrid rice.

Sci Bull As the Cultural Revolution was also taking place in China during this time, how were you able to continue your research?

Yuan We were able to continue our hybrid rice research thanks to the support of Mr. Hua Guofeng, a top Chinese leader who gave priority to agriculture. The main trial fields were shifted to Hainan and Guangxi, where we could work essentially uninterrupted and thus concentrate on research.

From the three-line to the two-line hybrid rice breeding system

Sci Bull In the 1980s, you proposed a two-line system breeding strategy to replace the three-line system. What were the reasons behind this?

Yuan Although the three-line breeding system improved rice production, it was far from perfect. In the three-line system, the maintainer line acts as an intermediate between male sterile and restorer lines; this means that male sterile lines are first crossed with maintainer lines for propagation and then crossed with restorer lines to produce high-yield hybrid rice seeds.

Limited choices were available for breeding maintainer lines, with only about 5 % of existing rice lines suitable for this role; in addition, breeding through an intermediate was reducing efficiency. Furthermore, the output of three-line hybrid rice had been stagnant for years, since the late 1980s. Given this dilemma, we searched for more efficient, prospective hybridization methods. We felt at the time that the two-line breeding system was the most promising method.

Generally speaking, two types of rice genetic materials are used in the two-line breeding system—photoperiod-sensitive genic male sterile (PGMS) lines and thermo-sensitive genic male sterile (TGMS) lines—that directly exploit inter-subspecific heterosis (*indica*/*japonica* hybrids). A maintainer line is therefore not needed. These MS lines can be used for hybrid seed production directly, with over 96 % of varieties able to restore them. Consequently, the two-line breeding system vastly broadens the range of available choices and increases the chance of breeding advantageous hybrid rice varieties. In 1995, we successfully developed the two-line hybrid rice breeding system.

In 1996, drawing on our accumulated experience with the two-line breeding system, we established a four-phase super rice roadmap using the two-line breeding system and reached yields of 700, 800 and 900 kg per mu (1/15 ha) in 2000, 2004 and 2012, respectively. This year is the fourth phase (Fig. 1).

As early as the 1980s, Japan and the International Rice Research Institute (IRRI) began to research super rice; Japan aimed for 800 kg per mu, while IRRI set a goal of 800–850 kg per mu. Unfortunately, neither of them has yet met their target. Since 2004, China has led the world in hybrid rice production (800 kg per mu).

Sci Bull Is there any disadvantage to the two-line breeding system?

Yuan Yes, of course—the two-line system has weak points, too. For example, the TGMS lines that we used for seed production in Yancheng, Jiangsu Province, failed in 2009: The temperature was abnormally low during the panicle developmental stage, and the male sterile state turned into a male fertile state.

Sci Bull Does this mean that there are some limitations on the two-line breeding system?

Yuan Yes. At present, two-line hybrid rice is mostly planted south of the Yangtze River, in areas below 33°N latitude.

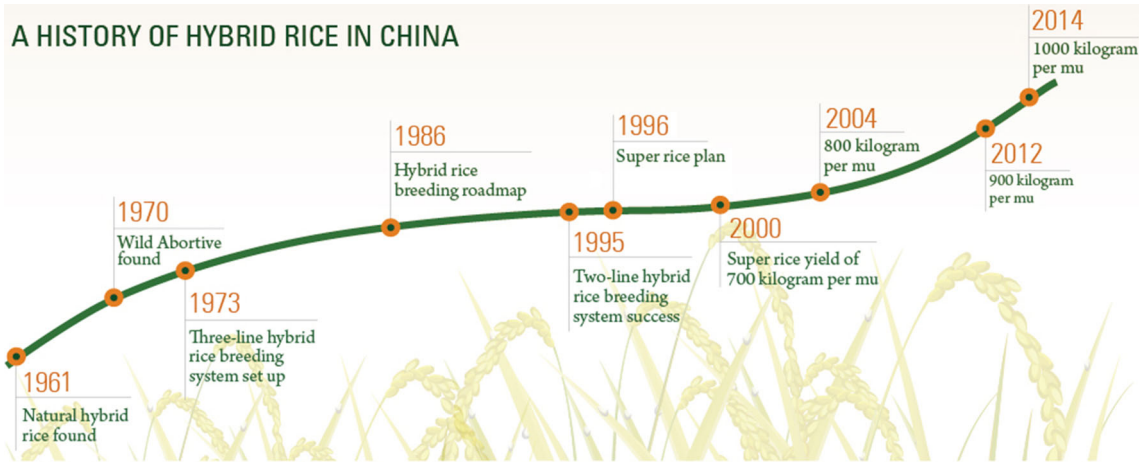

Fig. 1 Hybrid rice breeding research and development supervised by Longping Yuan in China (by Xiaoling Yu)

Sci Bull Is super rice sensitive to latitude and temperature?
Yuan Yes. We're improving the adaptability of super rice. It's important to note that morphological improvement and heterosis utilization are both major factors for yield enhancement. Super rice has a tall, erect-leaved canopy and a larger panicle size, characteristics that facilitate photosynthesis and increased seed production.

Sci Bull What's the upper limit on super rice output?
Yuan Although our super rice output has exceeded 1,000 kg per mu, there's room for improvement. Rice is considered to have a photosynthetic efficiency of about 5 %. If we can boost photosynthetic efficiency to 2.5 % in Hunan, super rice would reach yields of 1,500 kg per mu. This represents a huge potential yet to be fulfilled.

