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HYBRID RICE SUITABILITY AND FUTURE PROSPECTS

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Abstract *Hybrid rice breeding increases yield by hitchhiking on heterosis, a trait in an offspring that is better than the parents. Use the three-line (CMS) or two-line (EGMS) protocol. Hollingshead describes a three-line CMS system with male-sterile A, maintenance B, and fertility restorative R lines. The hybrid seed is created by crossing the two lines, with the A line maintained by the B-line. The two-liner EGMS uses TGMS or PGMS to achieve male sterility and remove the maintainer line. This is why the hybrid seed is generated from EGMS lines under sterility-inducing conditions. CMS hybrid rice breeding involves establishing and maintaining A, B, and R lines, testcrosses to find restorers and maintainers, backcrosses to improve the A-line, and combining ability tests to choose high-yielding hybrids. Digenic interactions affect complete genes, with epistatic interaction contributing most to heterosis. Hybrid rice has naturally inherited biological intellectual property rights that encourage private seed production. However, high seed costs, grain quality, and pest and disease vulnerability should be addressed. Therefore, wisely and properly managing agronomic requirements is necessary to maximize hybrid rice yields.*

Keywords: *CMS; EGMS; Testcross; Digenetic; Hybrid rice*

Introduction

Rice is one of the most widely traded cereals on the globe (Samal et al., 2022). It is also one of the most popular cereals in the world, with 510 million metric tons consumed annually (Maraseni et al., 2018). The global demand for rice is on the rise. Approximately 510,25 million metric tons of rice were consumed worldwide in 2021-2022 (Durand-Morat and Bairagi, 2021). The global rice consumption has surged by 87% during the past decade (Fahad et al., 2019). The global demand for rice resulted in USD 26.5 billion worth of rice exports. China, the Philippines, Saudi Arabia, the United States, and Bangladesh are the top five rice importers. These five importers account for 23% of rice imports worldwide. Pakistan is a major producer of rice (Ilyas et al., 2022). Pakistan's Basmati rice is the most coveted variety of rice due to its huge grain size, fragrance, and flavors (Mahajan et al., 2018). Kenya, Afghanistan, China, the Kingdom of Saudi Arabia, the United Arab Emirates, and a few African nations are among its customers (Ilyas et al., 2022). IRRI rice is the most widely exported variety of rice from Pakistan (Shahzadi et al., 2018). The value of IRRI's exports in 2021 was USD 875 million. In this category, Pakistan competes against the United States, Thailand, Vietnam, and India. Madagascar, Afghanistan, Kenya, Malaysia, China, and Malaysia are all consumers. If Pakistan increases its exports to other potential markets, such as the Philippines, Bangladesh, the United States, Iraq, Mauritius, Morocco, and Ivory Coast, trade will expand significantly. Basmati rice is the second most exported type of rice (Ilyas et al., 2022). Together, Pakistan and India export 85 percent of the world's basmati rice (Ilyas et al., 2022). Pakistan exports to the United Arab Emirates, Kenya, Somalia, Kenya, and Kazakhstan. The dossier identifies potential markets such as Saudi Arabia, Iran, Yemen, Kuwait, Canada, and Jordan. The third form of rice exported from Pakistan is broken rice. In this category, Thailand, India, Myanmar, and Vietnam are the rivals. Each year, Pakistan produces more than 8 million tons of rice, which places it seventh in the world (Ilyas et al., 2022). In 2021-2022, Pakistan would produce 9.3 million metric tons of rice annually, according to PBS predictions. Pakistan is the fourth-largest exporter of semi-milled rice by volume. In all significant categories, Pakistan is the leading rice producer. Global rice consumption has increased dramatically during the past decade. Over 500 million metric tons of rice were consumed during the 2021-2022 growing season. A graphical representation of consumption, population, and production data (Figure 1) indicates that worldwide rice production and consumption are roughly equivalent and directly proportionate to the global population.

