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REVIEW ARTICLE **OPEN ACCESS**

Hybrid Rice: Development, Constraints and Prospects–A review

Hausila Prasad Singh[1], Monica Jyoti Kujur[2] and Sonika Kalia[3]
[1*]Department of Plant Breeding and Genetics, [3]Department of Agricultural Biotechnology, CSK Himachal Pradesh Agricultural University
[2]Department of Plant Breeding and Genetics, Jawaharlal Nehru Krishi Vishwa Vidyalaya
Corresponding author: hausilaps@gmail.com

ABSTRACT
Rice (Oryza sativa L.) is the world's most important cereal crop that is consumed by a large part of the world's population after wheat and maize. It is the staple food for more than half of the world's population and global rice demand is estimated to rise from 8.52 × 10 ⁸ t in 2035. More than 90% of the world's rice is produced and consumed in Asia. Hybrid rice production is one of the best practically feasible and readily adaptable one options to enhance the productivity. Hybrid rice technology plays important role in increasing the rice production. The main reason for the 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. The increase in rice yields due to hybrid rice has, in turn, improved food security for an estimated 60 million additional people per year.
Keywords: *CGMS, EGMS, TGMS, CIMS, Heterosis and Apomixis.*

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INTRODUCTION

Hybrid rice technology exploits the phenomenon of hybrid vigour (heterosis) in order to increase the yield potential of rice varieties with a reported yield advantage of 15-20% over commercial high yielding varieties. Although it was first to report the existence of hybrid vigour in rice [1]. Hybrid rice technology is an important breeding approach to break current yield plateau of rice productivity. Like other crops, rice is also showing enough heterosis [2, 3 and 4]. The hybrid rice research began by Prof. Yuan Long Ping in 1964 [5]. 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 [6]. 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 the first country that put hybrid rice technology to real mass field production. Other countries, specifically Southeast Asia, initiated hybrid rice research in the 1980s and have been applying this technology commercially for rice production since two decades. This programme has also been started by India in 1989. In India, heterosis was first reported by Ramiah and Kadam [7, 8]. 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 [9]. Since hybrid rice technology is able to break current yield platue of rice productivity thus, to make it practically feasible there is a need for a strong system of hybrid seed production at commercial scale.

HISTORY OF HYBRID RICE TECHNOLOGY IN CHINA AND INDIA

In 1964, Yuan Long Ping was first to utilize the idea of heterosis in rice and further initiated the research on hybrid rice in China. In 1970, a pollen abortive wild rice plant (Wild Abortive WA) was discovered among the plants of common wild rice at Nanhong farm of Hainan Island of China and the available restorer genes in indica rice led the beginning of hybrid rice technology [10]. In 1972, the first group of

CMS lines such as Zhenshan 97A and V20A were developed by using WA as the donor of male sterile genes by way of successive backcrossing method.

In 1973 Photoperiod and Thermosensitive Genetic Male Sterility (PTGMS) in rice were discovered in China. The first three line hybrid rice was released in China in the year 1976. In 1994 first commercial two line rice hybrid released in China. In India, ICAR launched a mission mode project on hybrid rice in December 1989. In 1994 first time hybrid rice (APHR1, APHR2, MGR1 and KRH1) were released in India.

Ideotype of hybrid rice

The Ideotype of hybrid rice are following–

- Moderate tillering capacity.
- Heavy and drooping panicles at maturity.
- Plant height of at least 100 cm and long panicle height at maturity.
- Flag leaf length of 50 and 55 cm.
- All leaves should remain erect until maturity.
- Narrow and V shape leaves.
- Harvest index of about 0.55.

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 the 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 [11]. 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 [12]. Cultivation of hybrid rice leads to the increase in yield and food security for 60 million additional people per year [13]. Several types of techniques for making female may be tested and developed for hybrid seed production are below –

1. 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-line, but it differs in the cytoplasm which makes it self-fertile. Conventional breeding is more time and space taking to identify a large number of genotypes. Although, it is still being used to identify the fertility restorer lines used for developing new hybrids in rice [14]. The restorer gene in the form of dominant homozygous or heterozygous restores the fertility of the F1 hybrid. Hybrid seed production involves two steps, multiplication of A, B and R lines and Production of hybrid seeds. For the 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.

2. Environmental sensitive Genetic Male Sterility (EGMS)

This is also known as two line system. This was first observed by Martin and Crawford in the year 1951 in pepper. 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 of two line system of hybrid rice is simpler if become feasible. Heterosis is found to be more feasible in two line hybrid seed production i.e. 5 to 10% higher than three line hybrid seed production because of no cytoplasmic penalty. The Environment Sensitive Genetic Male Sterility is of the following type –

A. **Temperature sensitive genetic male sterility (TGMS)**

At higher temperature, most of the TGMS lines remains male sterile (>30°C for day temperature and >24°C for night temperature) and get revert back to male fertile at low temperature (<24°C for day temperature and <16°C for night temperature) for examples. IR68945, SA2, 5460S and H89-1.

B. **Reverse Temperature Sensitive Genetic Male Sterility (RTGMS)**

Reverse Temperature Genetic Male Sterility (RTGMS) lines show male sterility at low temperature and revert back to partial fertility at a higher temperature. This system is reverse of TGMS for examples. Dianxin 1A, IVA and JP 38.

C. **Photoperiod Sensitive Genetic Male Sterility (PGMS)**

Photoperiod Sensitive Genetic Male Sterility (PGMS) lines show male sterility under long day (>13h) conditions and revert back to male fertility under short day (<13h) conditions. A single recessive nuclear gene or pair of recessive nuclear gene control expression of male sterility in PGMS for examples. N9044S and N5088S.

