Food and Agriculture Organization of the United Nations

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HYBRID RICE DEVELOPMENT IN ASIA: ASSESSMENT OF LIMITATIONS AND POTENTIAL

Front cover page photo:

- *Rice flowers*
  (http://derivejapan.weebly.com/rice-fields.html)
- *A high-yielding hybrid seed production field in Vietnam, 2014*
  (by the courtesy of the Southern Seed Joint Stock Company – SSC, Vietnam)

Back cover page photo:

- *Hybrid rice panicles*
  (Dupont Pioneer, http://www.dupont.co.in/corporate-functions)

Hybrid rice development in Asia: Assessment of Limitations and Potential

Proceedings of the Expert Consultation
organized by
The Regional Office for Asia and the Pacific
of the Food and Agriculture Organization
of the United Nations (FAORAP)
and
The Asia & Pacific Seed Association (APSA)
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ACRONYMS

ADB	Asian Development Bank
AED	Agricultural Extension Division
AIAT	Assessment Institute of Agriculture Technology
APRC	Regional Conference for Asia and the Pacific
APSA	Asia & Pacific Seed Association
ARNRE	Agriculture, Renewable National Resources and Environment
BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BIOTEC	National Center for Genetic Engineering and Biotechnology
BLB	Bacterial Leaf Blight
BPH	Brown Plant Hopper
BRRI	Bangladesh Rice Research Institute
CIMMYT	*Centro Internacional de Mejoramiento de Maíz y Trigo* or International Maize Development
FAO	Food and Agriculture Organization
FAORAP	FAO Regional Office for Asia and the Pacific
FSC&RD	Federal Seed Certification and Registration Department
GIZ	German Agency for International Cooperation
HR	Hybrid Rice
HRDC	Hybrid Rice Development Consortium
HYV	High-yielding Variety
IAARD	Indonesian Agency for agricultural Research and Development
ICABIOGRAD	Indonesian Center for Agriculture Biotechnology and Genetic Research and Development
ICAR	Indian Council on Agricultural Research
ICRR	Indonesian Center for Rice Research
IFPRI	International Food Policy Research Institute
INGER	International Network for Genetic Evaluation of Rice
INTAFOHR	International Task-Force on Hybrid Rice
IPR	Intellectual Property Rights
IRRI	International Rice Research Institute
MAS	Marker-Assisted Selection
MNC	Multi-National Company

MoA	Ministry of Agriculture
MOU	Memorandum of Understanding
MRE	Myanmar Rice Federation
NARS	National Agricultural Research Systems
NATP	National Agricultural Technology Project
NHRAC	National Hybrid Rice Advisory Committee
NHRSRP	National Hybrid Rice Strategic Research Plan
NIAB	Nuclear Institute for Agriculture and Biology
NIBGE	National Institute for Biotechnology and Genetic Engineering
NSB	National Seed Board
NSC	National Seed Committee
OPV	Open Pollinated Varieties
PPP	Public-Private Partnership
R&D	Research and Development
RRS	Regional Rice Strategy
RTV	Rice Tungro Virus
SCA	Seed Certification Agency
SMTA	Standard Material Transfer Agreement
SRI	System of Rice Intensification
TCP	Technical Cooperation Project
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNIDO	United Nations Industrial Development Organization
VEC	Variety Evaluation Committee

FOREWORD

Rice is the staple food of about half the world's population, of which more than 90% of the rice consumers inhabit in Asia. Therefore, rice plays an important role in ensuring food security, and contributing to poverty and malnutrition alleviation in Asia and the world. As the world's population continues to increase, there will be further demand on rice supply to meet additional consumption. Since the rice lands have been diminished due to urbanization and industrialization or agricultural diversification, the increase of rice production in the future would primarily rely on the increase of productivity. Nevertheless, it is recorded that the growth of rice productivity has declined in recent years due to little improvement in the rice yield potential. To overcome this challenge, the adoption of hybrid rice technology as experienced in China would offer an alternative to raise further the rice yield potential by exploiting the genetic expression of heterosis or hybrid vigor. However, outside China, despite hybrid rice has been grown in several countries; the pace of adoption is still low or stagnant over many years.

In consideration of these developments, the FAO Regional Office for Asia and the Pacific (FAORAP) and the Asia-Pacific Seed Association (APSA) jointly organized a Regional Expert Consultation on "Hybrid Rice Development in Asia: Assessment of Limitations and Potential" in Bangkok, Thailand on 2-3 July, 2014. The Expert Consultation was attended by more than 70 participants, including policy makers, R&D officials and entrepreneurs from 15 countries, and representatives from FAORAP, APSA and IFPRI. In the Consultation, various regional issues on hybrid rice development in Asia and country reports were presented and discussed, besides deliberations were given to the Consultation's recommendations and the Regional strategy for sustainable hybrid rice development.

We wish to appreciate effective contributions of the speakers and all the participants in making the Expert Consultation a great success. We do hope that the outcomes of this Consultation will contribute to the invigorated efforts at regional and national levels in strengthening R&D on hybrid rice, collaboration and partnership between stakeholders, along with innovative policies relevant to hybrid rice development.

Lastly, on behalf of FAO and APSA, we would like to express our gratitude to Mr Chanpithya Shimphalee, Director General of Rice Department of Thailand for his gracious presence to inaugurate the Consultation. We would also like to thank all the speakers and participants for their invaluable contributions, and acknowledge the hard work of FAORAP and APSA staff, including Dr Bui Ba Bong, FAO Senior Agricultural Officer (Rice Expert), Ms Sompis Likhitapisit, APSA Project Coordinator and Membership, and Mr Benedicto S. Bayaua, APSA Facilitator, in preparation for the Consultation Meeting and finalization of the Consultation Proceedings.

We hope that this publication will become a valuable source of information for policy makers and other stakeholders involved in hybrid rice development.

Tom Burns
Director
The Asia & Pacific Seed Association

Hiroyuki Konuma
FAO Assistant Director-General and
Regional Representative for Asia and the Pacific

Participants of the Regional Expert Consultation on "Hybrid Rice Development in Asia: Assessment of Limitations and Potential", 2-3 July 2014, Bangkok

EXECUTIVE SUMMARY

Rice is the staple food of about half the world's population, of which more than 90 percent of the rice consumers live in Asia. Therefore, rice plays an important role in providing food security, and alleviating malnutrition and poverty in Asia and the world. It is projected that as the world's population continues to increase, rice production is required to increase every year to meet additional human consumption. To increase rice production, it is essential to improve rice yield because there will be little scope in further expanding the rice area, and hybrid rice could be a promise to raise further the rice productivity.

To explore this opportunity, FAO Regional Office for Asia and the Pacific (FAORAP) and the Asia & Pacific Seed Association (APSA) jointly organized a Regional Expert Consultation on "Hybrid rice development in Asia: Assessment of Limitations and Potential" on 2-3 July 2014 in Bangkok, Thailand. The Consultation Meeting was attended by more than 70 70 participants, including policy makers, R&D officials and entrepreneurs from 15 countries, and representatives from FAORAP, APSA and IFPRI.

The objectives of the Consultation were to analyze the status of hybrid rice development in Asia and identify new opportunities to promote the sustainable adoption of hybrid rice in the coming years, contributing to the enhancement of rice productivity.

The meeting agreed with following recommendations for follow-up actions at country and regional levels:

- Governments in the Asia-Pacific countries should better facilitate access to and exchange of germplasm between and among all stakeholders and between countries. Policies should be transparent, uniform, predictable and defined.

- Governments and agencies should encourage shuttle breeding to fast-track product development; the movement of the breeding nurseries should be allowed with minimal regulatory requirements.

- APSA, ISF and FAO should come out with position and advisory papers to make policy makers aware of the benefits of clear policies for the exchange of germplasm for the food security of countries.

- Harmonize seed movement regulations for both R&D and commercial materials.

- Harmonize seed variety testing and registration processes.

- Standardize sanitary and phytosanitary measures in the region through ASEAN and SAARC member country platforms.

- Facilitate the training of manpower for seed production.

- Intensify seed production research to develop best practices for seed production, cultivation and management practices; strengthening the capacity of domestic hybrid rice seed production and promotion of community-based hybrid rice seed production.

- Conduct awareness and training on postharvest management facilitated through member countries and companies.

- Develop CMS parental lines with better diversity combining improved outcrossing, disease and pest resistance and raise the heterosis level.

- Develop lines with better resource use efficiency so that they can be used in direct seeding.

- Promote joint venture research collaborations.

- Provide enabling facilities and support to farmers, particularly smallholder farmers to adopt hybrid rice.

INTRODUCTION

Rice is the staple food of about half the world's population, of which more than 90 percent of the rice consumers live in Asia. Therefore, rice plays an important role in providing food security, and alleviating malnutrition and poverty in Asia and the world. It is projected that as the world's population continues to increase, rice production is required to increase every year to meet additional human consumption. To increase rice production, it is essential to improve rice yield because there will be little scope in further expanding the rice area. It is recorded that since the early green revolution to date, there has been insignificant improvement in the yield potential of the high-yielding inbred rice varieties resulting in stagnancy of yield growth in recent years. Meanwhile, hybrid rice varieties due to their heterosis effects could increase yield by 15-20 percent over inbred varieties as experienced in China where at present hybrid rice is planted to 15.5 million hectares comprising more than percent of the total national rice area. The great success of hybrid rice in China has encouraged other countries like India, Viet Nam, the Philippines, Indonesia and Bangladesh to follow the adoption of hybrid rice technology since the 1990s, and more recently Myanmar strongly advocating hybrid rice production.

In China, a new breakthrough of hybrid rice varieties called "super hybrid rice" which could yield more than 13 tons per hectare was reported. On the contrary, the pace of hybrid rice adoption in countries outside China has been slow over the years, as at present the total hybrid rice area of 4.5 million hectares distributed in several Asian counties outside China comprises a small proportion (1-7%) of the total rice area in each country. Moreover, hybrid rice area in most countries outside China had decreased significantly in the last three years. These mixed trends imply that there are both limitations and potential of hybrid rice development in Asia.

In recent years, FAO has supported a number of Asian countries in various projects to disseminate hybrid rice technology primarily through training, technology demonstrations, capability building, policy development and consultancy missions. These activities have contributed to promoting hybrid rice adoption in countries involved. In continuation of these activities and in view of the new developments in hybrid rice adoption in Asia, FAO Regional Office for Asia and the Pacific (FAORAP) and the Asia & Pacific Seed Association (APSA) are jointly organizing a Regional Expert Consultation on "Hybrid rice development in Asia: Assessment of Limitations and Potential" outlined as follows.

Objectives

- To assess the current status of hybrid rice production in Asia and its impacts on food and nutrition security, farmers' income and poverty reduction, and environment protection; and identify issues and potential opportunities for its development in Asia;
- To exchange and share knowledge and technologies and learn from each other's experiences and lessons;
- To analyze constraints and gaps limiting the development and adoption of hybrid rice in Asia including access to parental materials, hybrid variety, crop management practices, seed production, seed quarantine, intellectual property rights, trade, marketing and business development; and recommend measures to overcome these constraints and gaps; and formulate a regional strategy on hybrid rice development; and

- To strengthen regional collaboration and networking; and develop a regional strategy for promotion of hybrid rice in Asia.

Outputs

- Regional and country status on hybrid rice production issues, potential opportunities and future plan of action presented;
- Knowledge shared and experiences learnt on the use of hybrid rice technology with greater attention to policy, research and extension, intellectual property rights (IPR), access to parental materials, capacity development on commercial seed production, seed quarantine, trade, marketing and business development, and public-private partnership;
- A regional strategy towards 2030 on hybrid rice development formulated;
- A regional network on hybrid rice established; and
- Proceedings on the outcomes of the expert consultation published.

Participants

There were 74 participants attending the Expert Consultation including governments' policy makers, R&D officials and leading seed entrepreneurs of private sector from 15 countries in the region - Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Japan, Lao PDR, Malaysia, Myanmar, Pakistan, the Philippines, Singapore, Thailand and Vietnam and representatives of international institutions - FAO, APSA and IFPRI.

Program structure

Apart the Opening and Closing Session, The Consultation covered three Technical Sessions: i) Regional hybrid rice development, ii) Status of hybrid rice development: country reports, iii) Themes presentation and discussion, four Breakout Sessions on Hybrid rice research, Hybrid rice seed production and extension services, Hybrid rice development across Asia: the need for regional and Country strategies & policies and one Panel Discussion. The detailed presentations of issues and themes and in-depth deliberations brought in valuable recommendation and farsighted thoughts for formulation of a regional strategy and collaborations in hybrid rice.

EXTENDED SUMMARY OF THE CONSULTANCY RESULTS

The results of the Consultancy are summarized below:

1. Opening session

1.1 Introductory Address

Mr Avtar Singh Dhindsa, President of the Asia & Pacific Seed Association

Mr Dhindsa stressed the challenges to be highlighted in the consultation, noting that for many years, there have been a lot of discussions and promises on the opportunities that hybrid rice had to offer and that 20 years ago, issues such as yield, seed production, germplasm, market access, uptake of hybrid rice and intellectual property rights were already raised and particularly highlighted in the APSA's official magazine "Asian Seed" in 1994. He noted that while there have been major advances in yield and seed production, the issues facing the hybrid rice seed industry 20 years ago remain the same challenges for today and most likely for the future. He looked forward to the active participation of partners in the deliberations, to the reaching out of seed companies to other partners in the seed industry and to building on the achievements of this inaugural meeting within APSA, being the largest association of producers and traders of hybrid rice seed in the world.

1.2 Welcome Address

Mr Hiroyuki Konuma, Assistant Director-General and Regional Representative, FAO Regional Office for Asia and the Pacific

In his speech, Mr Konuma recalled the two organizations' long history of cooperation which started in 1994 when APSA was established under the joint efforts of FAO and DANIDA, based on the recommendation made by FAO member countries at FAO's Regional Conference at that time. He congratulated APSA for its effective and important role being played in seed sector development in Asia.

