Mini Review

Hybrid Rice Technology: An Overview

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Abstract

Hybrid rice is one of the important innovations in agriculture along with the discovery of the semi-dwarf gene as well as the green revolution. Since releasing the first hybrid rice cultivar in China, the production of hybrid rice has grown rapidly in all world rice growing regions. Developing high yield hybrid rice cultivars with acceptable quality depends on the agronomic characteristics of their parents. This review discusses about the importance of the hybrid rice, methods for developing hybrid rice and their parents, and genes/QTLs associated with desirable agronomic traits.

Keywords: Hybrid Rice; Cytoplasmic male sterile; Environmental genic male sterile; Photoperiod genic male sterile; Temperature genic male sterile; Maintainer line; Restorer Line

Abbreviations: CMS: Cytoplasmic Male sterile; EGMS: Environmental Genic Male Sterile; PGMS: Photoperiod Genic Male Sterile; TGMS: Temperature Genic Male Sterile; B: Maintainer line; R: Restorer Line; M: Million; ha: Hectar

Introduction

Hybrid rice has proven to be an effective way to enhance rice production. It is defined as commercially grown rice from F1 seeds resulting from a cross between two genetically diverse parents. The advantages of hybrid rice over conventional rice cultivars include better grain yield (up to 15%) and higher durable resistance to biotic and abiotic factor. These advantages are due to a phenomenon known as heterosis [1]. The first hybrid cultivar, which produced more than 20% yield over the conventional rice cultivars of that time, was released in China in 1974 [2]. Then, the International Rice Research Institute (IRRI) made an effort to improve hybrid cultivars by developing superior hybrid parental lines. As a result, several commercial hybrid cultivars developed by the IRRI were released in India, Vietnam, the Philippines, Bangladesh, and Indonesia. The major hybrid rice producer in the world are as follows: China, 18.6 Million (M)th that is more than 63% total of rice area (TRA), India 1.5Mha (3.3%TRA), Bangladesh 7.35 Mha (6.5% TRA), Vietnam, 6.45 Mha (8.7% TRA), the Philippines, 3.46 Mha (7.8% TRA), Indonesia 6.2M ha (0.4% TRA) ha in USA, 5,000 ha in and 5,000 ha in Myanmar [3].

RiceTec Inc. was granted exclusive access to the hybrid parental lines, including Cytoplasmic Male Sterile (CMS) and Environmental Genic Male sterile (EGMS) lines applied for two-line and three-line systems, respectively, from the Chinese National Hybrid Rice Research Center at Changsha Hunan. In addition, restorer lines were originated from South China INDICA sources that are frequently used as parental lines to develop new restorer lines developed by IRRI. In 2006, RiceTec Inc. developed and released the first hybrid cultivar, XL6, rice for commercial production in the United States. However, XL6 was not successful due to high lodging and poor milling quality. Two years later, RiceTec Inc. released two other hybrid rice cultivars named XL7 and XL8, both of which showed less lodging and better milling quality than XL6 [4]. In 2018, Louisiana State University releases hybrid cultivar, LAH169 that demonstrated a good quality and low chalk [5].

Hybrid Rice Production Systems

Large-scale production of hybrid seeds is made possible via male sterile lines, which are developed to serve as the female parents. Two types of male sterility are utilized for F1 hybrid production in rice: Three-line system and Two-line system 6. The first hybrid rice cultivar released in China was developed via the three-line system 2, 6. This system requires three lines of cytoplasmic male sterile (CMS), maintainer (B), and restorer (R) lines. The CMS line is assigned as the female and the R line is used as the male parent. The sterility in CMS lines is caused by an interaction between genetic factors in the nucleus and mitochondrial genes in the cytoplasm [6].

