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Hybrid Seed Production: Techniques and Methods in Rice (*Oryza sativa* L.) Crop

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Rice (*Oryza sativa* L.) is a staple cereal crop, vital for global food security. It thrives in warm, waterlogged conditions, supports billions worldwide and provides essential carbohydrates, nutrition, and livelihood for farming communities**.**

Global rice production in 2025 reached about 800 million tonnes, with Asia dominating output. The top five producers were India [152 million tonnes (28%)], China [146.3 million tonnes (27%)], Bangladesh [37.6 million tonnes (7%)], Indonesia [33.6 million tonnes (6%)], and Vietnam [26 million tonnes (5%)], together contributing over 70% of global supply. Rice remains the world's most important staple, feeding more than half the global population (***USDA, 2026***).

It is one of the oldest cultivated crops, with origin traced to Asia (Indo-Burma region of Asia) around 10,000 years ago. It belongs to the family Poaceae (Gramineae), which includes other cereals like wheat and maize. Rice is classified into two major species: *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice). Within *Oryza sativa*, subspecies such as *indica japonica* and *javanica* are widely recognized, differing in grain type, adaptation, and cultivation practices. The rice plant is diploid, possessing 24 chromosomes (2n = 24), which makes it a model organism for genetic and genomic studies in cereals. Its classification highlights its importance as both a staple food and a genetic resource for crop improvement. The evolutionary origin and diversity of rice underpin its adaptability to varied agro-climatic conditions, ensuring its role as a cornerstone of global food security and agricultural sustainabilit**y.**

Rice is one of the world's most important crops, serving multiple utilities beyond food. It is the primary staple for more than half the global population, providing essential carbohydrates and energy. Rice cultivation supports millions of farmers, forming the backbone of rural economies in Asia, Africa, and Latin America. Its by-products—such as rice bran, husk, and straw—are widely used for animal feed, fuel, compost, and industrial applications. Rice straw is also utilized in paper making, mats, and handicrafts, while rice bran oil is valued for its nutritional and medicinal properties. Additionally, rice plays a role in cultural traditions, festivals, and rituals across many societies. Its adaptability to diverse agro-climatic conditions ensures food security, while hybrid and improved varieties contribute to sustainable agricultural development and higher productivity worldwide.

Rice is a monocotyledonous plant as an annual grass with a fibrous root system adapted to waterlogged conditions. The stem is erect, hollow, and jointed, bearing long, slender leaves with parallel venation. The inflorescence is a panicle, which carries numerous spikelets, each containing a single floret. The floret is enclosed by the lemma and palea, protecting the reproductive organs. Rice flowers are bisexual, with six stamens and a pistil bearing two feathery stigmas that are highly receptive to pollen. The crop is predominantly self-pollinated, though controlled cross-pollination is possible. The grain is a caryopsis, where the seed coat is fused with the pericarp, forming the edible rice kernel. With a diploid chromosome number of 2n = 24, rice serves as a model plant for genetic studies. Its botanical traits—panicle structure, floral biology, and adaptability—make it central to global food production.

Rice (*Oryza sativa*) possesses botanical traits that make hybrid seed production possible. It is a self-pollinated crop with bisexual flowers, but breeders exploit **male sterility systems** to enable cross-pollination. The rice flower is small, enclosed by lemma and palea, with six stamens and a pistil bearing two feathery stigmas that are highly receptive to pollen. Normally, self-fertilization occurs, but **cytoplasmic male sterility (CMS)** and **environment-sensitive genetic male sterility (EGMS)** prevent pollen formation, allowing fertile pollen from another line to fertilize the female parent. The synchronized flowering, stigma receptivity, and controlled planting of male sterile and fertile lines ensure successful hybridization. With a diploid chromosome number of **2n = 24**, rice provides genetic diversity and adaptability, making hybrid seed production feasible and enhancing yield potential.

Hybrid Seed ?

Hybrid seeds are the F_1 progenies produced after crossing between two genetically dissimilar breeding lines and having superior performance than average performance of its both parents and checks used in trials.

History of Rice hybrid Seed Production

Hybrid rice seed development began in **China during the 1970s**, pioneered by Yuan Longping, who utilized cytoplasmic male sterility to achieve commercial success. In 1976 the world first hybrid variety of rice was release for commercial cultivation. This innovation revolutionized rice cultivation by boosting yields significantly (***IRRI***).

In **India**, hybrid rice research started in the late 1980s, with large-scale adoption in the 1990s under ICAR and state programs and In, 1994 India's first hybrid variety (**CORH-1**) of rice was released for commercial cultivation by **Tamil Nadu Agricultural University** (**TNAU**). Today, hybrid rice contributes to food security by enhancing productivity and sustainability worldwide (***IIRR***).