Mr Konuma stressed the importance of rice, being the staple food of about half of the world population, to food security, hunger alleviation and poverty reduction in the region. In recognition of the importance of rice, he informed of the FAO publication of "*A regional rice strategy for sustainable food security in Asia and the Pacific*" which was endorsed in March 2014. One of the objectives of this strategy is to increase the productivity and nutrition value of rice sustainably to meet the increasing global demand, where hybrid rice technology is one of several options envisaged in the regional rice strategy.

He reflected on FAO's long history of supporting hybrid rice development in Asia to promote hybrid rice development through consultancy meetings, capacity building and technical cooperation projects (TCP) to several countries, including this latest consultation.

Mr Konuma emphasized the importance of hybrid rice for the benefit of smallholder farmers who produce the majority of rice in this region and who constitute over 80 percent of total farmer population.

1.3 Official Opening

Mr Chanpithya Shimphalee, Director General of Rice Department, Thailand

Mr Chanpithya highlighted the importance of hybrid rice in Asia for self-sufficiency or for export enhancement in various countries. While he noted the slow pace of adoption and the decrease in hybrid rice area, he appreciated FAO's consistent support to a number of Asian countries in various projects to disseminate hybrid rice technology through training, technology demonstrations, capability building, policy development and consultancy missions. He also emphasized Thailand's work in enhancing hybrid rice productivity with research and development as well as technology transfer with farmers and the private sector so as to implement and increase productivity especially in irrigated rice areas. In addition, the implementation of a hybrid rice strategy and technology related to value-addition in hybrid rice production would also enhance agricultural potential and farmers' well-being. These have motivated the Rice Department of Thailand to participate in the regional cooperation for hybrid rice development. He enjoined all participants to actively participate in the exchange of knowledge and transfer of expertise during the consultation, as he officially declared the regional expert consultation open.

2. Regional hybrid rice development

2.1 Hybrid Rice: Ensuring Food Security in Asia

Mr Frederic Top, Global Marketing Lead, Rice Seeds of Bayer CropScience

Mr Top noted that as more rice productivity is needed, therefore doubled efforts should be made to break the current yield which is plateauing. While committed on hybrid rice development, more collaborations and partnerships are to be encouraged. He showed the advantages of hybrid rice such as higher sustainable yield, more income for farmers, more resilience to abiotic stresses, better suitability for direct seeding, better CO2 sequestration (increased biomass), better nitrogen use efficiency and good water efficiency. Hybrid rice could play a significant role in shaping a sustainable rice production strategy with benefits to the economy, ecology and society.

Mr Top advocated the partnership in hybrid rice development, in which the private sector values and fosters partnership, while the public sector, in addition to sound country regulations can at its end to:

- Set up adequate mechanisms for allowing a free movement of seed material for hybrid development and sales (separate from food or grain security, for development but as well sales before the hybrid is produced locally, while ensuring protection of intellectual property rights);

- Facilitate public-private partnerships (PPPs) to research, develop, commercialize and promote new solutions (such as encouraging the introduction of innovative and sustainable solutions, harmonizing and implementing science-based regulatory systems in each country and providing training to facilitate the development of modern farming);

- Organize appropriate financing systems to allow farmers to access credit;

- Improve links between farmers and millers; and

- Build and maintain roads and storage facilities to enhance the movement of food and significantly decrease post-harvest losses.

2.2 Hybrid Rice: The technology and the status of its adoption in Asia

Dr Subash Dasgupta, Senior Plant Production Officer, FAO

The key strategies for improving hybrid rice technologies, according to Dr Dasgupta, include the following:

- The introduction of the first-generation rice hybrid varieties opened a new technological frontier in attempts to break the stalemate in key innovations since the discovery of semi-dwarf genes that set the stage for green revolution.

- While the use of the tools of modern biotechnology and molecular breeding have contributed to improving hybrid rice technology, these tools are also being used in breeding open pollinated rice varieties (OPVs) with high yield potential and resistance or tolerance to a broad range of abiotic (drought/submergence/salinity) and biotic (pest and diseases) stresses. This helped not only in stabilizing yields of OPVs across production environments but also in pushing them into more marginal environments raising the bar for the hybrid varieties to compete with OPVs.

- Increasing the level of heterosis is, therefore, seen as the key technological challenge for maintaining a sustainable lead of hybrid varieties over OPVs in grain yield that would boost competitiveness of rice hybrids.

- One of the options in this effort is wide hybridization between *indica* (grown in tropics) and *japonica* (grown in temperate zones) sub-species of rice. This has been facilitated by the discovery and introgression of wide-compatibility genes to overcome the problem of sterility in wide hybrids.

Dr Dasgupta also revealed the challenges in hybrid rice development that have faced by each of the hybrid rice growing countries in the region.

2.3 A regional strategy for sustainable hybrid rice development in Asia

Dr Bui Ba Bong, Senior Agricultural Officer (Rice Expert), FAO

The Outline of "A Regional Strategy for Hybrid Rice Development in Asia" was presented to provide background information for discussions at the Consultation meeting from which the Outline will be revised and improved for further development into the Strategy document as one of the outputs of the Consultation.

The Regional Strategy aimed at providing evidence-based strategic guidelines and options to stakeholder in hybrid rice industry and countries that would like to formulate or reorient the strategy and programs of hybrid rice development.

The Outline comprises of the following sections (A) Overview of rice sector development in Asia (B) Status of hybrid rice development in Asia (C) Strategy of sustainable hybrid rice development in Asia towards 2030 which is consisted of (a) Vision (b) Strategic objectives, and (c) Key themes and options.

3. Thematic Presentations

3.1. Economics of hybrid rice adoption in Asia: Technology adoption, public expenditures, and private incentives

Dr Patrick S. Ward, Research Fellow, International Food Policy Research Institute (IFPRI)

The rapid expansion of hybrid rice cultivation in China has contributed significantly to improving food security in the country since the 1980s. However, few other Asian countries have seen similar expansions in hybrid rice cultivation or the associated yield and output gains. This presentation examined the technical challenges, market opportunities, and policy constraints related to hybrid rice in South Asia, with specific emphasis on India and Bangladesh.

Dr Ward provided some constraints to technology adoption: limited access to credit, limited access to information, risk aversion, inadequate farm size, tenure arrangements, labour constraints, unreliable supply of complementary inputs and inappropriate transportation infrastructure. He discussed key considerations for adoption of hybrid rice: seed costs, quantity of seed required, quantity of complementary inputs required, labour requirements, yields, output price, and risk preferences and subjective probabilities.

The benefits of hybrid rice include direct benefits: yield improvement at ~15-30%, higher yields, hence production intensification, with the added advantage of reallocating land to other crops or to non-farm uses. The indirect benefits are hybrids confer biological protection of intellectual property and IP protection makes new technologies remunerative.

Dr Ward likewise discussed a framework or tool for understanding the wider systemic process of translating scientific knowledge into technology products and then into useful innovations and ultimately into outputs and impacts.

Delivery and adoption of hybrid rice will depend on improvements made in the discovery and development stages. Feedback mechanisms between the three stages can facilitate these improvements. These require research to understand the factors that motivate or constrain farmers' adoption of hybrid rice.

Dr Ward concluded that hybrid rice as a new technology has great potential. Widespread adoption will depend on advances in scientific discovery, improvements in international R&D cooperation, improvements in private R&D incentives, improvements in farm-level incentives, and further understanding of distributional aspects of adoption. Hence, policy solutions spanning science, technology, and innovation are necessary conditions for hybrid rice's diffusion in Asia.

3.2 Issues facing hybrid rice development in China and international trade

Mr Jiang Sanqiao, Winall Hi-Tech Seed, China

China hybrid rice is a labor intensive technology; that the development of the hybrid rice industry and urbanization make the technology face big challenges:

- Seed production becomes very costly due to increasing labor cost;

- Higher-priced seed is not suitable for mechanized rice production, because mechanization consumes more seeds; thus, some farmers turn to inbred;

- Enforcement agencies do not perform efficient supervision or punishment on infringement of growing hybrid rice varieties;

- New variety development can't keep up with the requirements of mechanized production.

- Hybrid rice seed price increase in China has led to import decline in some countries;

- China exports similar varieties with different importers; the homogenized competition leads to competitive pricing and thus both importers and exporters have little or no profits to make;

- Few governments make efficient regulations to promote hybrid rice seed international trade. Instead, most relative policies have negative impacts.

All the above mentioned issues are not isolated among various countries but are common regional problems. The solution can only be reached through strengthening cooperation among governments of Asia-Pacific countries; through calling on governments to enforce intellectual property right protection, to further open up markets and technology, to optimize allocation of international resources for hybrid rice breeding and seed production, to carry out local breeding aiming varieties suitable for each target country and to produce seed in the countries that more suitable for hybrid rice seed production. All above will promote international trade of hybrid rice seed in Asia-Pacific region and make contribution to world food security.

3.3 Hybrid rice development across Asia - Need of the hour

Mr Rajvir Rathi, General Manager, Market Acceptance, Bayer BioScience Pvt., Ltd

Rice is the most important cereal crop grown globally, and the staple food for about half the world's population, of which nearly 90 percent are from Asia. Today, rice is cultivated in 113 countries in the world producing approx. 600 million tons of rough rice each year. Rice is a way of life and a vital part of Asian cultural heritage. One simple cannot imagine life without rice in most Asian countries. Rice plays an important role in ensuring food security, alleviating malnutrition and poverty in Asian nations.

By the year 2050, the demand for rice will be nearly double than the world's current production. India's current rice growth rate is approximately 1percent per year, which is inadequate to meet future needs.

Hybrid rice is one such innovative solution which can enhance rice productivity to meet the increasing demand. Hybrid rice varieties due to its heterosis effects could increase yield by 15-20 percent over inbred varieties, grown in similar conditions as experienced in China where, at present hybrid rice was planted in 17 million hectares comprising 58 percent of the total national rice area. The great success of hybrid rice in China has encouraged other countries like India, Vietnam, Philippines, Indonesia and Bangladesh to adopt hybrid rice technology since 1990s.More recently, Myanmar has also strongly advocated hybrid rice production.

Hybrid rice is sturdier in adverse growing conditions, especially in unfavorable soil and changing climatic conditions – such as temporary drought, stress etc. It is possible to increase hybridization to 14 percent by 2022 in most Asian countries. However hybrid rice adoption has to accelerate if we want to achieve 30 percent more rice by 2030 (v/s. 2010), not only in current countries but also in newer geographies.

In order to enhance the development of new hybrids with higher heterosis and wider adoption to increase rice productivity in Asian countries, there is a greater need to improve several aspects within and among countries. These are highlighted below –

- Take up Hybrid rice development and adoption in mission mode

    - In collaboration with and in an inclusive manner involving all stakeholders (Public Private Partnership mode)

- Research & Development

    - Germplasm movement in line with international standards
    - Access and movement to germplasm - Pest Risk Analysis - Sanitary and Phyto-sanitary measures
    - Reduce the complexity in variety release procedure
    - Incentivize R&D to develop suitable hybrids (Tax benefit on investment)

- Need for broad germplasm base to support an efficient breeding program and a strong expertise in seed production

- Commercial seed movement

    - Harmonization of seed movement guidelines and regulations in region/global alignment

- Improve Seed Production research – currently lower productivity per acre,

    - Improve storage/ transportation facility for efficient supply chain

- Need for better IP Protection – enforcement against counterfeits

- Strengthen extension and education - adapt suitable agronomic practices

- Most important is to Include the Excluded

4. Country reports

4.1 Hybrid rice development in Bangladesh

Mr Md. Azim Uddin, Chief Seed Technologist, Seed Wing, Ministry of Agriculture of Bangladesh

Status

In Bangladesh, systematic efforts in hybrid rice research were started at the Bangladesh Rice Research Institute (BRRI) in 1996. In 1997-98 Boro season, four exotic rice hybrids from private seed companies were evaluated, and these hybrid rice varieties were officially released and registered from the Ministry of Agriculture in 1998-99 Boro season.

The hybrid rice technology has gradually gained its popularity with the area under hybrid rice increasing to 670,000 hectares in 2013-14 in the total rice area of 11.8 million ha (5.65%). There were 115 hybrid rice varieties released and registered for commercial cultivation, of which 100 hybrid varieties were developed by private sector. The yield of released rice hybrids are from 6.50 tons to 8.50 tons per hectare which is performing 15-20% higher yield compared to the most popular inbred rice varieties. The use of hybrid rice seed has reached to 8,000 tons in 2013-14, of which domestic hybrid seed production attained 7,400 tons (self-sufficiency of 92.5%). The seed yield was about 1300 kg/acre in 2012-13.

Limitations

- Chinese hybrid rice is sticky and soft, which is disliked by most consumers, while hybrids with high amylose content (above 25 percent) and good cooking quality have not yet been developed. There is lack of hybrid rice varieties with high yield potential, short life cycle, tolerance to biotic and abiotic stresses and superior grain quality;

- F_1 hybrid seed production efficiency has not yet achieved international standards (seed purity of CMS line, R-line, and B-line, low outcrossing rate);

- Molecular breeding has not been applied at satisfactory level;

- Limited availability of potential and suitable land for hybrid rice seed production;

- Limited availability of sunning floor for seed drying and post-harvest operation;

- The market price of hybrid rice grain has not yet gained its positive impact in comparison to inbred rice grain. General consumers in Bangladesh preferred long slender grains with high amylose percent and better cooking and keeping quality. Local OP variety, due to superior taste, gives higher market price compared to hybrids.

