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NEWS AND VIEWS

From Basic Research to Molecular Breeding — Chinese Scientists Play A Central Role in Boosting World Rice Production

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Abstract On November 18, 2018, the Future Science Prize Awarding Ceremony was held in Beijing. In the area of life science, Professors Jiayang Li, Longping Yuan, and Qifa Zhang shared the prize for their pioneering contributions in producing high-yield, superior-quality rice through systematic study of molecular mechanisms associated with specific rice features and application of novel approaches in rice breeding. The Future Science Prize is also touted as "China's Nobel Prize", fully affirming their achievements in rice basic research and breeding.

The 2018 China's Future Science Prize in Life Science was jointly awarded to Profs. Jiayang Li, Longping Yuan, and Qifa Zhang, in recognition of their groundbreaking discoveries leading to the development of innovative tools for breeding high-yield and superior-quality rice varieties (**Figure 1**). The Future Science Prize is one of China's highly regarded awards established in 2016 (http://futureprize.org/), being touted as the Chinese version of the Nobel Prize.

Rice is the staple food for more than half of the world's population, and in China, over 60% of its 1.4 billion people consume rice on a daily basis. The dramatic increase in population coupled with global climate change, reduced agricultural land, and environmental pollution pose a big challenge for food security in China. As such, increasing rice production is critical to sustain and improve people's livelihood, national economy, and even national security. Over the past six decades, China has made extraordinary accomplishments in boosting its rice production. Rice yield has experienced at least two quantum jumps; the first was brought by dwarf breeding, the so-called "Green Evolution" in the 1960s, and the second came from the introduction of hybrid rice in the 1970s.

The Green Revolution has dramatically increased crop production, thanks to the development of high-yield varieties through deployment of semi-dwarf genes in rice and wheat. The rice semi-dwarf gene *sd1* was first identified from the Chinese rice cultivar named "Dee-geo-woo-gen" and since then has been widely bred into the current rice varieties [1]. Guang-chang-ai is the first of its kind that was developed in China through the introduction of the *sd1* gene [2]. The semi-dwarf varieties accounted for 20%–30% yield increase

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Figure 1 A photo of winners, Science Committee Members, and Donors of the 2018 Future Science Prize in Life Science during the Awarding Ceremony on November 18, 2018, in Beijing

when compared with the conventional ones because of their high harvest index, resistance to lodging, and improved response to fertilizers [3]. Developing rice dwarf varieties has been widely considered as one of the most important achievements in rice breeding history.

Another breakthrough achievement was to harness heterosis by developing and growing hybrid rice. Heterosis or hybrid vigor refers to a situation in which the hybrids perform better than their parents, and this has been exploited to improve crop production for nearly a century [4]. Exploitation and utilization of heterosis in rice was first initiated by Prof. Longping Yuan in the 1960s, and a significant progress was made in 1970 due to the discovery of a cytoplasmic male sterility (CMS) line from wild rice (*Oryza rufipogon*) [5]. Five years later, large-scale hybrid seed production using a three-line system was fully established, making it feasible to commercially produce hybrid rice [6]. Several additional CMS lines were later identified and successively exploited [7], which had greatly expanded the germplasm pool of CMS. The subsequent establishment of the two-line hybrid system broadened the use of hybrid vigor both within and between subspecies, and this technology further increased rice yield by 5%–10% compared to the three-line system [6]. In 1996, the Chinese government launched a nationwide "Super Rice Breeding Program", with an ultimate goal to further boost rice yield through an improved understanding of the theory and practice of hybrid development. In recent field tests, Super Hybrid Rice has set a new world record by reaching an average yield over 1000 kg per mu (about 0.07 ha). The Super Hybrid Rice is characterized by its ideal plant architecture (ideotype) and utilization of the inter-subspecific heterosis [8]. After more than 40 years of application, hybrid rice has become one of the greatest innovations in agriculture, making a massive contribution to food security in both China and the world.

China has been a major player of the rice genome research, contributing to sequencing and resequencing genomes of many cultivated and wild rice varieties [9]. A wealth of genomic data combined with fast-growing biotechnologies greatly facilitated gene discovery and functional analyses. Prof. Jiayang Li and his team successfully cloned *MONOCULM 1* (*MOC1*), a key regulator controlling rice tiller number [9]. Thereafter, Chinese scientists have made great strides in isolating dozens of key genes relevant to important agronomic traits. Examples of such genes include the plant architecture controlling genes (*IPA1* [10], *PROG1* [11], and *D53* [12]), panicle architecture related genes (*DEP1* [13] and *NOG1* [14]), grain size controlling genes (*GS2* [15], *GS3* [16], *GS5* [17], and *GW5* [18]), rice grain quality genes (*Wx* [19], *ALK* [20], and *Badh2* [21]), cold resistance genes (*COLD1* [22], *CTB4a* [23], and *LTG1* [24]), heat tolerance genes (*TT1* [25] and *HTAS* [26]), salt tolerance gene (*SKC1* [27]), drought resistance gene (*DWA1* [28]), disease resistance genes (*STV11* [29], *PIGM* [30], *Bsr-d1* [31], and *Xa4* [32]), insect resistance genes (*Bph3* [33] and *Bph14* [34]), heading date genes (*GHD7* [35] and *GHD8* [36]), nitrogen nutrient efficiency gene (*NRT1.1B* [37]), and photoperiodic sensitive male sterile gene (*PMS3* [38]). Moreover, Chinese scientists have also made significant breakthroughs in elucidating the genetic and molecular mechanisms underlying rice heterosis [39,40], CMS [41], and fertility between *indica* and *japonica* varieties [42,43].

With so many genes mapped or cloned, it is pivotal to design a molecular strategy to breed better rice varieties that require less input and can adapt to various environmental constraints. This is particularly helpful for the smallholder farmers in sub-Saharan Africa and Asia who grow crops under stress conditions but have limited financial resources. For this purpose, Prof. Qifa Zhang, together with researchers from the International Rice Research Institute (IRRI) and Chinese Academy of Agricultural Sciences (CAAS) funded by the Bill and Melinda Gates Foundation, put forward a long-term strategy to develop the so-called Green Super Rice (GSR). GSR is a new strategy for generating high-yield varieties and hybrids that are tolerant to various abiotic stresses such as drought, floods, and salinity, resistant to multiple pests and diseases, and with high nitrogen and phosphorus use efficiency and superior nutritional quality [44]. After ten years of continuous efforts, the GSR program has achieved encouraging progresses. As of March 2018, 75 new GSR varieties have been developed, with total planting area exceeding 6.67 million hectare [45].

Breeding by design aims to bring together favorable alleles of all agronomically important genes into a single genotype [46]. This concept has driven the development of frontier technologies of crop breeding in China [47–49]. As an active advocator and practitioner, Prof. Jiayang Li and his colleagues have developed a series of well-designed lines through the ‘‘breeding by molecular design” approach. Examples of the germplasm include Jiayouzhongke series, Zhongkefa series, and Zhongke804, which possess high yield, superior quality, disease and lodging resistance, and resilience to environmental stresses [50]. Prof. Li's seminal work lays a solid foundation for future rice improvement.

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