Several sources of CMS have been identified. However, only 11 CMS sources are used for commercial purposes worldwide, including CMS-WA, CMS-DA, CMP-IP, CMS-DI, CMS- HL, CMS-KR, CMS-BT, CMS-TN, CMS-GAM, CMS-ARC, and CMS. O. perennis 6. These CMS
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so sources were discovered in different rice genotypes from the East and Southeast Asia. In CMS-WA, the cytoplasmic source of sterility was derived from a weedy (O. Sativa f. spontanea) rice with abortive pollen and the nuclear donor was the rice line “Zhen Shan 97”. In CMS-DA, the cytoplasmic source originated from a dwarf plant of O. Sativa f. spontanea, and the nuclear source was donated from the rice line “Xue Qin Zhao”. In CMS-HL, the source of cytoplasmic sterility originated from O. Sativa f. spontanea, and nuclear genes from the rice line “Lian-Tang-Zao”. In CMS-KR, the cytoplasmic source of sterility was derived from wild rice Oryza rufipogon, and nuclear donor was cultivar “Taihung 65”. In CMS-BT, the cytoplasm originated from the rice line “Chinsurah Boro II”, and the nuclear genes were donated from rice line Taichung 65. In CMS-TN, the source of cytoplasmic sterility was derived from rice line “Taichung N1”, and the nuclear genes originated from rice “Pankhari 203”. In CMS-GAM, the source of cytoplasmic sterility originated from “Gambiana”, and the nuclear donor was “Chao Yang 1”. In CMS-ARC, the cytoplasmic sterility was derived from “IRRI ARC1382”, a rice line collected from Assam, India, and the nuclear donor was from the IRRI line IR10179-2-3-1. Finally in O. perennis, the cytoplasmic sterility originated from O. perennis Acc. 104823, and the nuclear donor was “IR64R” [6-8].

The R lines possess a fertility restoration gene known as Rf gene [14]. The interaction between the CMS nuclear gene x Rf gene can be classified into two groups of sporophytic (e.g., CMS-WA) or gametophytic (e.g., CMS-BT) 8, 9. Several Rf genes have been identified however Rf1, Rf3, and Rf4 located on chr.s 10, 1, 7, respectively, are the most commercially used restorer genes for hybrid rice production [10-13].

In the two-line system, pollen sterility is induced by environmental conditions such as photoperiod, temperature, or both, which affect the expression of the sterility gene known as Environment-sensitive genic male sterility (EGMS). The primary advantage of the two-line system is that there is no need for a maintainer line, which is required for F1 seed production in the three-line CMS system. This reduces the time and labor of hybrid production. Another important advantage is that any fertile line can be used as a male parent, which greatly increases the flexibility of producing commercial hybrids [6,14].

The EGMS lines are classified into five categories according to which sterility gene(s) they possess; however, only two of them are used for commercial hybrid production: (A) photoperiod-sensitive genic male sterile (PGMS) in which the sterility happens when daylength exceeds more than 13.75 hours (10) and (B) thermo-sensitive genic male sterile (TGMS) in which the sterility occurs when temperature < 30°C for daytime and < 24°C for nighttime [1].

The first naturally photoperiodic genic male sterile mutant, Nongken58s, was discovered by 1973 in the japonica cultivar “Nongken58”. The source of Nongken58s sterility is in a gene pms3 located in chr. 12, and was detected in a 28.4kb fragment via 15 RADP markers [15-18].

Two photoperiod sterile genes, pms1and pms2 located on chr.s 7and 3, respectively, were identified in 32001, a PGMS line derived from Nongken58s. This study showed that the effect of pms1 is greater than pms2 [19]. Two RFLP markers of RG477–RG511, RZ272, are closely linked to pms1 and four RFLP markers, RG191, RG117, RG450, and RG266, are closely linked pms2, [20]. Liu et al. (2001) constructed a contig map including 7 BAC clones and localized pms1 locus in an 85kb DNA fragment that is flanked between two SSR markers, RG477/RZ77/C67A and R1807 [21]. The pms3 gene was found in two F2 populations of (58S x 1514) and (58S X Lunhui 422). Two RFLP markers, R2708–R2261, are closely linked pms3 gene 16. A study showed that sterility in a sterile line “Mine 9s” is controlled by a recessive PGMS gene, pms4, located on chr.4 [22].

So far, 10 TGMS genes (tms1, tms2, tms3, tms4, tms4, tms5, tms6, tms7, tms8 and tms-h) have been identified. The tms1 gene was detected on chr. 8, and two RAPD markers, OPB-19, RZ562, and RG978 and an SSR marker, RM 239 are linked to the gene [23,24]. The tms2 gene is located on chr.7 and four SSR markers, RM2, RM10, RM11, and RM214 are tightly linked to the gene [25]. The tms3(t) gene was found on chr.6 and four RAPD markers, OPF182600, OPB19750, and OPAA7550, are closely associated with the gene [26]. The tms4 gene was discovered on chr. 2 and four AFLP markers, E2/M5–600, E3/M16–400, E5/M12–600, and E5/M12–200, and one RFLP marker E5/M12–600 are linked to the gene [27]. The Tms 5 gene is found on chr.9 and five SSR marker, RM279, RM492, RM327, RM324, RM257, two AFLP markers, AF10 and AF8, one RAPD marker, RA4, one STS marker, C365-1, and three CAPs marker G227-1 are positionally linked to the gene [28,29]. The tms6(t) gene, detected on chr. 3, was found in a 0A15, a somatic TGMS mutant, and a RAPD marker S187-770, and two SSR markers, RM3152 and RM4455 are closely linked to the gene [30,31]. Finally, the tms8 gene was detected in chr.11, and two SSR markers RM21 and RM 24, are tightly linked to the gene [32].