Potential and future directions

- Increasing hybrid rice cultivation area to 20 percent;

- Developing hybrids with short-duration and desirable amylose content (>25 percent) and long slender grains; resistance to diseases (e.g., BLB) and insect pests, adaptability to a specific ecosystem, particularly stress-prone areas, and developing aromatic hybrid rice variety for all seasons;

- Refining hybrid rice seed production techniques and hybrid rice production practices;

- Expeditious and effective transferring of the hybrid rice technology already generated;

- Enhancing international cooperation regarding hybrid rice seed technology.

4.2 Hybrid rice development in China

Mr Ma Guohui, Deputy Director, Hunan Hybrid Rice Research Center, China National Hybrid Rice Research & Development Center

Status

Hybrid rice research was pioneered by Prof. Yuan Longping in 1964. In 1974, the first hybrid combination was developed, and hybrid rice was released for commercial production in 1976, Thus, China became the first country to put hybrid rice technology to real mass field production. Besides three-line hybrids, the theories and techniques of the two-line hybrid rice succeeded in 1995. It has been proven that the two-line system hybrid yields 5-10 percent more than the three-line system hybrid. The grain quality has also been improved. Subsequently, a super rice breeding program was launched in 1996. By 2013, the MOA certified 73 rice hybrids as “super rice”.

In 1991, hybrid rice area reached its peak at 17.6 million ha or 54 percent of the total rice area, but after that the area decreased and has stayed at about 15.5 million ha. The hybrid rice yield is 7.5 tons/ha or with 20% yield advantage over inbred.

Each year, more than 200 hybrid rice varieties were released. The Chinese rice seed industry is growing rapidly. By the end of 2012, altogether, there were 520 rice seed enterprises that have acquired business certificates. This techniques mechanized and optimized perform higher outcrossing seed setting rate (about 45%) and high yield by 2.7-3.0 t/ha on large scale in hybrid rice seed production.

Limitations

- The reduction of hybrid rice area in recent years was caused by a decrease in the area of double cropping of early hybrid rice and *japonica* hybrid rice and the conversion of rice area to other farming activities;

- The planting area of *japonica* hybrid rice has been limited to only 1-2 percent of total *japonica* rice in China for many years because of its relatively poor heterosis; and the sterility of its CMS lines is not stable enough to produce high purity of F1 seeds, and its poorer grain quality;

- There is a great yield gap of the yield of the super hybrids and the average yield of single-cropping rice;

- A large number of new hybrid rice varieties were released yearly but there was a lack of outstanding hybrids;

- Hybrid rice seed production, relying on the traditional labor-intensive technique.

Potential and future directions

- Increase the biomass by efficiently increase of the height plant from semi-tall, tall to super tall for the yield increas from 12- 4 tons/ha, 15-16 tons/ha to 18 tons/ha;

- Morphological improvement to establish the highly efficient photosyntesis populations;

- Further utilize heterosis by exploitation of indica/japonica heterosis, favorable genes;

- Enhance the lodging resistant;

- Maintain the higher harvest index with 0.5-0.55.

4.3 Hybrid rice development in India

Dr A.S. Hari Prasad, Principal Scientist, Directorate of Rice Research, India

Status

Realizing the potential of hybrid rice to increase the production and productivity, the Indian Council of Agricultural Research (ICAR) launched a mission mode project on hybrid rice in December 1989. In 1995, hybrid rice was grown on 10 000 hectares, the area under hybrid reached 1 million hectares in 2006 and attained 2.5 million hectares in 2013, which is about 5.6 percent of the total rice area in the country (43.95 million ha).

Extensive trials were conducted on various aspects of seed production technology at different locations under the hybrid rice network project. The optimum package for hybrid seed production and CMS multiplication has been developed. By adopting this package, the farmers were able to realize the seed yields in the range of 1.5-2.5 tons/ha.

Like in other crops, the private seed sector has taken a lead at 95 percent in hybrid rice seed production. The volume of hybrid rice seed produced in India, starting with less than 200 tons of total production in the year 1995, has crossed 40 000 tons from 30 000 hectares in 2013. India was self-sufficient in hybrid rice seed supply.

Limitations

- All the 69 released hybrids are based on a single cytoplasmic source (wild abortive "WA") which may be prone to outbreak of any major biotic stresses.

- In high productive rice growing states, the yield advantage of hybrids over high yielding inbred varieties was moderate (10-15 percent). There was a lack of parental lines and hybrids with long duration and adaptability to unfavourable ecosystems, and with suitable grain quality

- Higher seed cost is a major deterrent for large scale adoption.

- Lower market price offered and discrimination against hybrid rice produce by millers/traders.

- Very low number of breeders involved in hybrid rice breeding in the public sector.

- Lack of strong institutional mechanism for production and supply of quality seed of public bred hybrids.

- Inadequate funding support for public sector research on hybrid rice in recent years.

Potential and future directions

- Availability in abundance of qualified scientific and technical manpower for meeting the expanding seed industry need, and increased private sector participation in research and development of new plant varieties/hybrids; large and vibrant seed industry with proven capability to produce and supply quality seed

- New generation hybrids devoid of many of the drawbacks of the earlier released ones already available and many in the pipeline.

- Providing adequate funding support and human resources to the hybrid rice research and development in the country;

- Development of parental lines that can produce highly heterotic rice hybrids; diversification of CMS sources, development of heterotic gene pools, and identification of alternate sources suitable for hybrid seed production;

- Refining the seed production technology to enhance the seed yields, so that cost of hybrid rice seed can be reduced;

- Encouraging the contract farming models involving hybrid rice cultivation in different parts of the country;

- Providing a strong interface between the public sector and private seed sector for popularization of the technology;

- Efficient transfer of hybrid rice technology from the research farms to the farmers' field.

4.4 Hybrid rice development in Indonesia

Dr Satoto, Scientist/Hybrid Project Coordinator, Indonesian Center for Rice Research,

Status

Research on hybrid rice in Indonesia was initiated in 1983 with the evaluation of hybrids and introduction of breeding materials as the major activities. The adoption of hybrid rice in Indonesia has been increasing gradually since the year 2005 through both government program and non-government program. Seventy one hybrid rice varieties consisting of 21 developed in Indonesia and 50 introduced hybrid rice varieties have been released officially for commercial cultivation in Indonesia. The results of the demonstration plots indicated that heterosis range from -11 percent to 46 percent with the average of 14 percent.

Though hybrid rice seed is produced in Indonesia, the country still imports hybrid seed. During the period of 2005-2010, the highest demand for F1 hybrid seed was in 2009, wherein the country imported 4,868 tons of F1 hybrid seed (88% of total seed supply). Hybrid seed yield varied from 1.0-2.0 tons/ha. The Indonesian Center for Rice Research (ICRR) from 2006 to 2011 had been doing collaboration on licenced hybrid rice seed with private companies for seed production

Limitations

Several constraints in planted hybrid rice are as follows: hybrid rice seed shortage, pests and diseases (BPH, BB, RTV, stem borers), identical cytoplasmic source of the CMS lines among hybrids, highly fluctuating temperature and global climate change (rainfall during flowering period) affecting seed production, habit of using farmers' saved seed and limited suitable area for hybrid rice, and high hybrid seed cost due to low hybrid seed yield.

Potential and future directions

- Hybrid rice research is put as a high-priority program well into the next five-year program. The future direction of hybrid rice development is to breed hybrids that are really adapted for Indonesia, resistant to major pests and diseases (BPH, BLB, and RTV) and have better eating quality and could be developed by utilizations of local germplasm collections or combining of national and introduced lines.

- Research on hybrid rice seed production with flowering synchronization between parental lines will be conducted in different potential locations. The research will also include a refinement of cultivation technology for seed production. Strengthening capacity of public seed farms will be continued by conducting training and practices. More private seed companies and growers will be offered to participate in seed production of public hybrids.

- Research on hybrid rice cultivation to develop appropriate integrated crop management suitable for hybrid rice will be continued. Superimposed trials to adjust fertilizer rate, plant spacing, and seedling age suited to locality conditions will be conducted on the demonstration plots in different districts.

- Public-private sector partnership on hybrid seed production shall be fully established to accelerate the adoption of HR technology and some companies will produce seed of public hybrids.

4.5 Hybrid rice development in Myanmar

Ms Hla Min, Deputy Director, Extension Division, Department of Agriculture, under the Ministry of Agriculture and Irrigation of Myanmar

Status

Myanmar started the hybrid rice seed production in Northern Shan State in 2002-2003. At present, the country has already A, B and R lines. Hybrid rice in Myanmar can produce more than 200 baskets (10 tons/ha) per acre. Hybrid seed production is still carried out by the private sector and the Department of Agriculture (DOA). The hybrid rice (HR) seed production of Pearl Thwe and Basmati was carried out at Shwe Taung Farm, Wun Twin Township, Mandalay Region during 2011-2012. The average yield of F1 seed was 922.5 kg/acre (45 basket/acre) in monsoon season, 1004.5 kg/acre (49 basket/acre) for Pearl Thwe and 754.20 kg/acre (36.79 basket/acre) for Basmati in the summer (one basket is equivalent to 21 kg). In Myanmar, HR seed production is in cooperation with contact farmers and some private companies.

Limitations

- Limited yield heterosis in commercial rice hybrids by insect and pest infestation;

- Inadequate human resources in terms of number and quality of personnel available for HR research and seed production;

- Lack of collaboration among the farmers involved in hybrid rice research and development by extension work;

- Lack of effective coordination between hybrid rice research and seed production systems; and

- Inadequate incentives for development or expansion by the private seed industry of good hybrid rice variety and quality.

Potential and future directions

- Natural resources potential, private sector engagement, potential of increased productivity, olicy environment towards market economy, large skilled work force with relatively low wages; and skilled staff trained at the Shwe Taung Farm can share hybrid rice seed production to the state and regions.

- Need for significant increase in investments on research and development;

- Skills enhancement, hybrid rice seed industry facilities and infrastructure;

- Reduction of the gap between real and potential productivity of hybrid rice in a sustainable environment;

- Extension of public and private sector participation for environment-friendly agriculture production;

- Proven technology for hybrid rice seed production and development;

- Development of research work on hybrid rice production;

- Capacity building activities and human resource development for key staff;

- Development of seed processing plants for hybrid rice production;

- Provision of updated information through multimedia;

- Collaboration with NGO, INGO and other institutions.

4.6 Hybrid rice development in Pakistan

Dr Muhammad Akhter, Director, Rice Research Institute of the Agriculture Department of Pakistan

Status

The Rice Research Institute, Kala Shah Kaku initiated a time-based hybrid rice program in collaboration with IRRI in the late 1990s. In 2000, this program was strengthened by the Government with the approval of a research project titled, "Development of Hybrid Rice in the Punjab". The production of basmati hybrids was a part of this program. About 60 private seed companies have commenced importing hybrid rice seed in the country from China. A total of 3,000 to 4,000 metric tons of hybrid rice seeds were imported every year since the outset of the technology introduction.

The Institute is maintaining and evaluating 19 exotic CMS lines. Three CMS lines also have been developed locally, including two CMS lines in basmati background. However, all the CMS lines belong to WA source and the outcrossing rate of CMS line ranged from 15 to 46 percent which is quite low for getting good heterotic combination.

At present, hybrid rice is cultivated on an area of approximately 202,347 ha in Pakistan where average yield (milled rice) per hectare is 2.387 mt/ha (2012).

Limitations

- Hybrids imported so far are of inferior grain quality that is unacceptable for farmers due to lower prices in local and international market.

- The hybrids possess inadequate disease/insect pest resistance or less tolerance to high temperature during crop season.

- Supply of pure seed of parental lines for continuous development of hybrid rice is inadequate, causing non-availability of quality hybrid seed at commercial level.

- High production cost due to expensive hybrid seed and high rate of inputs application;

- Seed production cost is very high due to low seed yield high cost of hybrid rice seed (Rs. 800 per kg against Rs. 65 per Kg of local inbred variety).

Potential and future directions

Following recommendations may improve hybrid rice production and adoption in Pakistan.

- A joint venture with Europe, IRRI and China for technology transfer and training of breeders related to hybrid rice;

- Import germplasm form China and IRRI with higher yield and tolerant to biotic and abiotic stresses;

- Strengthening of infra-structure for genomic studies of basmati rice hybrids;

-Training of the hybrid rice breeders in much needed on a priority basis;

- A strict quality control regime at every level of production;

- The Government should encourage the private sector to promote the imported rice hybrids suited to local conditions;

- To lower the cost of production of rice hybrids;

- Technology dissemination and public awareness through effective extension are pre-requisites for gaining better harvest from rice hybrids.

- Training of rice breeders especially in the field of hybrid seed production technology is needed;

- The Government of Pakistan must review the unchecked import and cultivation of hybrid rice.

4.7 Hybrid rice development in the Philippines

Dr Dindo Agustin A. Tabanao, Chief, Science Research Specialist (SRS), Philippines Rice Research Institute (PhilRice) of the Philippines

Status

In 1989, the Philippines developed collaborations with various agricultural universities in China and with IRRI on hybrid rice research. The first rice hybrid, PSB Rc26H also known as Magat were released in 1994 leading to commercialization of hybrid rice. Data show that area harvested to rice started very small at 5 000 thousand hectares in 2001 and spiked to 369 000 in 2005, the highest figure to date. The following years saw a downhill pattern despite some recoveries in 2010 and 2012, the only years with positive increment over respective precedent years after 2005. Hybrid rice has demonstrated 15-20 percent yield advantage over conventionally bred varieties.

In 2012, a total land area of 1 500 hectares was used for hybrid rice F1 seed production. Data on hybrid rice seed yield suggest that seed production capacity has increased to a certain extent from levels of around 0.7 t ha^{-1} (2002 to 2004) to >1 t ha^{-1} in 2012.

Limitations

The challenges involved in seed production, cultivation per se, personnel technical capacity, economics and policy, and politics can be addressed by a multi-disciplinary approach.