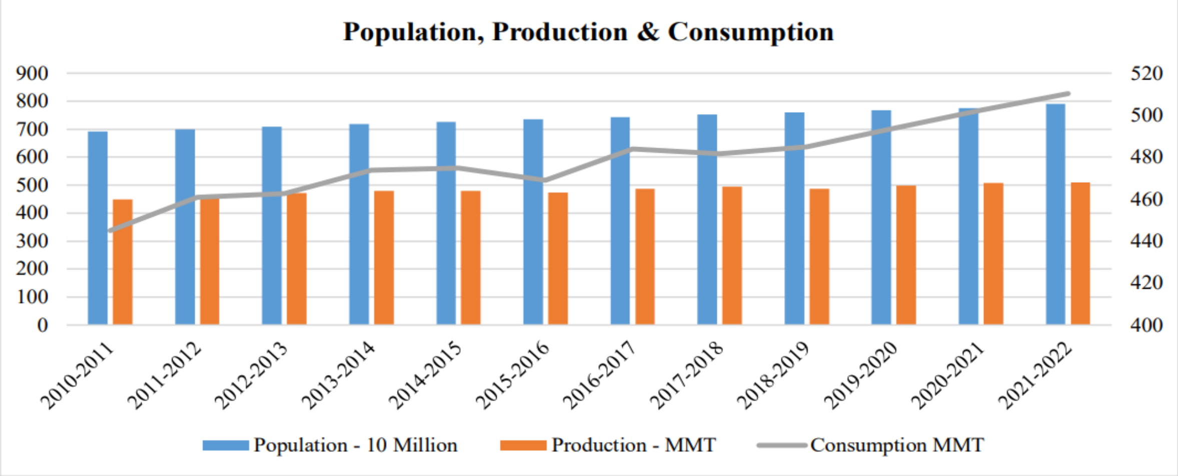

Figure 1. Population, Production and Consumption for rice

The yield per hectare is a useful indicator of agricultural production. China is the largest rice producer in the world, with an output of 6.95 tons per hectare. China's yield has steadily increased over the past five years, according to data from the five years prior. China generated 7.04 metric tons per acre in the year 2020. Vietnam has the second-highest yield per acre behind China. It yields an average of 5.69 tons per acre. Vietnam's yield has been on the rise since 2017, based on data from the prior year displayed in the graph below (Figure 2). In Indonesia, another major producer, the average rice yield per hectare is 5.15 metric tons. Its yield per acre has decreased marginally since 2015. India, the largest rice producer in the world, has an average yield per hectare of 3.85 tons per hectare.

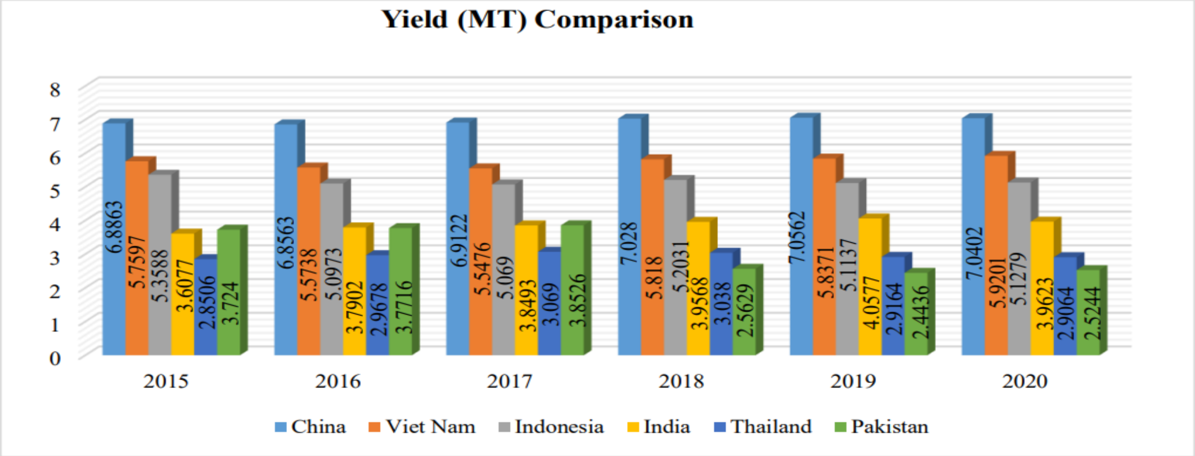

Figure 2. Five years rice yield

It peaked in 2019 at 4,05 tons per hectare before declining by 0.02% the following year. Thailand is second to India in yield per acre. Pakistan came in sixth place in this category. Each acre produces 3.14 metric tons on average. Since 2017, Pakistan's yield has been declining. In 2015, the average yield per acre was 3,7 tons, and it increased in 2016 and 2017. In 2017, the largest yield per acre was 3.85 metric tons. Since 2017, it has decreased, reaching 2.52 tons per hectare in 2018 (McBride et al., 2018).