Systems of Hybrid seed Production of Rice

In India, Hybrid seed of rice produced in two ways-

1. Three Line System

The three-line system is the foundation of hybrid rice seed production, ensuring purity and efficiency. It involves three distinct parental lines: The Cytoplasmic Male Sterile (A line) line, the Maintainer line (B line), and the Restorer line (R line). The CMS line is female and unable to produce viable pollen, making it ideal for cross-pollination. The maintainer line, genetically identical to the CMS line but fertile, is used to maintain and multiply the sterile line without restoring fertility. The restorer line carries fertility-restoring genes, which, when crossed with the CMS line, produces fertile hybrid seeds. This system ensures large-scale hybrid seed production with high genetic purity.

The botanical traits of rice—bisexual flowers, receptive stigmas, and synchronized flowering—facilitate this process. By combining vigour, yield potential, and adaptability, the three-line system has revolutionized rice breeding, contributing significantly to food security and productivity in countries like China and India.

2. Two Line System

The two-line system of hybrid rice seed production relies on environment-sensitive genetic male sterility (EGMS) lines and fertile lines, eliminating the need for a maintainer. EGMS lines become male sterile under specific environmental conditions such as Temperature [Temperature Sensitive Genetic Male Sterility (TGMS)] and Photoperiod (Photoperiod

Sensitive Genetic Male Sterility (PGMS)], allowing cross-pollination with fertile pollen parents. When conditions change, these lines regain fertility, enabling their multiplication without a separate maintainer line. This system simplifies hybrid seed production compared to the three-line method, reducing costs and enhancing efficiency. The rice flower's structure—bisexual florets with receptive stigmas and synchronized flowering—supports effective hybridization. By exploiting natural sterility-fertility shifts, breeders can produce hybrids with high yield potential, adaptability, and genetic diversity. The two-line system has gained importance in countries like China and India, offering flexibility and scalability in hybrid rice programs, while contributing significantly to food security and sustainable agricultural productivity.

Procedure of Hybrid Seed Production of Rice

Three-Line System

1. Selection of Parental Lines Identify three distinct lines:

- **A line** (CMS line): Cytoplasmic male sterile, female parent.
- **B line** (Maintainer line): Fertile, genetically identical to A line, used to maintain sterility.
- **R line** (Restorer line): Fertile male parent carrying restorer genes.

2. **Multiplication of CMS Line (A line)**

Since, the A line cannot self-reproduce, it is multiplied by crossing with the B line. This ensures a continuous supply of sterile seed for hybrid production.

3. **Maintenance of Restorer Line (R line)**

The R line is maintained separately to preserve fertility-restoring genes and desirable agronomic traits such as yield, disease resistance, and adaptability.

4. Field Layout and Isolation

Hybrid seed production fields are carefully designed with alternating rows of A and R lines in 4:2 ratio respectively. Isolation distance is maintained to prevent contamination from other rice varieties.

5. Synchronization of Flowering-

Flowering of A and R lines is synchronized through staggered sowing, irrigation, or nutrient management, ensuring maximum pollen availability during stigma receptivity that will leads to good seed setting.

6. **Pollination and Hybrid Seed Formation**

The feathery stigmas of the A line capture pollen from the R line. It is done by using a stick or a rope passed across the seed production fields. Cross-pollination produces hybrid seeds with enhanced vigour and productivity.

7. **Harvesting and Processing**

Hybrid seeds are harvested from A line plants, cleaned, dried and processed to maintain purity and viability and R line plant are harvested separately and discard it from hybrid seed as general harvested paddy.

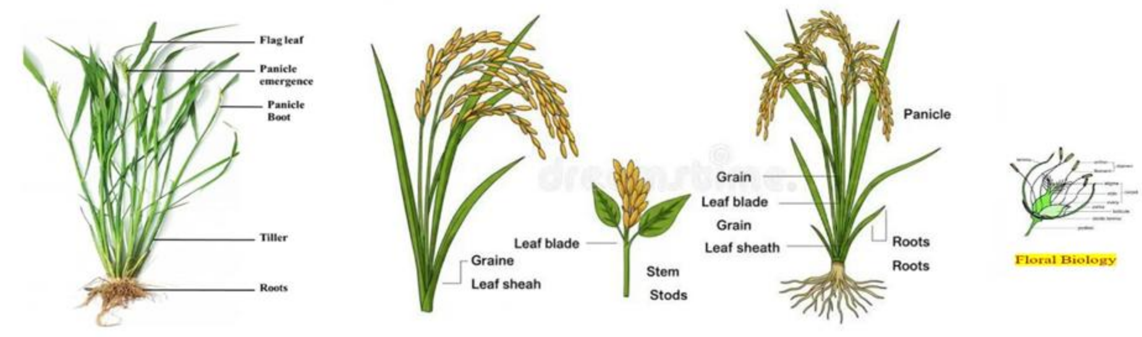

Fig. 01 General morphology of Paddy Crop Plant

8. **Quality Assurance and Distribution**

Seeds undergo genetic purity tests, germination checks, and certification before being distributed to farmers for commercial cultivation.