1. **Apomixis**

This comes under one line system. In this case, the f_1 plant produces seed by apomixis which will be true to the type of parent. In this case, heterozygosity will be fixed. Hence, production of hybrid seed will be easier and simple. In India till date, there is no hybrid rice developed by one line system. The effort is going on to identify apomixis in rice and its wild species but, it did not provide promising results. By use of physical and chemical induction of apomixis has been reported in rice [15].

2. **Chemically Induced Male Sterility (CIMS)**

Due to environmental concern, this system is not being utilized at commercial scale in India. This method induced male sterility by use of chemicals called male gametocides, male sterilants, pollen suppressants, androcides etc. In 1985 Mc Rae suggest the use of single term chemical hybridizing agents (CHA's). 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 arsenicals namely MG1 and MG2, GA3, ethrel, 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 [16]. Hybrids develop by this system comes under two-line hybrid seed production. An ideal CHA should be highly male and female selective, should be easily applied and has low cost.

3. **Transgenic male sterility**

Hybrid rice male sterility system using a nuclear gene named *Oryza sativa No Pollen 1* (*OsNP1*). The gene *OsNP1* encodes glucose-methanol-choline oxidoreductase which is responsible for the degradation of tapetum and pollen exine formation, it is especially expressed in tapetum and microspores. The mutant *OsNP1* plants show complete male sterility with normal vegetative growth. Gene *OsNP1* linked with α amylase to devitalize transgenic pollen and red fluorescence protein (DsRed) used as a marker for transgenic seed. 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 [17].

Another system of hybrid rice production through transgenic male sterility developed based on *Brassica napus* cysteine protease gene with specific promoter P12. It is based on the promoter of rice gene *Os12bglu38* isolated from developing panicle and named P12. It ligated with gusA reporter gene which expresses in tapetum and developing anther of rice. To develop nuclear male sterility, gene *BnCysP1* ligated with promoter P12. Transgenic rice with *P12-BnCysP1* show male sterility. The F_1's obtain from *BnCysP1* and normal plant show 1:1 (tolerant: sensitive) ratio with Phosphinothricin (PPT). To restore male fertility BnCysP1Si silencing system developed. Pollination of *BnCysP1* with *BnCysP1Si* resulting normal F_1's grain filling with 1:1 ratio of tolerant: sensitive by PPT and hygromycin [18].

Constraints in hybrid rice development

The constraints in hybrid rice development are following –

(i) The area has been at a standstill for years

Decreased in the area of double cropping of early hybrid rice and Japonica hybrid rice is the main reason. Another reason is the cropping system has been regulated by both the local government and farmers themselves to improve their farming income in the past 15 years such as cash crops or fish pools instead of growing rice.

(ii) Lack of japonica hybrid rice with high heterosis

The planting area of japonica hybrid rice has been limited to around 100000 ha, accounting for only 1-2% of total japonica rice in the world for many years because of its relatively poor heterosis (about 10% over conventional japonica rice), the sterility of its CMS lines is not stable enough to produce.

(iii) High yield with higher yield gap for super hybrid rice

The super hybrid rice in test area has shown the yield potential of 14.82 t ha^{-1} in Hunan (China) but the average yield of single cropping rice in Hunan was only 6.84 t ha^{-1} in the last five years. There is a great yield gap of 5.16 t ha^{-1}. We have to develop adaptable package techniques to gradually shorten the yield gap step by step for super hybrid rice.

(iv) Too many new hybrid rice varieties released yearly but very few breakthrough combinations

Hybrid rice Shanyou 63 was bred in 1981, its planting area ranked 1st national wide for 15 consecutive years. In contrast, now there are hundreds of new hybrid rice combinations officially released every year.

(v) The need of the breakthrough for the mechanized technology of hybrid rice seed production

Hybrid rice seed production process is complex and strict, with low efficiency and high labour cost. Hybrid rice seed production, relying on the traditional labour-intensive technique, becomes the key obstacles to develop hybrid rice in India. So it is urgent to mechanize the technology of hybrid rice seed production.

Prospect of hybrid rice development in the future

- Enhance three line system by proper techniques 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 at least up to 2.5-3.0 t ha-1 to make the availability of hybrid seed at a cheaper rate.

- Adoption of two line system: It does not require maintainer line, which reduces 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 [19].
- The magnitude of heterosis in two line hybrid is also 5-10% higher than in three line hybrids as it does not have a cytoplasmic penalty. Enhancing heterosis: a) To make rice economical and income generating we need to enhance the magnitude of heterosis in it. b) Rao and Kulkarni 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 [20]. c) Vaithiyalingan and Nadarajan, studied 42 inter and intra subspecific hybrids utilizing seven wide compatible varieties including two indica and five tropical japonica for nine biometrical characters including grain yield [21]. For most of the characters, the mean heterosis percent was 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 [22]. Revathi et al. reported SSR marker RM6100 linked to *Rf4* gene on the chromosome 10 and RM10313 linked to *Rf3* gene on the chromosome 1 showed 58 and 81% respectively [23]. Restoration of WA-CMS in rice is controlled by two nuclear genes *Rf3* and *Rf4*. The SSR marker RM1 is linked with *Rf3* gene on the short arm of the 1^{st} chromosome [24].
- Other important strategies 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 hybrids for longer duration (140-150 Days) to replace longer duration mega varieties like, MTU 7029 and BPT 5204 in India.
- Hybrid for Quality of the hybrids developed in India is lacking in good quality which is a major problem in the 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 the 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.

FUTURE PERSPECTIVES

1. Development of hybrid rice which should not have sticky in nature.
2. To develop hybrid rice having wider adaptation.
3. Hybrid rice should have enriched in major and micronutrient.
4. Development of hybrid rice which has a border in the genetic base so that it can minimize genetic vulnerability.
5. The area under hybrid rice cultivation should be increased 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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