In the past three decades, hybrid rice has significantly increased production and food security in China, making it one of the world's greatest innovations and marvels (Wijerathna-Yapa and Pathirana, 2022). In contrast, Pakistan's output is significantly below its potential due to obsolete production systems, biotic and abiotic restrictions, and insufficient investment in production technologies (Abbas et al., 2024a; Abbas et al., 2024b; Babar et al., 2020). National, regional, and international organizations have boosted their investments in rice cultivation in response to the growing demand for Pakistan's premium-grade rice. Current conditions are excellent for enhancing sustainable production and export, necessitating the expansion of existing partnerships to address issues along the rice value chain (Babar et al., 2020). Promoting the use of technologies for productivity enhancement, especially hybrid rice technology, is essential to achieving Pakistan's rice export objective. Rice hybrids have the potential to increase rice yield while enhancing the involvement of the private sector in the research and development of hybrid rice seed production (Rout et al., 2020). This research indicates the possibility of producing hybrid rice in Pakistan, as well as its commercialization potential and the techniques used to achieve this objective.

Challenges of hybrid rice adoption

Before hybrid rice may be widely utilized, Pakistan, like China, must overcome significant obstacles. These include the high price of seeds, concerns with grain quality, susceptibility to pests and diseases, the human capability for developing hybrid rice, and the difficulty in finding higher heterosis (> 25%) at the field level (Abebrese and Yeboah, 2020; Junaid and Gokce, 2024; Yousuf and Alim, 2020). In Pakistan, the majority of rice farmers have adopted the practice of utilizing their seeds. This technique may have evolved as a result of a dearth of trustworthy seed vendors who could guarantee a consistent supply of high-quality rice seeds. The vast majority of rice farmers continue to cultivate conventional types. The informal system is used by the few individuals that employ enhanced varieties.

Even though rice seed production is at an all-time high, more study is required before hybrid types may be introduced. Through subsidies, the Pakistani government works to ensure that farmers have access to excellent seeds. The biggest impediment to hybrid rice is whether or not local rice farmers are ready to pay a high price for the seed of hybrid rice during each harvest season. Consequently, the field-realizable yield benefit of hybrids should be sufficient. There is a technological limitation on the realizable field heterosis by hybrid varieties, although preliminary research suggests farmers can anticipate a 30% production increase over the finest inbred varieties now available (Gupta et al., 2019).

Pakistan is one of the few nations worldwide with average rice yields. This is largely attributable to inefficient agricultural processes and inputs, especially fertilizer (Fahad et al., 2019; Shahzad et al., 2019). Even if hybrids performance is marginally better than other varieties even under stress, their full potential can only be realized with the proper inputs. If local rice farmers wish to benefit from hybrids' higher yield, they must combine hybrid seeds with a properly researched agronomic program. A recurring concern is the susceptibility of introduced rice hybrids to local pests and diseases (Khanh et al., 2021). In addition to these obstacles, inferior grain quality was a significant barrier to the widespread adoption of hybrid rice in Asia. The majority of individuals favor rice varieties with long, slender, flavorful grains that cook slowly. These features, which are predominantly quantitatively inherited and challenging to incorporate into goods, will create a challenge for breeders.

Rice breeding methods

Millions of resource-poor farmers can enjoy the benefits of science and technology through rice breeding. Rice is one crop that has achieved tremendous breeding success. In the 1960s, the role of semi-dwarf types' in the green revolution, which helped avert a food catastrophe in Asia, is remarkable (Mohapatra et al., 2022). There are four types of rice breeding procedures: classical selection, selection in-vitro, molecular selection, and transgenic selection. Single seed descent, pure line selection, bulk method, recurrent selection, backcross method, pedigree method, and mass selection are examples of common selection breeding techniques (Begna, 2021; Rasheed and Malik, 2022; Rasheed et al., 2024). Currently, most of the time pure and bulk line selections are used to purify diverse species. The pedigree method is the most popular technique for creating new rice types. Out of currently available rice types, more than 85 percent were created using pedigree selection. Backcrossing is typically employed to transfer one or more genes to specialized or elite cultivars (Pandit et al., 2021).

The objective of hybrid rice development is to improve the production potential of rice over that of semi-dwarf varieties (Wu et al., 2018). In addition, a tiny amount of mutagenesis was applied to create some favorable rice types (Viana et al., 2019). In-vitro therapies include embryo rescue to aid in an extensive hybrid development process, such as the one that created NERICAs, somaclonal variation to identify beneficial variants and a second culture to yield doubled haploids. Embryo rescue was employed in the NERICA procedure to create viable offspring from crossings of *Oryza sativa* and *Oryza glaberrimum* (Nadir et al., 2018).

