Two-Line Hybrid Rice Breeding

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This entry enlightens a deep understanding of the molecular control of MF in EGMS liens and exploring the regulatory driving forces that function efficiently during plant adaptation under a changing environment.

Hybrid rice, EGMS, male fertility, sterility

1. Introduction

Generally, it is a global prediction that the human population will cross 9 billion up to the next decade (www.fao.org). Sustaining food or agriculture production for the rising population is the key challenge and main concern worldwide. Consequently, there is an urgent need to boost food production in an eco-friendly, sustainable, and safe way. Abundant plant species exist around the world, many hundred edible plants are cultivated, out of them only limited species are the main source of food. Rice is also an edible plant species and the staple food cereals for nearly half of the population worldwide, especially in countries that exist in Southeast Asia, East Asia, as well as African regions and is an important driving force to attain sustainable food security (FS) [1]. According to one estimate, only rice production demand will enhance to the 736–852 million tons during 2020–2035. If we examine previous records, the annual rice production increased just 1% while the efforts were carried out during the past two decades[2]. Rice cultivation is feasible in several countries. However, environmental alterations and biotic stress have been the off-putting reason for reaching the targeted high yield. E.g., temperature fluctuations, drought, salinity, soil fertility, pests, microbes, etc., adversely affect rice fertility[3]. Anther development is highly sensitive to the environmental changes during rice flowering, which accordingly poses a serious threat to agriculture by affecting current as well as long-term crop production[3][4][5]. Therefore, crop adaptation requires various changes at the genomic levels and scientists are working consistently to elevate the crop production in major crops and to feed the ever-increasing population[6]. Currently, the availability of the scarce resources and including several environmental constraints, e.g., the emergence of the evolving pests, disease-causing pathogens, and continuously changing environment for farming, is a constant threat to rice cultivation and remain the massive challenge.

2. Development of Hybrid Rice Technologies

Previous reports highlighted that crop production was not substantial to support increasing population around the world, a lot of regions of the world became the victim of uprising hunger, in the 1950s. Progressively, rice breeding technology has advanced via the introduction of semi-dwarf varieties (HYV) that were high yielding[7]. The maize and wheat enhancement programs paved the way toward high yield and improvement against lodging and disease resistance through genetic manipulation of the *semi-dwarf* (*sd-1*) gene among various species. These findings enabled the scientists of the International Rice Research Institute (IRRI) to develop the first semi-dwarf rice that has unique properties such as medium height, lodging resistant, a greater number of panicles and grains leading to high yield. During 1966, there was a more dynamic shift that was attained through the green-revolution by genetic manipulation of the rice IR8 variety. It was harboring the *semi-dwarf* (*sd-1*) gene and is known as the miracle rice, termed as international rice 8 (IR8), and enhanced rice yield[8][9]. This discovery and successful manipulation of the sd1 (the semi-dwarf mutant) gene in crops was the first "green-revolution" that facilitated in hunger eradication in the developing countries[10]. To feed the fast-growing population, crop yield was enhanced effectively in several parts of the world by introducing high yield new cultivars during the past few decades. However, rice production with marvelous effects has been in progress since as early as 1926 by investigating heterosis in rice[11][12]. Though the possibility to adopt hybrid-rice (HR) technology was started the first time in 1966 by Yuan Long-ping, later he was pronounced as the father of HR in China [13]. Being a scientist, global FS is an enormous task for human beings. HR gained popularity due to high yield and great advantages as compared to the inbred cultivar/lines[14]. It has also been evidenced that heterosis exploitation is a common phenomenon in crops and the most effective breeding tool against food scarcity worldwide. HR seed production comprises the crossing among two well defined genetically important inbred parental cultivar/lines (one female line and another male line). HR technology provides a better result to improve yield by producing superior quality containing F1 HR over its pure inbred or dwarf lines [15][16]. It is a practical way to enhance rice production by using F1 hybrids, which provided 20–25% more yield benefit over pure rice breeds [13][17][18]. Over time, the tremendous progress in the form of hybrid-breeding technology greatly benefited agriculture by HR with high yield and better tolerance against stressors (e.g., biotic stresses as the diseases, pests, and pathogen infestation and abiotic stresses as the drought, heat, salt, etc.) as compared to the inbred lines/varieties[4][19][20][21]. Rice is a self-pollinated cereal crop; its male fertility (MF, described as the release of the workable gametes or functional pollens that can fertilize female gametes) control demands the male sterility system to generate HR lines/varieties. Male sterility (MS, defined as the production of nonworkable gametes or nonfunctional pollens that can fecundate female gametes), acts as the central player in MF regulation for hybrid-seed production and provides the incredible germplasm to explore rice reproductive development and harness the influence of hybrid-vigor to gain more seed production, as the key breeding tools [22][23]. Overall, MS is grouped into two types such as cytoplasmic-male-sterile (CMS) and environment-sensitive-genic-male-sterility (EGMS)[22]. After the discovery of the male sterility system and its application in HR technology, that originated in China by using male sterility inducing nuclear and cytoplasmic genes to generate cytoplasmic-male-sterile (CMS) lines and CMS also termed as the three-line HR technology, displayed the innovative step towards HR production (Figure 1a) [22][24][25].

