Perspective

Strategic Vision for Hybrid Rice

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Life on Earth has been altered to favor mankind under the endeavor of human beings. Hybrid rice is one of the examples that has gone through three generations currently and has two generations likely to come in the near future.

The first generation of hybrid rice is the three-line system that utilizes cytoplasmic male sterility. The research was initiated in 1964, commercial hybrids with yield heterosis were first successfully released in 1973 and extended to more farmlands in 1976 in China. Three-line hybrid rice was topped in 13.5 million hectares (approximately 45% of the total rice planting acreage in China) during the past 40 plus years in China. Up to the current date, three-line hybrid rice still accounts for roughly 50% of the total hybrid rice or about 20% of the entire rice acreage in China. The three-line system has the advantage of male sterility stability, and the disadvantage of a highly restricted restoration and maintaining relationship.

The second generation is based on the two-line system in which thermo- or photoperiod-sensitive genic male sterility is utilized. The major advantage of two-line system is that almost all conventional rice varieties can be used as a restorer. Easier development of thermo- or photoperiod-sensitive genic male sterile lines is another notable advantage of the two-line system. Consequentially, it is easier to develop elite hybrids compared to that of the three-line system. As a result, most commercial super hybrid combinations are two-line hybrid rice. The disadvantage of two-line system is that male sterility/fertility of male sterile lines is affected by the temperature, which is difficult to control. Hybrid seed production often failed when the temperature is below the thresh point. In addition, seed multiplication of male sterile lines is also affected when the temperature is above the thresh point, resulting in lower seed production.

The third generation uses genetically-engineered male sterility. This system possesses the advantages of both the three-line and the two-line systems, resolving the issue of the instability of male sterility/fertility in the two-line system during the hybrid seed production and seed reproduction of male sterile lines, and also overcoming the limitation of mating partner of the three-line system. The genetically-engineered plants produce colored and colorless seeds with each accounting for half of the seeds produced. The colorless seeds are non-transgenic and serve as male sterile plants for hybrid seed production. Therefore, the hybrid rice seeds produced are also non-transgenic. The colored seeds, which are transgenic

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and fertile, are used for seed reproduction, and its self-pollinated progenies will also produce half colored and half colorless seeds. The mixed colored and colorless seeds can be easily separated by a color-based seed sorter. Therefore, both hybrid seed production and seed reproduction of male sterile/fertile lines are very simple, easy, and reliable. The preliminary yield trials suggest that some hybrid combinations with this approach are very promising. One indica-like hybrid, sown on June 17 and transplanted on July 14, 2018 in Changsha, China as a late-season crop in a double-cropping farming system, generated 795 million spikelets/hectare and yielded 15 metric tons/hectare; one japonica-like hybrid grown in one-cropping farming system, produced 870 million spikelets/hectare and yielded 18 metric tons/hectare. Rapid adoption of the third-generation hybrid rice will help ensure food security in China.

The fourth generation will be the development of C_4 hybrid rice. The photosynthetic efficiency of C_4 plants, such as maize and sugarcane, is believed to be 30–50% higher than that of C_3 plants such as rice and wheat [1]. C_4 hybrid rice with high photosynthetic efficiency and stronger heterosis will tremendously increase rice yield potential. The successful development of C_4 rice would likely be given the term of the 2nd green revolution by other experts, but I think it should be called the 3rd green revolution: The 1st green revolution was the success of plant morphological improvement, from tall plants to semi-dwarf plants, which greatly increased the harvest index; the 2nd green revolution was the success of hybrid rice, which utilizes positive heterosis.

The fifth generation will be the development of one-line hybrid rice in which heterosis of F_1 hybrids is fixed through apomixis. Apomixis is seed reproduction without fertilization. The genotype of diploid apomixis does not change from generation to generation. The genetic structure of offspring is identical as that of maternal parents, so the heterosis can be fixed, and non-segregating hybrids can be developed. As long as a highly heterotic hybrid plant is obtained, it can be rapidly deployed for large-scale commercial production by seed propagation. However, it is very difficult to develop obligate apomictic hybrids. With the advancement of molecular breeding technologies such as genome editing, I believe, it will be successful within the next couple of decades.

DISCLAIMER

This paper is translated from Yuan [2], a Chinese paper published in Hybrid Rice journal.

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