To enhance the efficiency and accuracy of conventional breeding, molecular markers are commonly employed in marker-assisted selection in molecular breeding systems (Hasan et al., 2021). Using genetic engineering (transgenic method), the gene pool of rice can be augmented to incorporate genes of any other genotype or species to confer a useful trait (Siddiq and Vemireddy, 2021). This method allows breeders to attain goals that conventional plant breeding cannot. Recent rice breeding attempts have incorporated genome editing techniques. Genome editing permits the modification of specific portions of the genome of rice. In contrast to genetic engineering, this method does not require the insertion of genes from other species into the rice genome (Mishra et al., 2018).

Rice varietal types

Inbred (pure lines), hybrid, and genetically modified (transgenic) are the three basic types of rice that can be bred using the aforementioned techniques (Ashraf et al., 2020). The majority of rice varieties are inbred. Hybrids are produced by mating two inbred lines with distinct genetic makeups. It is not advised to replant seeds from hybrid plants due to the loss of vigor, which results in a decreased yield and genetic segregation (Fiaz et al., 2021).

Each planting season, farmers should acquire fresh hybrid seeds from reputable suppliers. The higher earnings generated by hybrid varieties in comparison to pure line kinds more than compensated for the higher hybrid seed price. Genetic engineering is used to produce genetically modified (GM) rice. A transgene distinguishes the produced variants from typical (nontransgenic) inbreds, even if they reproduce consistently. Several transgenic rice lines have been created, however they have not yet been utilized in commercial agriculture. Golden rice is a well-known transgenic (GM) rice type that was created to produce beta-carotene to combat vitamin A deficiency (Regis, 2019).

Hybrid rice technology

Commercial hybrid rice is produced from F1 seeds derived from a cross between 2 genetically different parents. Due to the tight self-pollination of the rice plant, this was only possible through the adoption of a male sterility mechanism (Xu et al., 2023). Using the phenomenon of hybrid vigor, hybrid rice varieties boost rice production capacity beyond that of modern inbred varieties (heterosis). It has been revealed that traditional inbred cultivars offer a 15-30% yield advantage when grown under identical conditions (Xu et al., 2023). The first country to commercialize hybrid rice technology was China in 1964. However, the concept did not take shape until 1976, when a wild plant producing abortive pollen was discovered in southern China (Peng et al., 2023; Xu et al., 2023). Farmers must purchase new seeds each season to cultivate commercial crops, as heterosis only manifests in the first generation. Because hybrids increase output by 15-30% compared to pure line types, farmers often choose for them when they are affordable and widely accessible. Hybrids may give protection for biological intellectual property, encouraging private sector participation in seed production R&D (Dias, 2021).

Genetic basis of heterosis

Long ago, two hypotheses—the overdominance and dominance theories—were advocated to explain the phenomena of heterosis: the dominating and overdominance theories (Liu et al., 2024). According to the dominant theory, the activity and interaction of beneficial dominant alleles leads to hybrid vigor. In contrast, the overdominance argument asserts that heterozygous loci are preferable to homozygous loci. Consequently, in the heterozygous condition, two alleles work together to enhance gene expression (Groen et al., 2020). Recent research has shown epistasis, or interactions between loci, as playing a significant role in heterosis Recent research has shown epistasis, or interactions between loci, as playing a significant role in heterosis. Evidence from mating designs suggests that the epistatic component of variation is very minimal compared to the additive and dominant components. This is the situation due to the inability of statistical models to foretell epistasis. Using molecular markers, revealed the significance of epistasis as a potential genetic basis for heterosis in rice. Given that none of these theories effectively explains heterosis, it is proposed that the phenomenon be explained by combining the three hypotheses (Xie et al., 2022).

Breeding methods of hybrid rice

The CMS (three-line) method

At the moment, either the two-line (EGMS) (Fig. 4) or three-line (CMS) (Fig. 3) techniques are employed to develop hybrid rice (Virmani, 2012). In the three-line strategy, the A line (CMS), B line (maintenance), and R line (restorer lines) are utilized. A-line and B-line are genetically identical, with the exception that the A-line has a cytoplasm that is male sterile whereas the B-line has a normal (N) cytoplasm. In the F_1 hybrid, the dominant fertility restorer genes discovered within an R-nucleus restore the male fertility. Line B crosses line A to sustain and create A-line seeds, whereas A-line crosses line R to produce seeds of hybrid rice.