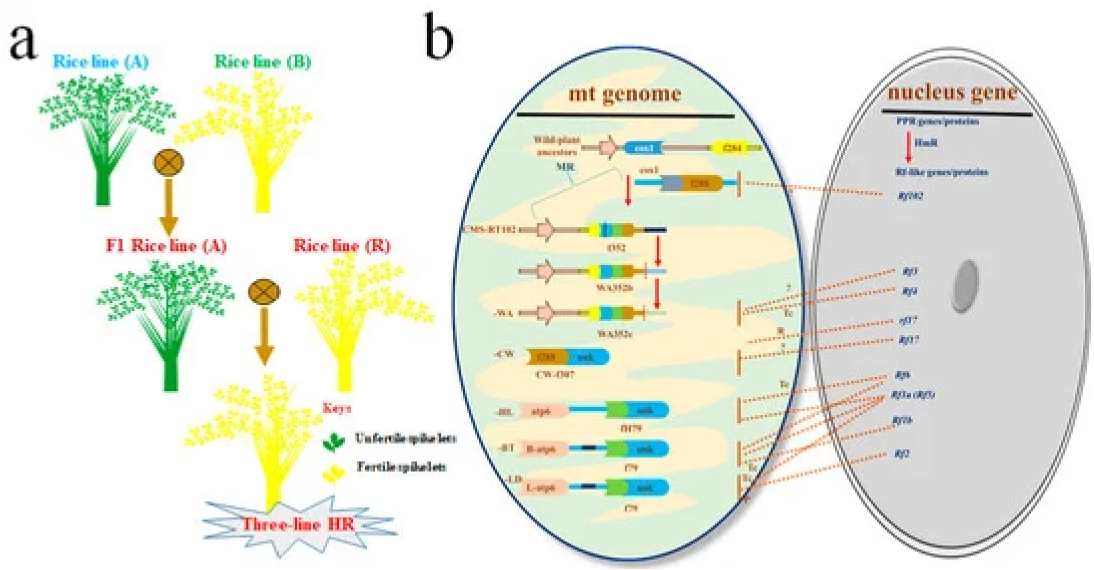

Figure 1. Three-line hybrid-rice technology. (**a**) Three-line HR technology works through three different rice lines, as rice-line A (cytoplasmic-male-sterile line), rice-line B (maintainer line), and rice-line R (restorer line). (**b**) The regulatory factors that can restore rice fertility. Several sequences of the mitochondrial (mt) genome undergo multirecombination (MR) through evolution in rice to generate structural mutations. The flow of sub-stoichiometric due to the variations in copy number of a gene and leading to the emergence of a functional cytoplasmic-male-sterile (CMS) gene. Expanding clusters of the pentatrico-peptide repeat resulted in functional-Rf alleles used for cytoplasmic-male-sterility restoration. The nucleus genes as Rf converse function of CMS gene(s) at transcriptional (Tc) and/or protein (P) levels, but the recessive allele like rf17 is retrogradely (R) upregulated through CMS gene(s). In the figure, MR, HmR, PPR, f284, f288, f352, fH7, f79, -WA, -CW, -HL, -BT, -LD, and unk represent multi-recombination, homologous-recombination, pentatrico-peptide repeat, orf284, orf288, orf352, orfH7, orf79, CMS-WA, CMS-CW, CMS-HL, CMS-BT, CMS-LD, and unknown, respectively.

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