Breeding Methodology

Commonly, the pedigree-based system is used for the hybrid parental lines. As with the conventional rice breeding program, a single panicle descent, a modification of single seed descent method, is used for development of these lines. Marker assisted selection is used for the identification of desirable plants/progeny. Methods such as single crosses, top-crosses, three-way crosses and backcrosses, test cross, combing ability test can be used for improvement of EGMS, CMS, B, and R lines. Pollen stain is one of the procedures for identification of male sterile plant. In this procedure,
pollens from a floral are collected and observed by microscope. A sterile pollen appears translucent while a fertile pollen has a dark color. Florals can be classified in 5 groups based on their percentage: sterile where the percentage of sterility is >100, sterile (99 to 90%), partial sterile (89-71%) sterile (31-70%), fertile (21-30%), and fully fertile (0-20%) [33-35].

Male Sterile Seed Production

Seed increase from male sterile lines is an important factor in hybrid rice parental line development. In the three-line hybrid production, the CMS seeds are produced by crossing the male sterile parent, which serves as a female parent, with its B line, which serves as is designated as the male parent. The pollen abortion in CMS line is due to an interaction between a sterility factor, known as S, located in the mitochondrial DNA and a homozygous recessive allele (rfrf) in the CMS nucleus. The fertility of the B line, despite continuing recessive restorer allele in their nucleus, is by its normal cytoplasm (lack of the S factor). While a B line has a homozygous rf gene, it has normal mitochondrial, and as a result, the line preserves its fertility, and it can propagate through self-pollination [6].

In the two-line system, the EGMS must meet certain environmental condition to produce seeds. One of the methods of male sterile seed increase is via ratooned selected male sterile plants, where plants are placed in optimum environmental conditions for seed increase (e.g., lower temperature and/or shorter day-length). For mass seed production, seeds from sterile plants are planted in an environment in which the plants meet the desirable photoperiod and/or temperature at their reproductive stage [2,5,36,37].

Hybrid Seed Production

Hybrid seeds are produced when the female parent (male sterile) is crossed with the male (pollen donor) parent. In the three-line hybrid rice production a CMS line is crossed with a restorer line that has normal cytoplasm and homozygous dominant restorer (RrFr) alleles. In the two-line method, there is no need for developing maintainer line and the EGMS line can be crossed with any rice genotype [38].

There are several essential keys for improving hybrid seed production. Synchronization of flowering between male and female parents is an essential key for an efficient cross pollination. Moreover, the panicle and the stigma exertion have the important roles for enhancing seed production. Application of gibberellic acid (GA3) can be beneficial for adjusting flowering dates between the male and the female parent and increase the panicle and the stigma exertion that can significantly increase seed production [39].

Hybrid Rice Seed Quality

Hybrid rice technology is a technical rice production that aim to develop high yield with good cooking and milling quality [40,41] meet the consumer’s expectation. For example, In the U.S. hybrid rice are developed to quality described for “typical southern U.S. cooking quality that is dry and fluffy, long grain, and non-aroma. Therefore, they hybrid rice should have intermediate (21-24%) amylose content and medium gelatinization temperature (70-74oC) (Chatterjee and Das, 2018, Khus et al. 1979). Amylose content shows volume expansion and degree of flakiness, and sickness [42]. Gelatinization determines time requires for cooking the kernels and Despite yield advantage over than conventional rice cultivars, milling quality of hybrid rice cultivars are low due to amount of chalk. Chalk is considered as an undesirable trait that has decrease rice milling quality. It occurs when loosely packed starch granules cause of formation of air spaces between amyloplasts is due to high nighttime temperature [43]. Further studies are needed to address such issue.

Conclusion

Food security will one of the important issues in future. Hybrid rice technology is considered an important method for increasing rice production. Developing high-yield and good-quality hybrid rice cultivars requires extensive efforts to developing superior hybrid parental lines as well as innovating new techniques for increasing hybrid seed production. Identification of genes/QTLs associated with agronomic traits and constructing markers related to the desirable characteristics significantly are essential for modern breeding though marker assisted selection. Hybrid rice technology will continue its important role to increase rice production and provide food security for people in the world.

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Conflict of Interest

The authors declare there is no finical interest, or any conflict of interest exists.

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