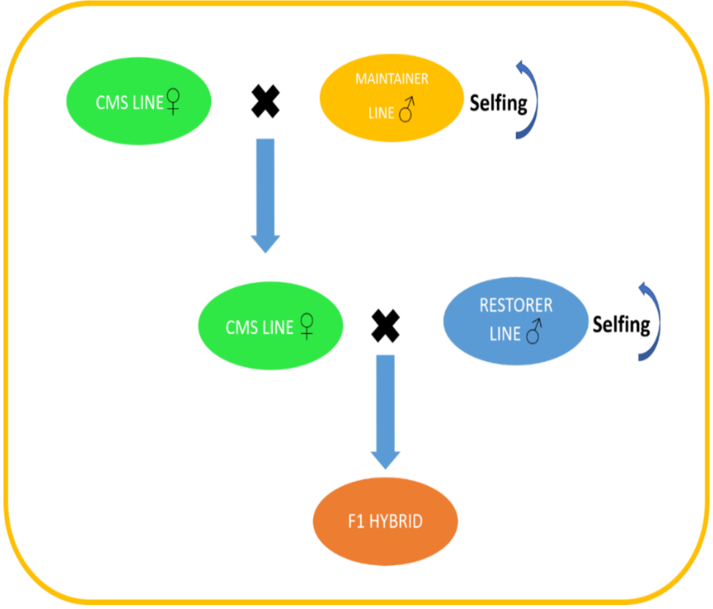

Figure 3. Three Line Hybrid System

Organization of hybrid rice breeding program using the CMS system

The three-line (CMS) breeding process is complex; thus, the management and development of parental lines is carried out in stages, each with its nurseries or collections of breeding materials. Before release, hybrids under experiments are often subjected to intensive testing on farmer fields. The nurseries include the source nursery, the backcross nursery, the combining ability nursery, the re-testing nursery, and the testcross nursery. There are elite CMS and breeding lines in the source nursery comprised of the capability to produce commercial hybrids. The testcross nursery is where F1s from the CMS and tester lines in the source nursery are put through pollen and spikelet fertility testing to find possible restorers (R-lines) and maintainers (B-lines). Using re-testcross nurseries, likely B lines are backcrossed into CMS lines, and prospective R-lines are confirmed and purified. The combining ability nursery assesses the general and specialized combining abilities of certain R and CMS lines. This nursery is essential to the development of hybrid rice because it identifies hybrids with higher yields (Abd El-Aty et al., 2022; Kulkarni et al., 2022).

As shown above, the IRRI's breeding strategy has undergone several modifications to increase its efficiency. Selected A and B line testers are chosen for the identification of new R-lines, while elite R-line tester inbreds are selected for crossing with new A-lines. Rather than crossing a large number of new A and R-lines, commercial A and R lines are utilized as testers once they are identified. In China, for instance, the top IRRI lines IR24 and IR26 were utilized as restorer lines. These restorers further served as a source of restorative genes for the creation of new restoration lines (Li et al., 2024). Creating a CMS line for a specific administrator. Typically, when lines are introduced to new sites, they are not adapted to the local environment. They may lack desirable grain quality characteristics or be vulnerable to local pests and diseases. This demands the transformation of accessible CMS lines into ones that are desirable and regionally relevant. After recognizing the inserted CMS lines maintainer from a cross of local lines onto a CMS source, it is necessary to do backcrossing to generate modified CMS lines (Li et al., 2024; Zheng et al., 2024). In the fifth and sixth generations (BC5-BC6) of backcrossing, the nuclear content of the original CMS source is almost entirely replaced by its counterpart maintainer. It is typically challenging to produce new CMS lines since local germplasm offers few alternatives for obtaining stable sterile lines (Zheng et al., 2024). Due to the instability of sterility in the BC1 and BC2 generations, it has been challenging to create new CMS lines from African cultivars (Abebrese and Yeboah, 2020).

The two-line method

In this model system, environmental factors like photoperiod, temperature, or both interact with nuclear genes to influence male sterility (Fan and Zhang, 2018). This is called environment-sensitive genic male sterility (EGMS) male sterility caused by the environment. Male sterility caused by line temperature is known as thermosensitive-genetic male sterility (TGMS), whereas male sterility caused by photoperiod is known as photo-genetic male sterility (PGMS), and male sterility caused by both line temperature and photoperiod is known as photo-thermo-genetic male sterility (PTGS) (Abebrese and Yeboah, 2020). This method makes it easier to organize and produce seeds than the CMS method. Multiplication of EGMS lines is accomplished by seeding them during window of optimal photoperiod and temperature conditions for fertilization. The creation of hybrid seeds is accomplished by seeding these lines so that the critical window of time corresponds with the photoperiod or temperature that induces total male sterility (Ali et al., 2021).