Potential and future directions

The prospects of hybrid rice include (i) development of new varieties with increased heterosis, expressed as increased grain yield potential and with resilience to biotic and abiotic stress, (ii) a revolutionized F1 seed production industry at the national level, (iii) human resource with significantly increased technical capacity on hybrid rice technology, (iv) well rounded policies, and (v) a well-utilized and well-developed implementation of the hybrid rice technology across the country in general. Further, the role of the public sector may have to be redefined to adapt to the new tasks at hand that could be more important, especially with the joining of more entities into the loop.

Future detections will focus on:

- It should be recognized that the promise of hybrid rice technology as a key tool to attain rice self-sufficiency will get to actualization;

- In the aspect of seed production, optimization of seed production technology to increase seed yield, identification of additional favorable sites for seed production to increase F1 seed production area and organization of seed producers in the country to build a strong seed supply network are among the priorities;

- Requiring location-specific tandem technology for greater performance, cultivation of hybrid rice varieties and its practices must also be optimized;

- There is still a need to review and make training curricula more comprehensive and geared towards application;

- Extension work has to be more aggressive in engaging farmers.

4.8 Hybrid rice development in Thailand

Dr Amorntip Muangprom, Researcher, National Center for Genetic Engineering and Biotechnology of Thailand

Status

In Thailand, hybrid rice had been developed by Rice Department since 1979. In 2001, CP, a private company, started hybrid research by introducing eight hybrid varieties from China for yield evaluation in Thailand. In 2011, the Rice Department released its first hybrid rice variety, RDH1, giving 51 and 23 % higher yield than Pathumthani 1 and Supanburi 1, respectively.

Hybrid rice had been planted in farmer fields since 2010. Total seed production by Crop Integration Business (CP) and Rice Department were about 100 tons in 2013. Planted area of HR during 2013 was estimated at about 1,600 hectares of the rice area, largely in Nakhon Pathom. The average yields of HR on sample farms were 7.58-9.42 tons per hectare.

Limitations

- The major constraints for HR development in Thailand are limitation of male sterile germplasm and breeder teams. For the three-line system, another problem is low seed setting rate of female parents. For the two-line system, another problem is the effect of environment on sterility/fertility of female parents, leading to impurity of hybrid seed produced;

- Hybrid rice seeds cost higher than that of inbred, as much as four- to six-fold. The profit from hybrid rice cultivation is not attractive to them because the yield of hybrids is not much higher than that of inbred elite lines.

- Few research and breeder teams on hybrid rice, limitations of research stations and field testing, limitations of funding for research and investment, and low collaboration within and between countries

- Thailand has set its HR policy in its Rice Research Strategy for 2012-2016. However, it does not have a specific plan or resource allocation for hybrid rice research and development

Potential and future directions

Thailand has large diversity of genetic resources that is beneficial for hybrid rice development with a good quality and high yield. In addition, future effective collaboration between good partners (outside and inside country) to share resources and knowledge will strengthen hybrid rice development. In addition, potentially clear direction of government on hybrid research will help to overcome several limitations.

New technologies available such as genomics and marker-assisted selection can be used to explore on a large scale identifying genes responsible for ever more yield and to reduce time for HR development.

Future directions will focus on:

- Developing male-sterile lines which are suitable for Thailand; producing hybrid seeds with reduced cost; utilizing new molecular technologies to speed up hybrid rice; and product development.

- Set demonstration farms for farmer learning and multi-location testing with farmer participation

- Private sector can obtain breeding material from the public sector, especiallyfrom the Rice Department.

- Public and private sector work together for regular varietal testing and evaluation;

- The Thai Government should support R&D investment in both public and private sectors by facilitating private companies to rapidly expand HR production and to set their research stations in Thailand.

4.9 Hybrid rice development in Viet Nam

Dr Nguyen Tri Hoan, Director General, Research Institute for Food Crops of Viet Nam

Status

Vietnam started hybrid rice research in 1980 by evaluation of rice hybrids provided by IRRI and commercial production in 1992. During 2000-2005, based on CMS lines introduced from IRRI, several three-line hybrids were developed and released for commercial rice production. Subsequently, several new TGMS lines developed in Vietnam were released for commercialization. The area of hybrid rice varied from 600,000 to 700,000 ha in the total rice area of 7.5 million ha (8-9%). Hybrid rice gave an average yield of 7.0 tons/ha for the spring season and 6.0 tons/ha for the summer season.

The average yield of F1 seeds in Vietnam was 2.2-2.5 tons/ha. A total of 1,500-2,200 ha were used for hybrid seed production every year, producing 3,000-4,900 tons of hybrid rice seeds. The country still depends on hybrid seed import accounting for 70-80% of hybrid seed supply.

Limitations

- When food security of the country had been controlled and there is an immense surplus of rice, rice growers get lower profit due lower paddy price, leading to lower demand for hybrid rice cultivation;

- The living standard of Vietnamese people sharply increased during the last 20 years, which led to high demand for higher quality rice in the domestic market;

- Shortage of human resources required for hybrid rice research.

- Lack of multi-disciplinary approach in hybrid rice research;

- Weak capability in hybrid rice research and hybrid rice seed production;

- Reliance on imported hybrid varieties and hybrid seeds.

Potential and future directions

It is expected that super high-yielding hybrid rice will play a crucial role to ensure food security for rice growing nations in Asia in the future as well as high quantity of rice which can be used for feeding livestock and other animals;

The high development of biotechnology tool in recent years can be exploited for hybrid rice development to develop rice hybrid with high yield, good quality, resistance to diseases and insect and good tolerance to high-stress conditions created by climate change.

Future directions should focus on:

- To exploit the advantage of agriculture research system through the cooperation of hybrid rice breeders with biotechnologists, entomologists, pathologists, agronomists, etc.

- To develop hybrid rice having high yield, good quality, resistance to major diseases and insects and tolerance to stress conditions such as drought, salinity and submergence created by climate change;

- To strengthen research and development of super high-yielding hybrid rice not only for food security but also for providing the material for processing food for livestock and other animals;

- To support cooperation between the public and the private sector.

- To support the development of irrigation systems, required machinery, etc. for F1 seed production;

- To support the training of seed growers as well as hybrid rice growers on advanced hybrid rice technologies;

- To strengthen extension systems to transfer hybrid rice technology;

- To create a new policy to support seed companies to accumulate land at optimum locations for use for 50 years for F1 seed production similar to industry land.

RECOMMENDATIONS

1 Recommendation from thematic working groups

1.1 Hybrid rice research

- To look further, through a second phase IRRI/FAO project, into CMS lines cytoplasmic diversity: focusing research on high outcrossing rate, grain quality and resistance to biotic and abiotic stresses and development of heterotic gene pools;

- To continue cultivation and management research with focus on labor saving technology, water use efficiency and nitrogen use efficiency;

- To set up a collaborative research institute/center, with country-to-country and government-to -government collaboration, where scientists from Asia-Pacific region work together to develop good parental lines and hybrids and share the benefits,

- To study possibility of germplasm exchange focusing on mutual sharing, free access, a common platform to share germplasm like IRRI and an easier method of hybrid seed production.

1.2 Hybrid rice seed production and extension services

- To allow import/export of hybrid rice parent/hybrid seed in case of requirement;

- To focus on seed production research to develop the best seed production/cultivation and management practices;

- To strengthen good collaboration among stakeholders-public sector, private sector and farmer groups;

- To develop compensatory mechanism to protect the interest of seed production farmers in case of low seed production/loss - possibly by way of crop insurance/common fund, etc.;

- APSA/FAO/IRRI to provide/facilitate training and workshop to impart knowledge and best practices of different countries at regular intervals;

- To maintain highest quality of breeder and parent seed;

- To ensure isolation distance as required (e.g., as done though cooperative farming in Vietnam, one of the best models to follow;

- To undertake awareness program and training on post-harvest care, with the help of member countries and companies;

- To formulate uniform and transparent policy for plant quarantine protocols to encourage member countries to freely export/import of seed in case of requirement.

1.3 Hybrid Rice Development Across Asia: the Need for Regional and Country Strategy & Policies

- Conduct comparative analysis of existing regional polices on seed movement.

- Encourage respective governments to promote hybrid rice, i.e., import, testing, introduction, commercial distribution, attractive pricing of the produce.

- Technology: access to germplasm mechanism, germplasm (land races, new developed and improved lines) G@G is easy; breeding should be guided on need based, biotic and abiotic stress tolerant, suitable to consumer choice/market demand, DNA fingerprinting facilities, development of seed production capacities

- Commercial purposes: Standardization of Sanitary and Phytosanitory measures for the region (ASEAN/ SAARC member countries), export and import of commercial seeds, pest risks analysis, enforcement of IP Laws (Acts and Rules), establish trade and free flow of technologies (Access).

- Policy: Harmonize seed movement regulations (Acts and Rules) in the region, importation, testing, variety registration Infrastructure and capacity building, PPP - needs to be streamlined, uniform national polices on variety registration for commercial sale, subsidy mechanism in the initial stage, confronting commercial issues such as number of hybrids, counterfeit products - copycat /look alike

- Strengthen regional cooperation (a) Within FAO: Adoption of small-scale farming coupled with credit availability and access by financially challenged farmers, capacity building at grass roots level, and (b) Within APSA: Arranging platforms, contractual legal agreements for exchange of germplasm for commercial purposes, protecting and respecting IP, developing templates /formats, dispute settlement platforms, set within timeframes

1.4 Access to germplasm

- Governments in the Asia-Pacific countries should facilitate access to and exchange of germplasm between public, private organizations and among countries. Access policies should be transparent.

- Government and other agencies should encourage exchange of germplasms between and among public and private sectors and as well as among countries.

- The germplasm exchange and access policies should be uniform, predictable and transparent.

- Governments and agencies should encourage shuttle breeding to fast track product development. Germplasm movement of the breeding nurseries should be allowed with minimal regulatory requirements.

- APSA, ISF and FAO should come out with position and advisory papers to make policy makers aware of the benefits of clear policies for the exchange of germplasm for the food security of countries.

2 Recommendations of the Consultancy Meeting

- Governments in the Asia-Pacific countries should better facilitate access to and exchange of germplasm between and among all stakeholders and between countries. Policies should be transparent, uniform, predictable and defined.

- Governments and agencies should encourage shuttle breeding to fast-track product development; the movement of the breeding nurseries should be allowed with minimal regulatory requirements.

- APSA, ISF and FAO should come out with position and advisory papers to make policy makers aware of the benefits of clear policies for the exchange of germplasm for the food security of countries.

- Harmonize seed movement regulations for both R&D and commercial materials.

- Harmonize seed variety testing and registration processes.

- Standardize sanitary and phytosanitary measures in the region through ASEAN and SAARC member country platforms.

- Facilitate the training of manpower for seed production.

- Intensify seed production research to develop best practices for seed production, cultivation and management practices; strengthening the capacity of domestic hybrid rice seed production and promotion of community-based hybrid rice seed production.

- Conduct awareness and training on postharvest management facilitated through member countries and companies.

- Develop CMS parental lines with better diversity combining improved outcrossing, disease and pest resistance and raise the heterosis level.

- Develop lines with better resource use efficiency so that they can be used in direct seeding.

- Promote joint venture research collaborations.

- Provide enabling facilities and support to farmers, particularly smallholder farmers to adopt hybrid rice.

Introductory Address

Dr Avtar Singh Dhindsa
President
The Asia & Pacific Seed Association (APSA)

Delegates, special guests, ladies and gentlemen.

It is my great pleasure to welcome you all here today to this expert consultation on hybrid rice development in Asia.

It is most gratifying to have such a distinguished group of speakers and delegates attending this meeting. I wish to extend my special thanks to Mr. Hiroyuki Konuma and FAO for their support of this meeting and their foresight on the importance of hybrid rice to the seed industry and to the world.

This week poses many challenges for you as delegates and speakers. For many years now there has been a lot of discussions and promises on the opportunities that hybrid rice has to offer, particularly yield.

In planning for this meeting I had the opportunity to review past issues relating to hybrid rice. Twenty years ago, issues being raised were yield, seed production, germplasm, market access, uptake of hybrid rice and, surprisingly or perhaps not, intellectual property rights. This year APSA is celebrating its twentieth year as the regional association for the Asia-Pacific seed industry. Since the publication of APSA's official magazine, "Asian Seed", in 1994, many issues have highlighted these same needs and the potential of hybrid rice. While there have been major advances in yield and seed production, the issues facing the industry 20 years ago remain the same challenges for today and for the future.

So I look forward to the outcomes and recommendations from those of you attending this meeting. What are the major limitations of hybrid rice in the region and what is the potential?

I would ask you all to include in your recommendations how we should follow up on this meeting.

Meetings like this are often like movies; some are instant flops while others are blockbusters that have sequels that never make the grade. Don't let this meeting follow those trends. Make it a success with follow-up meetings that build on the achievements of this, the inaugural meeting. As the largest producers and traders of hybrid rice seed in the world, our future may rely on the outcomes and recommendations that you offer over these two days.

To our seed company colleagues: As a fellow member of APSA and a seed producer, I ask you to reach out to your fellow delegates. Like the vegetable, flower and other sectors of the seed industry, seed companies like your own are the future of the hybrid rice seed industry. You offer the industry and the consumer, the greatest potential for locally adapted, superior, high-yielding and quality varieties produced under optimal conditions in sufficient quantities to meet needs. Take the opportunities that these two days offer to contribute to the future of the hybrid rice seed industry.

Finally, I wish you all an enjoyable and productive meeting.

