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Hybrid rice: Development, achievement, challenges and prospects

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Introduction:

Hybrid rice technology exploits the phenomenon of hybrid vigor (heterosis) in order to increase the yield potential of rice varieties with reported yield advantage of 15–20% over commercial high-yielding varieties. Although Jones (1926) was first to report existence of hybrid vigour in rice. Hybrid rice technology is one of the most important and practically feasible technologies to enhance the rice productivity. Like other crops, rice is also showing enough heterosis (Siddiq 1997, Singh and Haque 1999, Singh et al. 2013). The hybrid rice research begun by Prof. Yuan Long Ping in 1964 (Yuan 1996). After nine years of hard work, all the three genetic lines for hybrid rice production, i.e. cytoplasmic male-sterile line, maintainer line and restorer line, became available in 1973, resulting in the realization of "three-line system" to produce commercially viable hybrid rice (Hui and Ping 2015). The first hybrid combination was developed with good heterosis and high yield in 1974. In 1975, technology for large-scale hybrid seeds production was completed. One year later, hybrid rice was released for commercial production. Thus, China became first country to put hybrid rice technology to real mass field production. Other countries, specifically Southeast Asia, initiated hybrid rice research in 1980s and have been applying this technology commercially for rice production since two decades. This programme has also been started by India in 1989 (Singh et al. 2015). In India, heterosis was first reported by Ramiah (1935) and Kadam et al. (1937). In 2008, the rice areas covered by hybrid rice in the world were about 20 million hectares, and 3 million of them were in the countries outside China, mainly in Bangladesh, India, Indonesia, Philippines, United States and Vietnam (Xangsayasane et al. 2010). Hybrid rice technology is one of the strongest tools to break the yield barrier. To make hybrid rice technology practically feasible it needs strong system of hybrid seed production at commercial rate.

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Some of the popular hybrids grown in the country are Arize-6444, PHB-71, KRH-2, PRH-10, PA 6129, Saihhadri, Suruchi, JKRH-2000, PAC 837 and DRRH-2. Other rice growing countries have also started hybrid rice research and its cultivation. Because of complicated seed production system, higher seed cost and less preferred qualities of hybrid rice varieties the enhancement in area coverage under hybrid rice in India is rather slow. Hence, proper strategies have to be adopted for research and development to overcome the above limitations to enhance hybrid rice acreage and ultimately to boost the rice production. The attempts have been made in super rice breeding in China and other countries in recent years.

Techniques of Hybrid Rice Seed Production

Since rice is a self pollinated crop, one of the parents to be used as female must be made male sterile through proper technique. The main reason for cultivation of hybrid rice is to obtain better yield followed by higher pricing ability, better taste, higher profitability, suitable for parboiling, better resistance to pests and diseases (Nirmala et al. 2013). Short duration high yielding hybrid rice such as KR15-14 etc. have potential to give maximum grain yield than rest of the varieties. It could be due to the better growth attribute that results in higher grain yield (Ranjitha et al. 2013). The increase in rice yields attributable to hybrid rice has, in turn, improved food security for an estimated 60 million additional people per year (Li et al. 2013). Several types of techniques for making female may be tested and developed for hybrid seed production are below-

Cytoplasmic Genetic Male Sterility (CGMS)

This is also known as three line system i.e. A, B and R line Male sterility is controlled by the interaction of mitochondrial and nuclear gene. A line is male sterile when the male sterility- controlling factor S in the cytoplasm and recessive alleles present in the nucleus. B line is isogenic to the A, but it differs in cytoplasm which makes it self-fertile. Conventional breeding takes more time and space to identify large number of genotypes even then it is still being used to identify the fertility restorer lines to be used for developing new hybrids in rice (Sharma et al.2012). The restorer gene in the form of dominant homozygous or heterozygous restore the fertility in the F1 hybrid. Hybrid seed production involves two steps: Multiplication of A, B and R lines and Production of hybrid seeds. For successful production of the A line, it is grown in six or eight rows interspersed by two rows of a maintainer line in an alternating manner. B and R lines are maintained by selfing.

Environmental sensitive Genetic Male Sterility (EGMS)

This is also known as two line system. First observed in pepper by Martin and Crawford in 1951. In this system, male sterility condition is due to the interaction of nuclear genes with environmental factors such as photoperiod, temperature or both. Hybrid seed production through two line system is simpler if it becomes feasible. Magnitude of heterosis in two-line hybrids is usually 5 to 10% higher than in three line hybrids because of no cytoplasmic penalty. The EGMS is of following type-

Temperature sensitive genetic male sterility (TGMS)

Most TGMS lines remain male sterile at high temperature (day temperature >30 ºC/night >24 ºC) and they revert back to partial fertility at a lower temperature (day <24 ºC/<16 ºC night), for example, 5460S, IR68945, H89-1, and SA2

Reverse temperature sensitive genetic male sterility (RTGMS)

RTGMS lines remain male sterile at low temperature and they revert back to partial fertility at a high temperature. It is reverse of the TGMS system, for example, JP 38, Dianxin 1A, and IVA.

Photoperiod sensitive sensitive genetic male sterility (PGMS)

PGMS lines remain male sterile under long-day (>13.75 h) conditions and revert back to fertility under short-day (<13 h) conditions example, N9044S and N5088S. Male sterility expression in EGMS lines is governed by a single nuclear recessive gene or pair of nuclear recessive genes that are sensitive to environmental conditions.

Apomixis

This is also known as One Line System. In case of apomixis, the F1 plants will produce seeds without fertilization which will be true to the type of parent. In such case, the heterozygosity will be fixed. Hence, the hybrid seed production will be as easier as of normal seed production of inbred varieties. But till date, this technique could not be developed in rice. Efforts in identifying apomixis in rice and its wild accessions did not provide promising results. Induction of apomixis has been reported in rice through use of physical and chemical mutagens (Chen, 1992).