Five to ten percent more heterosis is seen in two-line hybrids than in three-line hybrids. A lack of stable TGMS germplasm is one of the most critical obstacles to creating and exploiting TMGS lines in tropical regions. Hybrids produced by crossing these lines, the resulting hybrids are entirely fertile independent of the growth season's temperature and day length conditions (Gangurde et al., 2019). This is the result of recessive regulation of the PGMS, TGMS, and PTGMS genes (s). Despite its attractiveness and potential as a method for utilizing heterosis, the EGMS system has a variety of benefits and drawbacks. The three-line method is more costly and time-consuming than the two-line method, but it is considerably more reliable. Due to the absence of a maintainer line in the two-line system, any line may be employed as a pollen donor. Therefore, the two-line method is more likely than the three-line method to identify hybrids with superior yield. Climate change affects the sterility of the temperature-sensitive line, as well as the inability of the two-line system to reliably produce hybrid rice due to the requirement for more acreage in regions with varying day lengths (Gopala Krishnan et al., 2022).

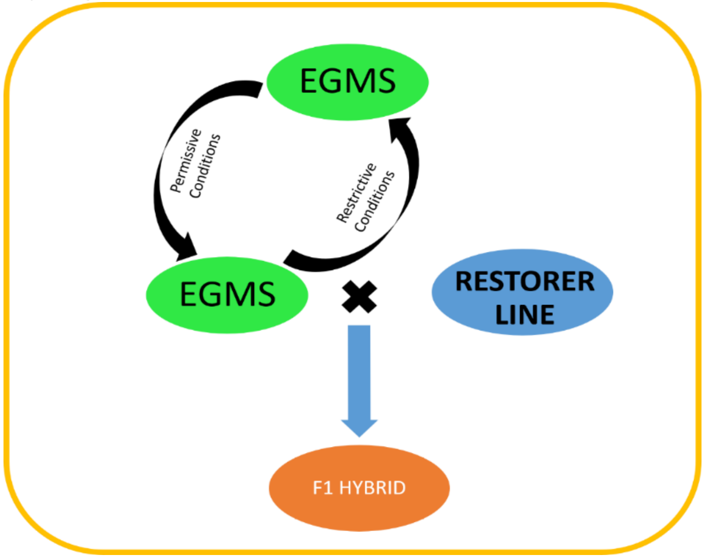

Figure 4: Two Line Hybrid System

Why hybrid rice production area is decreasing in China?

To calculate the complete feasibility of hybrid rice in Pakistan, it is necessary to know why hybrid rice is on the decline in its pioneer country, China. China's production area of hybrid rice has shrunk as a result of the switch to direct from manual sowing or automated transplanting. This is owing to acute labor shortages and rising labor costs in agricultural production, both of which are a result of urbanization (Chan, 2018). It is believed that direct-seeded and machine-planted rice makes up more than 40 percent of China's total rice-producing area (Lu et al., 2024). Changes in techniques of crop establishment are resulting in higher planting costs and affect the rice varieties that many rice farmers favor (Hussain et al., 2020). Although hybrid planting rates are half or less than those of inbred varieties, higher seeding rates encourage the abandonment of hybrid cultivars due to the high cost of hybrid seeds (Basnet et al., 2022). Typically, hybrids have a larger ability for tillering, allowing for lower seeding rates. The cost of hybrid rice seeds ranges from $6 to $15 per kilogram of seed (Kaya and Ashraf, 2024), whereas the cost of storing inbred rice seeds for the following season is approximately $0.45 per kilogram of seed. The price of hybrid rice seed becomes extravagant when combined with current, highly productive agricultural practices. An expansion in the country's middle class has led to a greater need for premium rice quality in China, low quality of grain is typically considered as a major barrier to the production of hybrid rice (Mahajan et al., 2018). It appears that hybrid rice breeders have surmounted this obstacle, as new varieties of hybrid rice with excellent quality of grain have just been developed. However, the main issue is still there, hybrid rice types with higher quality grain are extremely costly (Rout et al., 2020). This prevents them from becoming important rice seed suppliers in a growing planting context. In conclusion, despite their beneficial qualities, hybrid types are not always compatible with the most productive agricultural methods. In general, hybrid rice yields greater grain than inbred rice only when there are additional resources (such as water and fertilizers) available (Huang and Liu, 2022), but it's not accurate entirely. This is consistent with observations regarding the equilibrium between favorable traits and yield. It is believed that hybrid rice's high fertilizer requirements result in high usage of fertilizer, hence reducing farmer returns (Xu et al., 2021).