Welcome Address

Hiroyuki Konuma
Assistant Director-General and FAO Regional Representative for Asia and the Pacific

Dear Mr Avtar Singh Dhindsa, President of the Asia-Pacific Seed Association,
Dear Mr Chanpithya Shimphalee, Director General of the Rice Department, Ministry of Agriculture and Cooperatives, Thailand, Distinguished guests,
Ladies and gentlemen,

On behalf of the Food and Agriculture Organization of the United Nations (FAO), I wish to welcome you to the Regional Expert Consultation on "Hybrid rice development in Asia" co-organized by FAO Regional Office for Asia and the Pacific (FAORAP) and the Asia-Pacific Seed Association (APSA). I would like to convey my gratitude to the Director General, Rice Department, Ministry of Agriculture and Cooperatives of the Kingdom of Thailand for his attendance and hosting this important event in Bangkok. I also wish to express our appreciation to the President of APSA for its renewed partnership with FAO in jointly organizing this consultation meeting. FAO and APSA have a long history of cooperation, started in 1994 when APSA was established under a joint effort of FAO and DANIDA based on the recommendation made by FAO member countries at FAO's Regional Conference at that time. FAO was regarded as a father of APSA, and APSA has grown considerably and became an attractive and well established organization with the active participation of many private seed companies and other partners. In this opportunity, I wish to congratulate APSA for its effective and important role being played in seed sector development in Asia.

Rice is the staple of Asia and it is central to the food security of about half of the world population. Asia accounts for more than 90 percent of world rice production and consumption. Indeed, rice plays a significant role in ensuring food security, and alleviating hunger and poverty in the region. In recognition of the importance of rice, not only in the present but also in the future, a few months ago, FAO published "A regional rice strategy for sustainable food security in Asia and the Pacific" which was endorsed by FAO member countries at the 32nd Session of the FAO Regional Conference for Asia and the Pacific (APRC) held in Mongolia in March 2014. The strategy is to set up with guiding directions and strategic options for re-orientation of the regional rice sector with a vision of "food-secure, better- nourished and prosperous rice farmers and consumers in the Asia-Pacific region who benefit equitably from a vibrant, innovative and transformed rice sector that is more productive, efficient and environmentally sustainable by 2030". The document is available for distribution at this meeting.

One of the objectives of the Regional Rice Strategy (RRS) is to increase the productivity and nutrition value of rice sustainably to meet the increasing global demand. Sustainable increase of rice productivity would be a challenge in the years to come due to the aggravating constraints in production such as shortage of water, land and labor, and the adverse effects of climate change and environmental problems. As a result, the stagnation of rice productivity growth has been seen in many rice producing systems in recent years.

To sustain the growth of rice productivity under the mentioned-above constrains, hybrid rice (HR) technology is one of several options envisaged in the RRS. HR was planted in China for the last 40 years and has occupied around 17 million ha or more than half of the total rice area of the country. The success of HR in China was historical and phenomenal as it has provided farmers with higher yields of 30% on the average, saved 5 million ha of rice land for farm diversification or industrialization and created additional rural employment. But outside China, the adoption pace of HR technology has been very slow over the years and limited in a few countries including India, Vietnam, Indonesia, Bangladesh, Philippines, Pakistan and Myanmar with 4 million ha in total, occupying a small percentage of the rice area in each country, whereas pressing need to increase rice production in many Asian countries either for self-sufficiency or for export enhancement.

Against these backdrops, there have been growing high expectations for emerging technologies and policy developments to offer new opportunities for HR development and adoption in Asia. In China, new breakthrough of hybrid rice varieties called "super hybrid rice" which could yield more than 13 tons per hectare was reported; similarly better hybrids have also been developed by other countries and IRRI to meet the demand of growers and consumers. The increasingly active involvement of private sector provided viability for HR seed production and supply to enable the expansion of HR planting.

Ladies and Gentlemen,

FAO has a long history of supporting hybrid rice development in Asia. In 1995, FAO and IRRI jointly established the International Task-Force on Hybrid Rice (INTAFOHR) with the participation of 12 member countries. Over the years, FAO has extended support to promote HR development through consultancy meetings, capacity building and provided technical cooperation projects (TCP) to several countries including Vietnam, Myanmar, Bangladesh, Philippines, Indonesia and India. At present, one ongoing TCP on HR supported by FAO is being implemented in Myanmar. In continuation of these efforts, today's regional expert consultation on "Hybrid rice development in Asia" is jointly organized by FAO and APSA to gather expertise and knowledge on HR issues across the region to identify technical and strategic options, and formulate a Sustainable Hybrid Rice Strategy for further development of HR in this region under the insights of the Regional Rice Strategy.

The name of "Hybrid Rice", sometimes sound as a technology to benefit a big agro-enterprises or seed companies or rich farmers who can afford to buy hybrid seeds every season. I wish to emphasize the importance of hybrid rice for the benefit of smallholder farmers who produce the majority of rice in this region and constitute over 80 percent of total farmer population. Indeed, we need to move forward for "sustainability" ; for sustainable hybrid rice development towards expansion and adoption of the technology at grassroots level with sustainable local production of hybrid rice seeds, instead of creating a dependence to imported seeds. This would in tern, accelerate the expansion of hybrid rice and create a long-term benefit in hybrid rice sector as a whole.

Finally, wish to express my gratitude to all of you once again for your valuable participation to this meeting, and wish to look forward for a fruitful discussions and outcomes.

Thank you.

Official Opening

Mr Chanpithya Shimphalee
Director General Rice Department, Thailand

Mr Hiroyuki Konuma, Assistant Director-General of FAO and Regional Representative for Asia and the Pacific,
Mr Avtar Singh Dhindsa, President, the Asia & Pacific Seed Association,
Distinguished delegates,
Ladies and Gentlemen,

First of all, I would like to welcome you all to Thailand and to the Expert Consultation on "Hybrid Rice Development in Asia: Assessment of Limitations and Potential". It is my great pleasure to be assigned by the Permanent Secretary, Ministry of Agriculture and Cooperatives of Thailand, to deliver my opening remarks to and officially open the meeting.

We would like to express our heartfelt thankfulness for the initiative and precious partnership of the Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific (FAORAP) and the Asia & Pacific Seed Association (APSA) for jointly organizing this important Expert Consultation.

The importance of hybrid rice in Asia has risen in recent years due to the need of producing more rice for self-sufficiency or for export enhancement in various countries. However, the pace of hybrid rice adoption in countries outside China has slowed down during the last three years; consequently, hybrid rice area still comprises a small proportion of the total rice area in each country. These trends indicate that there are both potential and limitations of hybrid rice development in Asia. In view of this backdrop, I understand that FAO has consistently supported a number of Asian countries in various projects to disseminate hybrid rice technology through training, technology demonstrations, capability building, policy development and consultancy missions.

In Thailand, the Rice Department has been working to enhance hybrid rice productivity with research and development as well as technology transfer within farmers and private sectors so as to implement and increase especially the irrigated rice productivity. The productivity development of parental line for "F1 hybrid rice seed" has been successfully developed involving pest and diseases management. Strategic planning and formulating for hybrid rice should make a balance of productivity and resource efficiency. In addition, implementation of strategic and technology related to value-added of hybrid rice production would also enhance agricultural potential and farmers' well-being. Keeping these factors in view, the Rice Department of Thailand wishes to participate in the regional cooperation for hybrid rice development.

The Consultation is a regional floor, gathering many experts from various fields of hybrid rice across the region. The exchange of knowledge and transfer of expertise will ensure, thereby, equipping the international hybrid rice workforce with the best tool that would enable them to significantly contribute to better rice yield. We do expect fruitful outputs from the Consultation.

This Expert Consultation meeting is held in Bangkok which is a well-known tourist destination. Bangkok offers opportunities for you to find Thai culture and attractions showing an integration of local and modern city life. We wish you enjoy our hospitality atmosphere and fulfill with knowledge from experienced speakers. If there is anything that we could assist you in any possible way, please contact our staff from the Rice Department or delegates from Thailand for further information.

Eventually, I wish this Expert Consultation on Hybrid Rice Development in Asia reaches all objectives and you all have a meaningful meeting and pleasant stay in this angel city of Thailand. I would like to officially declare the opening of the Expert Consultation Meeting on Hybrid Rice in Asia.

Thank you very much.

Ensuring Food Security in Asia

Frederic Top
Global Marketing Lead
Bayer CropScience – Rice Seeds

The early years of the 21st century have seen sharply rising staple food prices, culminating in the global food riots of 2008. In 2010, the wave of protest and revolution in Arab countries was driven not only by a desire for political freedom, but also by poverty in rural communities. Rice – especially *indica* rice produced in Asia - is the main staple consumed by those communities across the world, nourishing half of the global population. Although *indica* rice prices have been quite low for some months, the expected return of large traditional importers like the Philippines, Indonesia and Bangladesh to the international marketplace, the increased consumption of rice in Africa and the effect of a potential El Niño phenomenon will most likely stop this price erosion. As the Food and Agricultural Organization (FAO) reported in its bi-annual Food Outlook Report last May, "the expected sluggish performance of the [rice] sector in 2014 may mean that, for the first time in ten years, world production could fall short of utilization, triggering a small contraction of world rice inventories carried over in 2015."

This short-term prediction may unfortunately be a sign for more long-term concerns. By 2030, it is estimated that the world will need to produce 135 million tons - or 30% - more than it did in 2010 in order to provide enough rice for a burgeoning population. In addition, change in the weather patterns (especially playing on water availability), shortage of labor in some key production areas, shrinkage of land because of urbanization and industrialization will put even more pressure on rice production. In this context, public and private bodies, governments, corporations, local communities and individual farmers must work together toward sustainable solutions. Such solutions must help feed a fast-growing global population, provide farmers in developing countries with a decent income and take a long-term view of the impact on environment.

Hybrid rice is one such innovation. As the International Rice Research Institute (IRRI) puts it, "…because hybrid rice can outyield other varieties of rice, it is a key technology that meets the increasing global demand for rice." Hybrid rice seed is produced by crossing two parental lines with very distinct genetic backgrounds. The result is a high-performance plant offering what is known in agriculture as hybrid vigor or heterosis. Hybrids have proven to consistently yield at least 20% more than the best semi-dwarf inbred varieties that currently dominate the Asian markets. When adapting their agronomic practices to hybrid rice cultivation, farmers achieve also a better return-on-investment than with the cultivation of inbred rice varieties. The investments made by rice growers in purchasing these high quality seeds are compensated through additional volumes harvested from their fields and also by savings on some inputs. All across Asia it is not uncommon to find that the adoption of hybrids, in comparison to inbreds, regularly double the farmers' net income.

Hybrid rice not only gives higher yields, but also permits to reduce the environmental footprint of rice production. The hybrid vigor is reflected, amongst other parameters, by a much more developed root system which enables the rice plant to have a better nitrogen- and water-use efficiency. This latter feature enables the farmer to switch from transplanting - the traditional way to cultivate rice in Asia – to direct seeding of the rice crop, which limits the use of water and reduces the emission of methane, a potent greenhouse gas. This gives as well the farmers more flexibility as the crop duration can be reduced by up to 14 days, allowing farmers to plant the seeds later if the monsoon season is delayed, for example. Added to that, a shorter crop cycle means less exposure to pests and disease and thus a lower risk of crop failure. Finally, direct seeding is also less labor-intensive, which is a boon for regions which today lack manpower due to a strong rural exodus, like in several Indian states.

The private sector continuously cooperates with IRRI and other partners to investigate further benefits from hybrid adoption in rice production. Aside bringing the hybrids' inherent better resilience to abiotic stresses – like temporary drought or flood - to the market, as presented above, the private sector's extended capacities in molecular biology offer the opportunity to identify, mark and introgress several useful native traits into hybrids' parental lines, thus combining the usual yield advantage of hybrids with various modes of tolerance to several abiotic and biotic stresses. For instance following Bayer's launch of Arize ® Dhani in 2008, the first hybrid tolerant to Bacterial Leaf Blight (BLB), a noxious disease occurring under wet conditions and with no chemical treatment, the private sector is now offering a number of hybrids tolerant to this plague, opening the market for hybrids in the wet season in Bangladesh and the Philippines for example. Hybrids with tolerance to blast, the most widespread rice disease, and to Brown Plant Hopper (BPH), a deadly migratory pest which sucks the rice plant's sap and transmits viruses, have just been brought to the market in India, and it is planned that other native traits like tolerance to submergence and salinity, two abiotic stresses that are increasing under the current climate change, are introduced in the years to come. In most of the cases, tolerance to these stresses are achieved through the combination of several genes with different modes of action, rendering this tolerance sustainable as it is unlikely the pathogens will acquire in a short time a resistance to all these genes. When native tolerance to certain diseases or pests is not available, like in the case of stem borers or leaf folders, the private sector is investigating other ways to bring this tolerance, with the help of mutagenesis or plant biotechnology.

Hybrids can therefore play an important role in shaping a sustainable rice production, under both the economic (yield security and secured income for the farmers, imports reduction for states), the ecologic (adaptation to climate change, better resilience to pests and diseases) and the societal (food security, livelihood development) angles.

Rice plants are mainly self-pollinating and therefore the production of hybrid rice, which necessitates crossing distinct rows of male and female plants, takes some time to be scaled up. Hybrid varieties have, over many years, boosted the yields of other more readily crossed cultivars like maize for instance. But hybrid rice, first grown in China, has taken some 30 years to develop. According to the FAO, China and India were the world's biggest rice producers in 2013, producing respectively 203 and 159 million tons of paddy rice. However average yield in India stood at 3.5 tonnes/ hectare, whereas the figure in China was almost double at 6.6 tonnes/ hectare. This substantial difference is partly due to the facts that close to 60% of China's paddies are planted with hybrids, compared with around four percent in India. Excluding China, and considering only the Asian countries (India, Vietnam, the Philippines, Indonesia, Pakistan and Bangladesh) where hybrid rice seeds have already been commercialized at a certain scale, it is estimated that hybrid rice has been planted at a mere 4 percent of the total paddy acreage of these countries in 2013. It is nevertheless certainly possible to grow the hybridization rate to 14 percent by 2022 but hybrid rice adoption has to accelerate if we want to achieve 30 percent more rice by 2030 (vs 2010). That means not only reaching out to more farmers in these countries but also expanding in new geographies like for instance Malaysia, Thailand, Cambodia and Myanmar.