Sci Bull To reach this target, what types of efforts must still be made?
Yuan We're optimizing our breeding system to generate better seeds. In addition to excellent seeds, three other factors are essential for high-yield rice: an appropriate growing method, favorable weather and sufficient irrigation. I call these the "four prerequisites for high yield," much like building a house: Good seeds are the blueprint, appropriate growing methods are the materials and crew, fertile farmlands are the foundation, and favorable weather is the money (Fig. 2).

Dreams still to be fulfilled

Sci Bull In addition to two-line system breeding, you've also mentioned an ambitious plan for hybrid rice breeding development.

Fig. 2 Longping Yuan carefully examining super rice grains in the field (courtesy of Yeyun Xin)

Yuan We began with the three-line system, now use the two-line system, and in the future will exploit a one-line system; in other words, we're progressing from inter-varietal hybrids to inter-subspecific hybrids to distant heterosis. By using yield-enhancing genes from other plant species or genera, the one-line system will have enormous advantages.

Sci Bull Can you detail some of the advantages of the one-line system?
Yuan With respect to the one-line system, the breeding of apomictic lines to fix hybrid vigor—with the assistance of the cutting-edge tools of molecular biotechnology—is currently the most promising path. The reliance on apomixis means that hybrid advantage would pass through seeds, with offspring having the exact same genetic structure as their parents; thus, the onerous breeding process is avoided. Once we obtain good breeding material, the grains can be used for rapid propagation.

Sci Bull That sounds challenging. How would molecular biology techniques help?

Yuan We still use conventional methods for three-line and two-line system breeding of plants (including super rice). One-line breeding involves genes of distant relatives such as Chinese pennisetum, thus requiring molecular-level manipulation and the use of advanced biological technologies. Although scientists around the world are making great efforts to generate one-line hybrid seed, there have been few breakthroughs. We're continuing to explore methods to improve super rice production.

Sci Bull Are you transferring C_4 genes of maize into the rice genome?

Yuan Yes. We're trying to transfer maize C_4 genes to rice, which would greatly enhance rice photosynthetic efficiency. We've pinpointed three of the four genes and transferred them into rice, but no satisfactory results have yet surfaced (Fig. 3).

Sci Bull Gene engineering, especially gene transfer in crops, has sparked widespread controversy in China.

Yuan As I mentioned, future high-yield rice breeding will involve gene transfer from other species. This trend is inevitable, as conventional breeding methods have been almost fully exploited.

I understand the concern of some people regarding genetically modified (GM) crops; however, our country has not issued a single growing permit for commercial GM crops except for cotton and pawpaw. And the approved GM crops in the world themselves are harmless; for example, GM soybeans imported into our country are as safe as traditional soybeans.

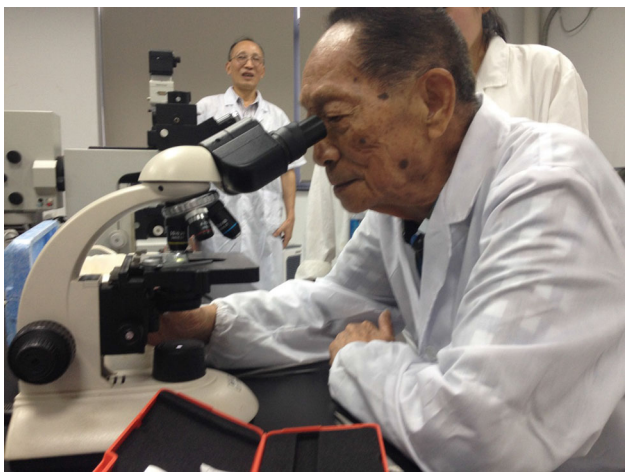

Fig. 3 Longping Yuan observing rice tissues through a microscope and instructing his students in the laboratory (courtesy of Yeyun Xin)

Sci Bull As an agricultural country, China has always put an emphasis on agriculture, rural areas and rural laborers. What's your opinion regarding agricultural development in China?

Yuan This is a complicated question. I think rural laborers in China are always on the lowest rungs of our society and do not have sufficient economic security. About half of the Chinese population consists of rural laborers, which means our agricultural production efficiency is low. When more people become employed in the service industry and fewer people are engaged in agricultural production, China will be a developed country.

In my vision, the ideal agriculture ecosystem will have five characteristics: It will be mechanized, electrified, intelligent and attractive with an educated and well-bred populace. To be more specific, future farmers in China will live a lifestyle as modern as their urban counterparts. Rural areas will be more prosperous and beautiful—like the setting of a poem.

Sci Bull As an agricultural scientist, your concerns go beyond China's food supply and extend to the problem of world hunger. We know that you're looking forward to having more hybrid rice planted in other countries.

Yuan Indeed. There are 2.2 billion mu of rice fields in the world, if the planting area of hybrid rice was expanded to 1.2 billion mu, the rice yields could feed another 400-500 million people.

Because of various policy restrictions, we've not been able to fulfill this dream. Although our hybrid rice has been planted in the USA, it required special approval jointly signed by the Chinese Ministry of Agriculture, the Ministry of Science and Technology and the Ministry of State Security of China.

We actually possess the core techniques and hybrid rice patents, so there's no need to worry about copyright infringement and leaks. I hope our country will become more open and encourage local seed companies to more readily enter the international market.

Acknowledgments The author thanks Dr. Yeyun Xin for constructive suggestions during the writing process of this report.