In addition, it is believed that hybrid rice is more susceptible to planthopper infestation (Laodelphax striatellus, Nilaparvata lugens, and Sogatella furcifera), stem borers (Sesamia inferens, Chilo suppressalis, and Scirpophaga incertulas), leaf folders (Cnaphalocrocis medinalis), and bacterial infections that cause leaf blight (Xanthomonas). This can result in an increase in pesticide consumption and a decrease in hybrid yields. In addition, there are several other factors as illustrated in Figure 4.

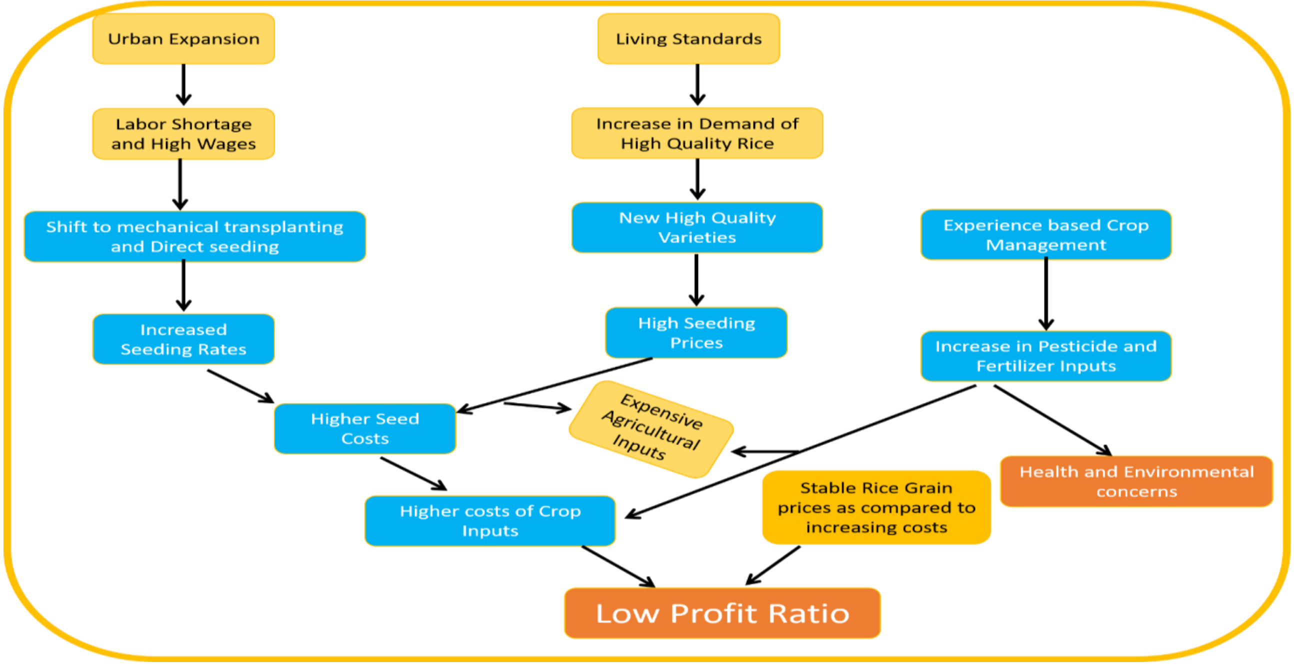

Figure 4. Factor effecting rice cultivation

Status of Hybrid Rice in Various Countries

In addition to China, over forty additional nations have promoted and introduced this technology. Initially, IRRI provided both technical assistance and essential parent materials (Collard et al., 2019). Subsequently, the majority of nations were able to create their hybrid rice breeding programs, resulting in an assortment of heterotic hybrids. In 1989, after China, India was the first nation to adopt hybrid rice technology, and it achieved significant progress. The hybrid rice acreage in India is currently 3.0 million hectares, or 6.8 percent of the total cultivated area of rice (SUMON, 2020). In 1992, Vietnam, was the nation on the second number after India to implement this approach, reaching yields of 6.3 to 6.8 tonnes per hectare from 0.7 mha, or roughly 10 percent of their total cultivated area of rice (Islam et al., 2021).