Chemically Induced Male Sterility (CIMS)

In India, this system is not being used at commercial scale due to environmental concerns. This non-genetic method of inducing male sterility involves the use of chemicals called hybridizing agents (CHA's) or Gametocides. These chemicals kill the male gametes and make the plant male sterile. This method is very useful for plants with bisexual flowers in which it is difficult to obtain GMS or CGMS. Chemicals which have been evaluated in rice are, arsenics, GA3, ethrel, FW450, MH etc. Out of these, only zinc methyl arsenate and sodium methyl arsenate have been reported to be effective for producing commercial hybrids in China (Zhao et al. 1988). Hybrids produced by chemically induced male sterility are also called two-line hybrids in rice. Chemically induced male sterility is used sporadically because the effective and safe chemicals for inducing male sterility are not available.

Transgenic male sterility

Hybrid rice male sterility system using a nuclear gene named Oryza sativa No Pollen 1 (OsNP1). OsNP1 encodes a putative glucose-methanol-choline oxidoreductase regulating tapetum degeneration and pollen exine formation; it is specifically expressed in the tapetum and miscrospores. The osnp1 mutant plant displays normal vegetative growth but complete male sterility insensitive to environmental conditions. OsNP1 was coupled with an α-amylase gene to devitalize transgenic pollen and the red fluorescence protein (DsRed) gene to mark transgenic seed and transformed into the osnp1 mutant.

Self-pollination of the transgenic plant carrying a single hemizygous transgene produced nontransgenic male sterile and transgenic fertile seeds in 1:1 ratio that can be sorted out based on the red fluorescence coded by DsRed Cross-pollination of the fertile transgenic plants to the nontransgenic male sterile plants propagated the male sterile seeds of high purity (Chang et al. 2016).

Prospect of hybrid rice development in the future:

a) Enhancing row ratio in three line system by proper technique of higher pollen dispersal. In India, a ratio of 2: 8 or 2: 10 (R: A) is followed. Seed production has been improved in China by increasing the ratio up to 2:16, which should be made possible in other countries too. The hybrid seed productivity should be enhanced atleast up to 2.5-3.0 tonnes ha-1 to make the availability of hybrid seed at cheaper rate. b) Adoption of two line system: It does not require maintainer line, which reduce the labour, expenditure and area requirement. To get success in achieving the target, the increase in rice productivity is the only option left, since the other alternatives like cultivable land, water and other natural resources are either stagnant or declining (Yashitola et al. 2002).

Magnitude of heterosis in two line hybrid is also 5-10% higher than in three line hybrids as it does not have cytoplasmic penalty. Enhancing heterosis: a) We have to enhance the magnitude of heterosis in rice to make it more economical and income generating. b) Rao and Kulkarni (2004) found heterobeltiosis for grain yield in inter-subspecific hybrids 25.2% and standard heterosis 56.8%, whereas in intra-subspecific hybrids 9.3% heterobeltiosis and 19.5% standard heterosis. c) Vaithiyalingan and Nadarajan (2010) studied 42 inter and intra subspecific hybrids utilizing seven wide compatible varieties (WCVs) including two *indica* and five tropical *japonica* for nine biometrical characters including grain yield. For most of the characters, the mean heterosis per cent were in the order of *indica/japonica* F_1 >Tropica *japonica/indica* F_1 > *indica/indica* F_1 > Tropical *japonica/japonica* F_1.

The major research in the future about indica-japonica hybrid rice varieties would be breeding, and select varieties with higher yield and suitable amylose content, and then evaluate the rice quality in comparison to the conventional indica and japonica rice. In general, indica-japonica hybrid rice would be widely concerned due to multipurpose and high yield ability (Zhou et al. 2017). Other important stratefies such as breeding super hybrid rice, breeding for transfer of resistance for biotic stress in a and r lines through marker assisted selection, screening of large number of restorer lines through marker assisted selection/conventional breeding, breeding for different agro-climatic zones and agroecosystem and hybrids for longer duration (140-150 Days) to replace longer duration mega varieties like, MTU 7029 and BPT 5204 in India.

Revathi et al. (2013) reported that the SSR marker RM6100 linked to *Rf4* gene on chromosome 10 and RM10313 linked to Rf3 gene on chromosome 1 showed eighty five and eighty one percentages, respectively. Restoration of WA-CMS in rice is controlled by two nuclear gene *Rf3* and *Rf4*. The SSR marker RM1 is linked with *Rf3* gene on the short arm of 1st chromosome (Ahmadikhah et al. 2007). Hybrid for Quality of the hybrids developed in India are lacking in good quality which is a major problem in large scale spread of hybrid rice in the country. Majority of the Indians prefer non-sticky cooked rice whereas most of the early hybrids are showing stickiness.

Farmers get higher price of long slender aromatic varieties which is lacking in most of the hybrids developed in India. If hybrids with these quality traits are developed, it will certainly help the country in large scale adoption of hybrid rice technology. However, India has become the first country in releasing Basmati type of hybrid (PRH-10) in 2001 which became very popular in the country.

Suggestion:

1. Development of hybrid rice which should not have sticky in nature.
2. To develop hybrid rice which is having wider in adaptation.
3. Hybrid rice should have enrich in major and micro nutrient enrich.
4. Development of hybrid rice which have border in genetic base so that it can minimize genetic vulnerability.
5. Area under hybrid rice cultivation should be increase so that it can support food for growing population.
6. Other problem such as panicle exertion should be resolve by introgression of genes and increase resistance to biotic and abiotic stress.

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