To extend to such a large scale will only be possible if there is a coordinated and concerted effort between the public and private sectors to join forces and create an enabling environment. It means increasing public budgets for agriculture and facilitating Public Private Partnerships (PPPs) to research, develop, commercialise and promote new solutions including hybrid rice. The private sector values and fosters the development of PPPs with local and international public institutes as a key mechanism to deliver the hybrid technology. Collaborative partnerships can effectively bridge the gap between public and private sectors' distinctive competencies in order to meet farmers' needs.

More precisely, we believe the first role of the private sector is, thanks to the exchange of germplasm with the public sector, to create better hybrids. However, in that case government-level leadership is crucial: plant breeders require access to a wide range of germplasm to permit genetic improvement and increase yields. Governments need to ensure there are adequate mechanisms for allowing a free movement of seed material - separate from food or grain security - for further development, while ensuring protection of intellectual property rights. We think as well that the private sector is the best placed along the rice value chain to provide, with the help of the local extension services, complete farmers' training to allow a fair adoption of the technology. Last but not least, providing hybrids to the farmers is a way for the private sector to contribute to strengthen and empower the local communities, by ensuring enough food for the family, keeping rice farming as attractive for the young generation and giving employment to people in the hybrid seeds production areas.

Indeed reliable production of high-quality hybrid rice seeds is still a complex task. Establishing sustainable hybrid production requires long-term investment. It is essential that local authorities understand this point to ensure there are sound regulations established. Congruent to the necessary free movement of seed material, if the public sector wants to encourage the introduction of innovative and sustainable solutions (ultimately including those derived from plant biotechnology), it has to harmonise and implement pragmatic and science-based policy and regulatory systems around the world. Finally, farmers will be able to reap the full benefit of hybrid rice, only if the public sector is facilitating their access to credit and is improving the post-harvest situation by building and maintaining roads and storage facilities, and easing links with the millers.

Conclusion

Innovations that increase crop yields, safeguard the environment and benefit communities will play an essential role in building sustainable solutions. Hybrid rice is an innovation that can feed Asia's growing population and at the same time reduce the environmental footprint of agriculture. Today, the private sector is committed to commercializing hybrid rice in multiple geographies, including India, the Philippines, Vietnam, Pakistan, Bangladesh and Indonesia, with a network of breeding stations resulting in a comprehensive hybrid rice portfolio which is higher yielding, of high quality and well adapted to local tastes. Tomorrow, other countries like Malaysia, Thailand, Cambodia or Myanmar are poised also to make profit of this technology.

However the adoption of hybrid rice as a more profitable and sustainable solution requires considerable efforts. The many stakeholders involved must all work together to create an enabling environment to support the adoption of such an innovation by the rice farmers and their communities. The private sector sees this both as a long-term investment for its future and for the future of agriculture.

Hybrid Rice:
The Technology and The Status of its Adoption in Asia

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Introduction

Hybrid technology is based on exploitation of *heterosis*, a genetic phenomenon whereby the first-generation (F_1) offspring from crossing two genetically dissimilar parents exceeds the performance of both parents in terms of growth, vigour, and economic yield. However, not all F_1 combinations exhibit heterosis or exhibit at levels that are economically attractive. It is generally assumed that heterosis is primarily due to non-allelic interaction of genes. This effect is maximized if the parents are homozygous for a maximum number of loci. In cross-pollinating plants, this is achieved by repeated cycles of inbreeding, and this was the reason that heterosis was traditionally exploited in such plants with the most dramatic improvement of productivity recorded in maize, a cross-pollinating plant.

The discovery in China of wild abortive (WA) type of male sterility in rice in 1970 for the first time opened the possibility for modification of rice plant's reproductive system to facilitate commercial-scale exploitation of heterosis in rice. The year 1974 marked the development by Chinese scientists of the first sets of three lines (A, B, and R lines), the components of three-line system of hybrid rice technology that Chinese farmers started using in rice production since 1976. While hybrid rice production rapidly expanded in China, its introduction in other major rice-growing countries of Asia was much slower. This paper explores different aspects of hybrid rice technology development, dissemination, and its status of adoption in major rice-growing countries of Asia.

Key features of hybrid rice technology

Unlike conventional open-pollinated rice, hybrid rice technology rests on multi-step procedures that require the use of additional labour and inputs thus making it more expensive. It entails maintenance and seed multiplication of parental lines and production of hybrid seed for commercial use through mixed planting of female and male parents.

In the three-line system, the A line stands for cytoplasmic male sterility (CMS), meaning it is incapable of self-fertilization and is suitable for use as female parent in hybrid seed production. The B line is designated as maintainer line because of its ability to maintain the male sterility of A line and thereby ensuring continuity of the supply of A line seeds. The B line itself produces viable pollen grains and sets normal seeds. The R line is the restorer line and, as the name suggests, it can be any rice cultivar that restores fertility of the A line when crossed to it. The product of this hybridization, the seed set on the A line by crossing with R line, designated as F_1 seed, is the commercial product for sowing as seed in hybrid rice cultivation. F_1 emphasizes that heterosis will be limited only to the first generation of population of rice plants that grow from F_1 seeds.

In the two-line system, there is no need of maintainer line (B) since male sterility in the female parent (A) is conditioned not by cytoplasmic factors but by interaction of nuclear genes with environmental conditions, meaning the same plant can be sterile or fertile by manipulating exposure of its flowering time below and above a critical threshold of temperature (thermo-sensitive genic male sterility or TGMS) and duration of day light (photo-period sensitive genic male sterility or PGMS). PGMS lines are sterile lines that regain fertility with daylight fluctuations. Therefore, they can only be used in temperate zones. TGMS lines regain fertility when the temperature fluctuates, which means they can be used in the highlands of the tropics. In this system, any fertile line can be used as pollen parent (R) line for crossing to the male sterile line.

Agronomic practices have been standardized for maintenance and multiplication of hybrid parental lines and seed production in different agro-ecological environments. The A line is maintained by crossing with the B line in standard row ratios. This line is maintained by growing in isolation, at least 5 m away from any rice variety. The R line is also maintained by growing in isolation, at least 5 m away from any rice variety. Hybrid rice seed production technology involves a number of considerations to improve cost-effectiveness, increase seed purity (>99%), and seed yield. These are choosing appropriate seeding time and season (synchronization of flowering of parental lines); raising nurseries and seed rate; maintenance of isolation (by physical barriers, varying planting time and space); planting geometry (row ratio and planting pattern); gibberellic acid (GA_3) application (maximize panicle exertion from sheath in female parent); rouging, flag leaf clipping, and supplementary pollination (increase seed setting).

Advent of hybrid rice cultivation

Hybrid rice cultivation expanded dramatically in China since 1976 emerging as the game changer in the country's rice production with far-reaching consequences for bolstering its food security. It allowed the country to maintain continued growth in rice production while decreasing aggregate cropped area under rice that stimulated diversification of cropping. In 1992, hybrid rice accounted for 45.4% of the country's area under rice; in 2010 this figure rose to 51.8 %. In 2012, hybrid rice was cultivated in 17 million hectares (mha) out of 30 mha (58%) of rice-cropped area in China (8).

Elsewhere in Asia, the expansion of hybrid rice cultivation was limited and its impact on overall rice production was insignificant. The International Rice Research Institute (IRRI) took the lead since 1979 in the development of parental lines and hybrid seed production technology suitable for the tropics. The results of the initial efforts were disappointing, but hybrid rice programme was revived since the late 1980s and IRRI started actively collaborate with National Agricultural Research Systems through the 1990s for development of hybrid rice technology suitable for tropics. This effort was further stepped up with the establishment of Hybrid Rice Development Consortium (HRDC) in 2008 to strengthen collaboration between public and private sectors in hybrid rice technology development and dissemination.

Unlike in China, where the government provided a highly enabling environment for hybrid rice introduction through concerted institutional support including research, technology generation, subsidies to seed companies and free distribution of hybrid seed to farmers, hybrid rice cultivation in these countries started mainly with the efforts led by the private sector that didn't enjoy this level of public sector support.

Started since early 1990s, commercial cultivation of hybrid rice in these countries advanced at a much slower pace. Throughout the 1980s and the late 1990s, hybrid rice research and development activities in these countries were carried out mostly in public sector agricultural research institutions. It is only after private sector seed companies, both domestic and multinational, stepped in with significant investment in import and local production of hybrid seeds that hybrid rice production in these countries started to take off.

In India, the area under hybrid rice stagnated at levels below 1 percent of all area under rice until 2003. It picked momentum since 2005 and in 2010 hybrid rice accounted for 4.6 percent of all area under rice. In Bangladesh, hybrid rice cultivation followed a similar trend until 2004, but expanded at a faster pace subsequently with 9.5 percent of all rice area under hybrid rice in 2007, then started declining and this figure fell to 6.8 percent in 2010 (17).

Vietnam is the only country outside China where the growth path of hybrid rice cultivation was more consistent than other Asian countries. The much longer time lag between hybrid rice technology generation and its dissemination, the slow and uneven pace of its adoption reflect the difficulties inherent in adapting hybrid rice technology to humid tropical rice growing environments and socio-economic contexts of Asian small-holder farming.

Key strategies for improvement of hybrid rice technology

The introduction of the first-generation rice hybrid varieties opened a new technological frontier in attempts to break the stalemate in key innovations since the discovery of semi-dwarf genes that set the stage for green revolution. But in the real world these hybrids were beset with many shortcomings that limited their acceptability for large scale cultivation even when they were producing more yields than conventional high yielding varieties. While in China, the initial difficulties were addressed through massive state support, an entirely different scenario unfolded in countries outside China, where hot and humid growing conditions proved more challenging for cultivation of these hybrid varieties. Therefore, research efforts focused on several frontiers to address the challenges facing rapid expansion and adoption of hybrid rice technology.

A key strategy was to search for new genetic sources of cytoplasmic male sterility (CMS) in order to overcome *male sterility*-induced deficiencies in plant morphology and floral traits that inhibit outcrossing causing poor F_1 seed yields. In rice, flowering of WA-CMS lines usually starts later than the male parent (conventional rice) with other poor flowering habits such as enclosed panicle in sheath (panicle exertion), unbloomed spikelets, spikelets blooming diversely, and decreased viability of stigma (20).

The number of genetic sources for inducing cytoplasmic male sterility (CMS) has now increased from one (WA-type) to eight. The National Agricultural Research Systems (NARS) in major rice-producing Asian countries launched systematic backcross breeding programmes to transfer the CMS trait from Chinese-origin and IRRI-developed materials into the background of domestic elite breeding lines suitable for local growing conditions. These efforts have led to improvement of floral traits contributing to increase in the yield of hybrid seeds. In second generation of CMS lines developed in China, stigma exertion ranges from 66.8% to 82.3% and outcrossing from 69.5% to 75.6% compared to 39.6% stigma exertion and 35.7% outcrossing in the first-generation hybrids. As a result F_1 hybrid seed yields increased from 2.2-3.0 t/ha to 3.0-4.5 t/ha in China (4). In India, stigma exertion in new generation CMS lines was reported to range from 79% to 86% and outcrossing from 57% to 69% (5).

The wide-ranging use of the tools of molecular breeding such as, mapping desirable genes and quantitative trait loci (QTLs) on chromosomes and their linkage with various genetic markers (RFLP, RAPD, SSR, EST, etc.), marker-assisted screening of genotypes for the presence of useful genes and marker-assisted selection in early generation segregating populations, cloning and pyramiding these genes in breeding populations have contributed to overcoming the major constraints and improving the efficiency of hybrid rice breeding.

Substantial progress has been achieved in China, Vietnam, India, the Philippines and other Asian countries with this approach in developing hybrid parental lines with multiple resistances to pests and diseases. The DNA marker data base for key parents of hybrid rice comprises 75 genes or QTLs identified, 63 localized and 20 cloned for resistance to leaf blast (BL). The corresponding figures for bacterial blight (BB) are 35, 24, 7; for brown plant hopper (BPH) 27, 20, 1 and for white-backed plant hopper (WBPH) 8 and 1 (20).

Tools of molecular breeding and functional genomics are also being used to improve grain quality and plant type aimed at enhancing consumer acceptability and making further gains in yield potential of hybrid rice. In China, this approach was reflected in formulating the concept of *Super Hybrid Rice*, a plant ideotype-based breeding making wider use of biotechnology tools. The Super HR plant type is based on tall erect-leaf canopy (upper three leaves - long, erect, narrow, v-shape, thick, height of canopy: 1.2 m above), lower panicle position (the tip of panicle is 60-70 cm above the ground during ripening stage), and bigger panicle size (grain weight per panicle around 6 g, number of panicles around $250/m^2$). This plant architecture is designed to intercept solar radiation from both sides, achieve higher leaf area index and stiffer leaf blades and maximize photosynthetic function through delaying leaf senescence (12). In 2011, Super HR variety *Y liang you 2*, planted on 7.2 ha area in Hunan province of China produced grain yield as high as 13.9 t/ha (4).

The discovery by Chinese scientists in the mid-1990s of new genetic control whereby male sterility/fertility in the same plant is triggered by variations (critical phase) in daylight (photo-sensitive) and temperature (thermo-sensitive) marked another major step at improving cost-effectiveness of hybrid rice seed production. It rendered multiplication of the female line simple like any ordinary genotype through self-pollination under the fertile phase. Several markers closely-linked with TGMS and PGMS genes were identified that allowed using the MAS approach for transfer and pyramiding these genes into suitable parental lines (13).