Several well-known hybrids have been produced and commercialized. In the Philippines, cooperatives of "seed growers" have been responsible for the production of 60-70% of hybrid seed. In Bangladesh, a lot of hybrids from China, India, and the Philippines have been introduced and commercialized. They generate around 8,000 tons of hybrid seeds a year, which is sufficient to cover about 800,000 acres, making them nearly self-sufficient in this area. In addition, Indonesia has a sizeable hybrid rice area, which has produced several high-quality rice hybrids, which have yield advantages of 0.7 to 1.5 tons per hactare over local inbred varieties (Denis, 2020).

The United States embraced this technology in the year 2000, creating and marketing a variety of two- and three-line hybrids (Mohapatra et al., 2022). The vast majority of hybrid rice cultivars in the United States utilized Clearfield (CL) technology, which enabled selective control of weedy red rice. There are several hybrids that are marketed by RiceTec (new plant type). They demonstrate yield improvements of 16 to 39% over inbred cultivars (North, 2019).

Future prospects of hybrid rice in Pakistan

Rice hybrids have the potential to boost rice exports, productivity, and output in Pakistan. Using the heterosis phenomenon, the primary objective of hybrid rice technology is to surpass existing inbred semi-dwarf types. By increasing production and promoting the use of hybrids, it will be able to realize its full potential. In addition, it will enable the bulk of the population to purchase essential goods at moderate prices, so promoting political stability. Pakistan has relied primarily on the unsustainable expansion of its land area to increase rice production. The technology of hybrid rice can reduce the amount of land required for rice farming and put it to greater use. Additionally, the technology can increase participation from the business sector in rice seed development. The absence of functional plant variety protection (intellectual property) procedures to secure their new varieties has been a problem for public sector, multinational, and other local private seed companies operating in Pakistan. Because the hybrid system gives some form of biological intellectual property via the control of hybrid parents, the public sector and seed companies may be able to repay their initial investment. This would offer farmers in Pakistan access to high-quality rice seed, which is now scarce. For hybrid rice farming, fresh F1 seed is required throughout each growing season. This will need the formation of seed firms that will serve as the infrastructure for hybrid seed production, processing, and marketing (public, private, or NGOs). This may result in additional rural employment opportunities, particularly for women and youth.

Keeping in mind the issues being faced by China after 20 years of research and efforts we need to overcome those issues to build a future of hybrid rice in Pakistan (Bin Rahman and Zhang, 2023). Approaches like as: (1) reduction in the cost of seed production of hybrid rice through mechanical culture; (2) developing highly resource-efficient rice production systems (high efficiencies in use of water and nitrogen); and (3) Improving methods for the mechanical planting of rice fields to save seeds (Bin Rahman and Zhang, 2023). Planthoppers stem borer, leaf folder, sheath blight, Magnaporthe oryzae (blast), and (Ustilaginoidea viridans (false smut) are just some of the common rice pests that have been combated using a variety of mechanized techniques. Other methods include the mechanical harvesting of hybrid seeds, the use of aerial vehicles for pollination, and the application of gibberellin and pesticides. It can be attributable to a combination of technology and, perhaps more importantly, societal reasons (Fig. 4), (1) To increase rice production, particularly of hybrid rice, it is necessary to implement acceptable pricing policies and fair government subsidy programs for agricultural inputs and hybrid rice products (Alta et al., 2023).

Conclusion

Hybrid rice technology can boost Pakistani rice output and exports. Heterosis-based hybrid rice variants have a yield drag of 15-30% compared to inbred varieties. This may help the country meet the world's growing rice demand while gradually growing its export market share. However, hybrid rice adoption in Pakistan must overcome various obstacles, including Diseases, weeds, and high hybrid seed costs that need frequent replacement throughout the seasons. Introduced hybrid varieties are susceptible to diseases and quickly invaded by pests. Grain quality may be affected by the lack of relevant structures or knowledge on hybrid seed production and distribution. Since China and India have a lead start, Pakistan should examine these strategies to maximize hybrid rice's potential. Developing affordable, mechanized hybrid seed production technologies. Hybridization from local germplasm. And which are good grain quality and local environmental fit. One problem is financing hybrid rice and creating incentives to make it economically useful to farmers. Increasing public-private collaboration in ASF for hybrid rice research and seed development. With the correct policies and investments, hybrid rice can revolutionize Pakistan's rice sector, increasing productivity, export possibilities, and revenue from farmers in a resource-sustainable way. Long-term, large-scale efforts should overcome the challenges.

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