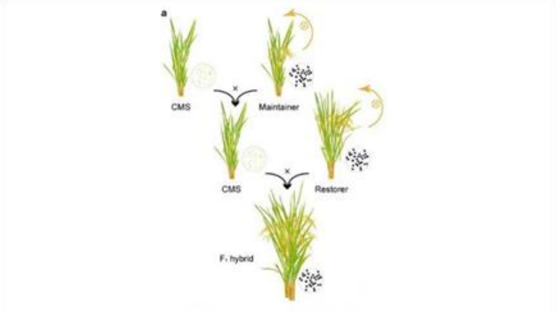

Fig. 02 A schematic presentation of Three line system

Steps in Two-Line System Hybrid Rice Production

1. **Selection of Parental Lines**

Choose an **Environment-Sensitive Genetic Male Sterile (EGMS) line** as the female parent and a fertile line as the male parent. The EGMS line becomes sterile under specific conditions (TGMS or PGMS).

2. **Multiplication of EGMS Line**

Under favourable conditions (where fertility is restored), the EGMS line is self-pollinated or crossed with another fertile line to maintain and multiply the sterile seed stock.

3. **Preparation of Fertile Male Parent**

The fertile line is maintained separately, selected for desirable traits such as high yield, disease resistance, and adaptability. It serves as the pollen donor during hybridization.

4. **Field Layout and Isolation**

Hybrid seed production fields are arranged with alternating rows of EGMS and fertile lines. Isolation distance is maintained to prevent contamination from other rice varieties.

5. **Induction of Male Sterility**

By planting the EGMS line under specific environmental conditions (e.g., long day length or high temperature), male sterility is induced, ensuring no self-pollination occurs.

6. **Synchronization of Flowering**

Flowering of EGMS and fertile lines is synchronized through staggered sowing, irrigation, or nutrient management to maximize cross-pollination.

7. **Pollination and Hybrid Seed Formation**

The receptive stigmas of the EGMS line capture pollen from the fertile line, producing hybrid seeds with enhanced vigour and productivity.

8. **Harvesting and Processing**

Hybrid seeds are harvested from EGMS plants, cleaned, dried, and processed to maintain purity and viability.

9. **Quality Testing and Distribution**

Seeds undergo genetic purity checks, germination tests, and certification before being distributed to farmers and after found satisfactory it will be distributed to the farmers for cultivation.

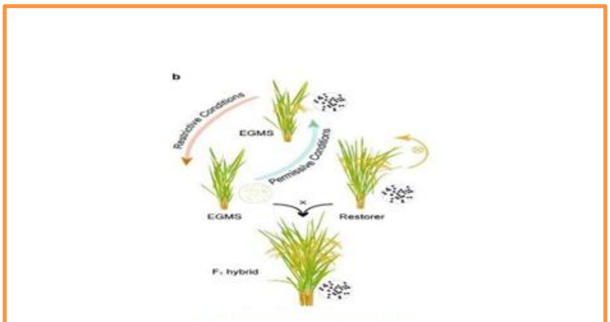

Fig. 03 A schematic presentation of Two line system

General tips to Farmers while using Hybrid seeds for Crop Production.

Farmers adopting hybrid rice seeds should follow certain best practices to maximize yield and ensure sustainability. First, it is important to purchase certified hybrid seeds from reliable sources to guarantee genetic purity and avoid admixtures. Since hybrid seeds do not retain their vigour in the next generation, ***farmers must avoid reusing harvested grains as seed and instead procure fresh seed each season***. Proper land preparation is crucial, with well-leveled fields ensuring uniform water distribution and better crop establishment. Timely sowing, preferably within the recommended window for the region, helps the crop escape adverse climatic conditions. Seedlings should be transplanted at the right age (20–25 days) with optimal spacing to reduce competition and enhance tillering. Adequate fertilizer management, especially balanced application of nitrogen, phosphorus, and potassium, is essential, as hybrids respond strongly to nutrient availability. Farmers should adopt integrated pest and disease management practices, including resistant varieties, biological control, and judicious pesticide use, to protect the crop without harming the environment. Water management plays a key role; maintaining shallow water during vegetative growth and proper drainage during maturity ensures healthy development. Since hybrid rice often requires more intensive care, farmers should stay updated with extension advisories and local recommendations. Finally, post-harvest handling, including timely harvesting and proper storage, safeguards grain quality and market value. By following these guidelines, farmers can harness the yield advantage of hybrid rice while maintaining soil health and long-term productivity.

Fig. 04 **Field view of Hybrid Seed Production plot**

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