Cultivation of two-line hybrids rapidly expanded in China with 3.5 mha (about 20 percent of planting area under hybrid rice) planted under two-line hybrids in 2010 (4). In Vietnam, TGMS lines with stable pollen sterility under critical temperatures of 23-24°C were developed that were used as female parents in development of 12 promising two-line rice hybrids (7). Two-line rice hybrids have also been developed and entered in the national trial for multi-location tests in India (19).

While the use of the tools of modern biotechnology and molecular breeding have contributed to improving hybrid rice technology, these tools are also being used in breeding open pollinated rice varieties (OPVs) with high yield potential and resistance or tolerance to a broad range of abiotic (drought/submergence/salinity) and biotic (pest and diseases) stresses. This helped not only stabilizing yields of OPVs across production environments but also pushing them into more marginal environments raising the bar for the hybrid varieties to compete with OPVs.

Increasing the level of heterosis is, therefore, seen as the key technological challenge for maintaining a sustainable lead of hybrid varieties over OPVs in grain yield that would boost competitiveness of rice hybrids and make hybrid rice cultivation economically more attractive. One of the options in this effort is wide hybridization between *indica* (grown in tropics) and *japonica* (grown in temperate zones) sub-species of rice. This has been facilitated by the discovery and introgression of wide compatibility (WC) genes to overcome the problem of sterility in wide hybrids.

In a 2008 trial conducted in Vietnam involving six *indica*/*japonica* and eight *indica*/*indica* type hybrids, the *indica*/*japonica* hybrids out yielded the *indica*/*indica* hybrids by an average 5.5% (12). In China, *indica*/*japonica* rice hybrids were reported to produce on average 6-17% more yield compared with the *indica*/*indica* hybrids (4). Mapping of QTLs for grain yield and their introgression into parental lines, identification of restorer lines with good combining ability that leads to maximizing non-allelic interaction of genes (*epistasis, overdominance*) holds the promise for increasing the level of heterosis.

Current state of hybrid rice production

In almost all major rice growing countries in Asia, efforts on hybrid rice research and development have morphed into a wide ranging collaboration and partnerships between the public and private sectors. This has been facilitated in some countries by enactment of legislations to protect intellectual property rights paving the way for private sector investments in development of hybrid parental lines and organizing local production of hybrid seeds.

While the public sector institutions remain engaged in undertaking basic and applied research in hybrid rice technology development, the private sector is taking the lead in technology dissemination through import, local production, and distribution of hybrid seeds. The prospect of commercialization of hybrid rice technology remains the major driving force for sustaining the focus on hybrid rice despite inconsistent performance of hybrid varieties across production environments and over the years.

In Vietnam, the area under hybrid rice increased consistently from 11 094 ha in 1992 to 709 270 ha in 2009 (9.5 percent of total rice cropped area), but average hybrid rice yields increased from 6.22 t/ha in 1992 to 6.50 t/ha at just 0.4 percent annually. The average yield advantage of the hybrids relative to open pollinated varieties declined from 39.5 percent in 2005 to 24.3 percent in 2009 (Hoan Tri). In the Philippines, hybrid rice area rapidly expanded from 5,371 ha in 2001 to 368 634 ha in 2005 and then started declining with 197 600 under hybrid rice in 2009 (7.6 percent of total rice area). Average yields of hybrid varieties increased from 5.44 t/ha in 2001 to 6.12 t/ha in 2009 at just 0.9 percent annually. Average yield advantage of hybrid rice production was reported to be 8-14 percent higher than inbred varieties. Out of the total 44 hybrid rice varieties released in the country, the public sector contributed 20 and the private sector 24 varieties (14). In Indonesia, in a farm-level trial conducted in 2011 involving six released hybrid rice varieties, the average yield advantage of these varieties relative to highest yielding inbred check was found to range from 4.4 percent to 19.0 percent. Of the 71 hybrid varieties released, 21 varieties have been developed in the country and 50 have been introduced by the private sector mostly from China. (15)

In India, hybrid rice currently accounts for 4.4 percent of the area planted to rice in 2012. Of the 66 hybrid rice varieties available in India today, 31 were developed in the public sector and 35 in the private sector (6). The average yield advantage of hybrid varieties compared to inbred check varieties were found to range between 7 percent and 19 percent in a multi-location test conducted at five locations over 2009-2011 (16).

In Bangladesh, hybrid rice cultivation, started in 1999-2000, reached its peak in 2007-2008 with 1.1 million hectares planted to hybrid varieties. It then started declining and in 2012-2013 the area under hybrid rice dwindled to 640 000 ha out of 11.39 mha under rice. (18). The average yield advantage of hybrid rice relative to inbred checks varied in the range from 24 percent to 29 percent between 2004 and 2007 (3). Six promising hybrid varieties produced on average 4.5 percent more yield than inbred checks in a yield trial conducted at four locations during the 2010-2011 *Boro* season (1). The total number of hybrid varieties released in the country stands at 107. Of these, private seed companies introduced 93 varieties and only five were developed in public research institutions (6).

Overwhelming reliance on imports of hybrid seed (F_1) is still a key feature of hybrid rice cultivation in many countries despite successes achieved in increasing yield level and cost-effectiveness of hybrid rice seed production. In India, average F_1 seed yield increased from about 1 t/ha in the early 1990s to 1.5-2.5 t/ha at present. In Bangladesh, four publicly developed hybrids yielded on average 2.15 t/ha of seed in a trial conducted in 2011-2012 (1).

Imports and local production by private seed companies account for more than 90 percent of F_1 seed supply in the country. In Vietnam, hybrid seed yields rose from 0.3 t/ha in 1992 to 2.5 t/ha in 2009. In Indonesia, average seed yield of 2.3 t/ha was reported in a trial conducted in 2008. Imports contributed 66.6 percent of the total supply of hybrid rice seeds in the country in 2010 (17).

Key issues limiting adoption of hybrid rice in selected countries

Despite substantial efforts invested and policy support from national governments, adoption of hybrid rice technology in Asia, particularly in countries outside china, is yet to take off on a long-term steady and consistent growth path. Unlike the adoption of high-yielding open pollinated varieties, a major segment of hybrid rice industry is dominated by the private sector to fill the annual requirement of seed supply because farmers can't use seeds saved from previous harvests and need to buy F_1 seeds every planning season at premium prices. Because of the high cost of seed production due to both environmental and organizational complexities of hybrid rice seed production technology, cost-effectiveness and profitability of cultivating hybrid varieties relative to best-performing open pollinated varieties remain at the top of the issues standing in the way of large-scale expansion of hybrid rice cultivation. The major issues that limit adoption of hybrid rice in selected countries in Asia are summarized below:

Indonesia

- Currently available hybrid rice varieties do not show significant superiority compared to inbred, mainly arising from increased vulnerability to pests and diseases and lower grain quality.

- Hybrid seed quality is less than optimum in terms of purity and viability.

- Influenced by dynamic seasons and pests, farmer stewardship and grain price, hybrid rice seed production is still not economically feasible to be conducted locally.

- Government is yet to produce a clear development roadmap for hybrid rice particularly with regard to support to industry that has invested in building local seed production.

- Seed subsidy program is poorly targeted distorting the market mechanism and discouraging private sector investment (9).

Bangladesh

- Current varieties, most of which are imported from China, are not well adapted under Bangladesh conditions.

- Low amylose content of these varieties leads to stickiness upon cooking which does not fit taste requirement of local consumers (10).

- Most varieties lack tolerance to major diseases.

- Cost of hybrid seed production is much higher than the cost of the seed of the open pollinated varieties.

- Farmers are not much familiar with hybrid rice cultivation techniques and methods. There is lack of effective campaigning by government field extension personnel in support of hybrid rice production (2)

Philippines

- Low seed production
- Limited trained human resources in hybrid rice development
- Short storage period of F_1 seeds and seeds of parental lines
- High cost of seed production
- Limited support from the government Department of Agriculture on hybrid rice (11).
- Lack of extension/promotion support.
- No seed subsidy/assistance to farmers.
- Limited credit assistance (14)

India

- Marginal heterosis - unattractive for commercial exploitation
- Narrow genetic base - a major concern
- Limited choice of hybrids for unfavourable ecologies
- Susceptibility of parental lines to major pests and diseases
- Meeting grain quality requirements to satisfy diversified consumer preferences (5).
- No strong institutional mechanism for production and supply of seed of public sector bred hybrids.
- Continued 'Trust Deficit' between public and private sector institutions in exchange of knowledge and material.
- No uniform subsidy component on hybrid seed cost, which varies from State to State (0 to 100 percent)
- The condition that notified hybrids alone are entitled for subsidy on seed cost, restricts adoption of many good truthfully labelled hybrids from the private sector
- Lack of focused extension strategy for popularization of new hybrids of promise.
- Price discrimination against hybrids because of apprehended low percentage head rice recovery.
- Number of breeders engaged in hybrid breeding especially in the public sector, is too low (<20) as compared to China (>150) (16).

Vietnam

- Lack of hybrid combinations with good grain quality, tolerance to pests and diseases, short growing duration (105-115 days) that meet requirements of the various agro-ecological zones of the country.
- Limited genetic materials required to develop hybrid rice varieties suitable for the Southern part and resistance to pests and diseases for the varieties targeted for summer season cultivation crop in the Northern part of the country.
- Currently, hybrids are resistant to blast disease but susceptible to major diseases such as bacterial leaf blight, sheath blight. Hence, they perform well only in the spring season due to lower disease pressure.

- Conditions are not suitable for hybrid rice seed production in the North where hybrid rice is mostly cultivated due to erratic climate and late harvesting time. Hence, there is a need to develop alternative seed production sites

- Lack of strong local seed production system involving both public and private sectors.

- Reluctance of small farmers to locally produce hybrid rice seeds due to greater risk, very high financial requirement, lack of proper ware house, space and cold storage for unsold seed, unavailability of pure CMS lines and farmers' preference for imported seeds (7).

China

Although the country is pioneer of hybrid rice and leads the world in hybrid rice technology development, a number of factors have contributed to much slower than in the past rates of expansion of hybrid rice cultivation. The constraints also reflect the maturity of hybrid rice industry in China unlike in other countries. Some of these are as follows:

- Disconnect between basic research and technology development. Basic research including innovations in breeding technology remains firmly in the hands of public research institutes and universities. The seed enterprises, many of them in the private sector, that are the main vehicles of hybrid rice promotion have limited access to those researches and as a result their capability for variety breeding remains constrained.

- Asynchronous development of agricultural mechanization tailored to agronomic and management practices for cultivation of hybrid parental lines and seed production. This poses a major challenge in view of shortages of manual labour due to demographic shifts and increased migration from rural to urban areas.

- Restrictions imposed by industrial policy and commercial environment. Market access of new varieties controlled through variety certification system remains restricted and as a result some varieties with potential for breakthrough remain out of the market that cannot meet the demand of seed enterprises (8).

Conclusion

It is evident from the foregoing discussion that superiority of rice hybrids in grain yield compared to open pollinated varieties remains approximately at the same level as in the past with the modest yield gains fluctuating in a broad range. This is a common issue in all Asian countries that are actively engaged in introduction and expansion of hybrid technology as an avenue for rapidly increasing the production of rice, the key grain cereal vital for food security.

In other words, little advances were achieved in increasing the level of heterosis since the first generation of hybrids was launched in the 1970s. Bulk of the research efforts were directed at improving the structural features of rice plant that facilitate cross-pollination and agronomic practices that improve out-crossing and seed-setting on female parent through better synchronization of flowering time, planting geometry to optimize pollen dispersal and other management factors.

The adaptation of the plant type concept and the molecular breeding platform to rice breeding including hybrid rice has led to improvement in magnitude and stability of grain yield of both open pollinated and hybrid varieties. The expectation that improved capability to induce cross-pollination in rice and easing the production of F_1 seeds using genetically dissimilar parents would automatically lead to exhibition of heterosis at significant levels has not been justified. The yield advantage of hybrids conferred solely by heterosis in many instances becomes so marginal that its exploitation raises questions on the ground of profitability and cost-effectiveness.

Mere genetic dissimilarity of parental lines is not adequate; they also have to be homozygous for a maximum number of loci in order for maximization of non-allelic interaction of genes believed responsible for exhibition of heterosis. On-going research to introduce greater genetic diversity in hybrid parental stock through inter sub-specific hybridization involving *indica* and *Japonica* rice varieties is a promising step in efforts to elevate the level of heterosis. But more basic research is needed to unlock the underlying genetic mechanism of heterosis in rice to make its use economically attractive and render hybrid rice technology unquestionably competitive relative to high-yielding open pollinated varieties.

Lack of adequate tolerance to major pests and diseases is a major constraint to large-scale adoption of hybrids, particularly in hot and humid regions of Asia. Aspects of grain quality such as lower amylose content of hybrids don't fit the taste requirement of consumers in many countries and limit their acceptability. Sub-optimal grain quality of hybrids also reduce market price relative to open pollinated varieties. In almost all countries, hybrid seed production is the most pressing issue because of the costs involved, the challenges posed by weather-related constraints and the requirements of logistics and organizational management of its production in small-holder farming without state subsidies to provide incentives to farmers to adopt hybrid varieties. Various forms of partnerships and collaboration between public and private sectors have emerged as the institutional model for stepping up hybrid rice seed production.

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The Economics of Hybrid Rice in Asia: Technology Adoption, Public Expenditures and Private Incentives

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1. Introduction

During the last two decades, several studies suggest that hybrid rice can contribute to food security in developing countries, especially in parts of Asia where rice production is so vital to the rural economy and where rice remains a staple of both urban and rural food consumption (Spielman et al., 2014; Li et al., 2010; Lin and Pingali, 1994). The higher yields attributable to hybrid rice have the potential to increase food availability for farm households' own consumption, while also increasing farm incomes through sales of larger marketable surpluses. These larger marketable surpluses can result in increased food supplies that reduce or stabilize prices for both urban and rural food-insecure households (See e.g., Lin and Pingali, 1994 and Xie and Hardy, 2009).

To a large degree, these declared benefits of hybrid rice have been realized in China, where widespread adoption of hybrids is credited with improving food security and feeding an estimated 60 million additional people per year (Li et al., 2010). Despite the apparent success of hybrid rice in China, however, its diffusion has been much slower in many other Asian countries. While over half of total area under rice cultivation in China is allocated to hybrid rice, its cultivation in other Asian countries accounts for a relatively small portion of total rice area. In India, Indonesia, and the Philippines, for example, less than 5 percent of total rice area is used for hybrids, while only about 7 percent of total rice area in Bangladesh and 10 percent of total rice area in Vietnam are under hybrids. The sluggish adoption of hybrids is particularly notable in South Asia, where overall growth in rice yields has been slow in recent decades and where policymakers, scientists, and others have repeatedly called for investments to accelerate productivity growth (Janaiah et al., 2002; Xie and Hardy, 2009).

There are several challenges constraining the widespread adoption of hybrids outside of China. These challenges include not only technical barriers associated with the development of suitable breeding and multiplication technologies, but also institutional challenges–failures of both the state and market that require strategic interventions and a careful balance of roles played by the public and private sectors in developing and promoting hybrid rice.

This paper addresses these issues with an analysis of the factors that encourage or inhibit the discovery, development and delivery of hybrid rice in South Asia, with a particular emphasis on the Indian and Bangladeshi experience to date. This analysis draws on the role of

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innovation systems in product development described by Sumberg and Reece (2004), and mirrors the analysis by Gerpacio (2003) on maize development in Asia. Specifically, the analysis examines (1) key actors, assets and processes engaged in the production, exchange, and use of new technologies; (2) the actions and interactions that enable these actors to invest in process innovations; and (3) the policies and institutions that influence their actions and interactions. Such an analysis of the complex systems surrounding hybrid rice can provide a clear picture of the precise areas in which policy interventions can result in accelerated development and delivery.

The remainder of this paper is organized as follows. Section 2 introduces some basic economic concepts related to technology adoption and the decision-making process by which farmers decide whether or not to adopt a particular technology. Section 3 discusses the data and data sources used in this study. Section 4 provides a historical and contextual background of hybrid technologies in general and some of the specific concerns regarding hybrid rice. Section 5 reviews the history and patterns of hybrid rice adoption in India and Bangladesh, identifying key constraints, challenges, and risks specific to the Bangladeshi experience. Section 6 explores the technical, social, economic, and policy dimensions of hybrid rice. Finally, Section 7 concludes with a set of actionable policy recommendations for further research, development and delivery of hybrid rice in India and Bangladesh.

2. Hybrid rice adoption

Despite the heralded benefits of new agricultural technologies like hybrid rice, widespread adoption is, at least initially, a slow process. Economic theory suggests that individual farmers evaluate the expected utility (or pleasure) they would attain from consuming food and non-food items with the income and food produce they derive from agricultural production under various available technologies. Since agricultural production is, in almost all cases, dependent upon weather, which is inherently risky, farmers must consider the possible output from different technologies under different states of the world as well as the probability that various states of the world are actually observed. If farmers expect that adopting a new technology will maximize their total utility, then economic theory would suggest that the farmer will adopt the new technology. There are obviously several different considerations that go into this equation, including seed costs (inclusive of any subsidies), the quantity of seed required), any complementary inputs that are required (such as irrigation, chemical fertilizers, herbicides, pesticides, etc.), labor requirements, yields (including consideration of whether the output is to be consumed at home or marketed), output price and farmers' idiosyncratic preferences toward underlying uncertainty.

Farmers make these decisions in an environment of uncertainty, in which they do not know what the resulting production will be, nor do they necessarily know the appropriate application of complementary inputs such as chemical fertilizers and herbicides. The degree of uncertainty and farmers' aversion to such uncertainty often result in sub-optimal decisions. Farmers will never be able to resolve all uncertainty such as risks related to abiotic stresses (such as droughts, floods, etc.) or biotic stresses (such as pest infestations), but many of the uncertainty can be resolved over time through learning processes. When it comes to agricultural production, farmers learn both by their own experiences as well as by observing their neighbors (Foster and Rosenzweig, 1996; Conley and Udry, 2010; Ward and Pede, 2014). As farmers gain more direct and indirect experience with a technology, they learn more about its performance as well as best practices for its use.

All of these different factors complicate the decision-making process, and the interaction of these leads to different patterns of adoption across different contexts. As far back as Griliches (1957), researchers have observed technology diffusion to follow an S-shaped (or logistic) trend function (Figure 1). The very first individuals to adopt a new technology tend to be progressive innovators, but given supply constraints, uncertain and uneven yield performance, and their rarity, the cumulative rate of adoption is relatively sluggish. As supplies increase and the technology becomes more commercially available, and as many of these other constraints are overcome, there is a period of rapid diffusion, during which the vast majority of the cumulative adoption takes place. Eventually, this period of rapid diffusion subsides, after which follows another period of slow diffusion in which only a few of the remaining farmers who have not yet adopted decide to take up the technology. Very few, if any, technologies achieve a total penetration of their target market. Most reach some steady state level of diffusion well below totality. This varies depending upon the technology as well as the particular context. Adoption curves for the same technology in different contexts may look very different, with different origins, different slopes throughout the cumulative diffusion process, and different steady state levels of ultimate adoption (or ceilings). Studying the diffusion of hybrid corn (maize) in the United States, Griliches showed that, for example, hybrid corn cultivation began much earlier, widely diffused at a faster rate and settled to its ceiling of near 100 percent of total corn area earlier in Iowa than in other states.

Throughout the remainder of this chapter, we will explore some of the supply- and demand-side factors that will ultimately play a role in whether and the pace with which hybrid rice is adopted, with a particular geographic focus on experiences in South Asia, particularly India and Bangladesh.

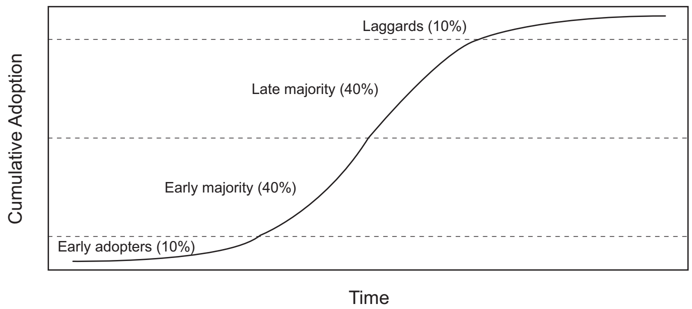

Fig. 1. The process of technology diffusion

3. Data and data sources

Data used in this paper were drawn from both primary and secondary data sources. Primary household data from India were drawn from two sources. The first source is a household survey on rice cultivation and the rice seed market during 2008–2009 that was conducted by the Francis Kanoi Marketing Research Group survey (Francis Kanoi, 2010), a commercial entity. The Francis Kanoi survey covered 11 076 randomly selected rice farmers across 139 districts (districts with more than 30 000 hectares under rice cultivation) in the 16 major rice-growing states of India for the 2008–2009 agricultural season.

The second source is a household survey conducted during the last two quarters of 2010 and the first quarter of 2011 under the auspices of the Cereal Systems Initiative for South Asia (CSISA), a project led by the International Rice Research Institute (IRRI) and the International Maize and Wheat Improvement Center (CIMMYT). The survey covered 2 627 randomly selected households across districts where CSISA was operating in Bihar, eastern Uttar Pradesh, Haryana and Tamil Nadu. While the Francis Kanoi survey approaches statistical representativeness of India's main rice-growing states, the CSISA survey provides greater depth and insight into the farming systems and socioeconomic characteristics of rice-growing households.

Primary household data from Bangladesh are drawn from the Bangladesh Integrated Household Survey (BIHS) conducted by the International Food Policy Research Institute (IFPRI) in late 2011 (Ahmed et al., 2013). The BIHS contains data on 5 503 households drawn from 64 districts in the seven primary divisions and is representative at both the national and divisional levels. The survey covers topics that are standard to most income and expenditure surveys in developing countries as well as topics related to agricultural production, plot utilization, input use and postharvest management.

Secondary data and analysis were drawn from a range of sources, including peer-reviewed journal articles, government statistical reports, project reports and industry documents that are cited throughout the paper. Additional insight was gathered from a series of unstructured interviews held from 2008 to 2010 in several locations across both India and Bangladesh. See Spielman et al. (2012, 2014) for further details.

4. Hybrid technologies and smallholder farming

The primary characteristic distinguishing hybrids from traditional varieties is heterosis (or hybrid vigor), which describes the increase in yield, uniformity, or vigor of cultivated plants that results from genetic contributions derived from the crossing of distinct parental lines. Its economic value lies in the fact that yield gains conferred by heterosis decline dramatically after the first generation of seed (F1), thus compelling farmers to purchase new F1 seed each season in order to continually realize these yield gains. This contrasts with conventional open-pollinated varieties (OPVs) or self-pollinating inbred varieties (e.g., rice), in which harvested grains can be stored and used as seeds in the following year.

The unique advantage conferred by heterosis has been a driving factor behind the commercial success of hybrid maize, sorghum, millet, cotton and many horticultural crops in both industrialized and developing countries. Success has followed a general pattern that first emerged during the early twentieth century with public research on maize hybridization in the United States. The discovery of maize heterosis by U.S. scientists led to the development of a lucrative maize seed industry during the 1930s, highlighted by the entry of many small and medium-sized seed companies breeding and marketing hybrid maize seed to farmers (Fernandez-Cornejo, 2004; Fuglie et al., 1996). By the 1960s, almost all maize cultivated in the United States was grown from hybrid seed. The technology spread rapidly to developing countries in Latin America, Sub-Saharan Africa, and Asia (Morris 1998). Hybrids of other crops such as pearl millet, cotton, sorghum and many vegetable crops have also made inroads in developing countries (see, for example, Pray and Nagarajan, 2010).

In spite of the benefits of hybridization to both breeders as well as farmers, there are several substantial criticisms that are often raised regarding the suitability of hybrid seeds in developing-country agriculture. First is the concern that seasonal or annual purchases of hybrid seed are too costly for many small-scale, resource-poor farmers in developing countries (Kuyek, 2000). Second is the concern that hybridization leads to greater risk in the form of (1) lower *in situ* genetic diversity and greater susceptibility to pests and disease and (2) fewer management alternatives to cope with weather-related production risks. A third concern is that hybridization concentrates market power in the hands of a few companies that are able to breed and market superior hybrids (Kuyek, 2000). While there is some evidence of concentration in some markets for both seeds and traits, the levels of concentration are estimated to be moderate at present and suggestive of room for further growth in Asia (see, e.g., Spielman et al., 2014; Fuglie et al., 2011). Finally, there are concerns about the inferiority of the current generations of hybrid rice in terms of pest and disease resistance, taste, cooking qualities, and yield variability under stress, particularly in South Asia (Janaiah, 2002; Janaiah et al., 2002; Janaiah and Hossain, 2003 and 2005).

Importantly, these criticisms of commercially marketed hybrid seeds for smallholders highlight the importance of trade-offs in the development and delivery of hybrid rice to smallholders. This means that context and site specificities are key to weighing the aggregate benefits of higher yielding rice against the costs of purchased seed, forgone *in situ* biodiversity conservation, and possibly lower marketing margins for inferior grain. This makes the broad promotion of hybrid rice less clear-cut than immediately suggested, although these issues are overlooked in India's agricultural strategy that aims to introduce hybrid rice on 25 percent of all cultivated rice area by 2015, or Bangladesh's similarly supportive disposition to hybrid rice in its national development strategy.

5. Findings

A starting point in this analysis is an evidence-based deconstruction of the rhetoric against hybrid rice cultivation in India and Bangladesh. For instance, consider the argument that own-seed saving strategies are preferable to market purchases. In fact, seed replacement rates for rice are already high in both India and Bangladesh even in the absence of significant acreage under hybrid rice. Rice seed replacement rates were estimated at 26 percent in India and 25 percent in Bangladesh in 2007 (Seednet, 2007; BSGDMA, 2007). And in Bangladesh, data from the BIHS suggest that 15 percent of all rice-growing households pursue combined strategies for seed acquisition. Specifically, while almost 45 percent of farming households in Bangladesh reported using saved rice seed in 2010-11, more than 75 percent also reported using purchased rice seed from private sector sources.

Relatedly, consider the argument that farmers are paying extraordinarily high prices for hybrid rice seed because these markets are monopolized by a small number of companies acting in concert. A look at the evidence suggest that while hybrid rice seed is indeed costlier than OPV rice seed (hybrid rice seed is sold at approximately 10 times the price of OPV seed in both countries), these costs are partly defrayed by a lower seeding rate and higher yields.[2] Likewise, while there is some evidence to suggest that the markets for seeds and traits are moderately concentrated both globally and nationally (see Fuglie et al., 2011; Spielman et al., 2014), there is insufficient evidence to argue that hybrid rice seed companies in India and Bangladesh are engaging in strategic behavior, forming cartels, or otherwise reducing competitiveness in these markets to extract monopoly rents from farmers. Estimates from Kumar (2008) and Viraktamath and Nirmala (2008) suggest that there are between 30 and 60 companies engaged in developing hybrid rice varieties, while Spielman et al. (2014) suggest that the private sector is investing US$6–$12 million per year in hybrid rice research.

Next, consider India's specific experience. Systematic research on hybrid rice in India only began in 1989 under a relatively small programme of the Indian Council of Agricultural Research (ICAR), focusing on hybrids for irrigated cultivation (Janaiah, 2002). Subsequent research programs between 1991 and 2008, totaling approximately $8 million, were funded by several international organizations, multilateral donors and charitable foundations (Spielman et al., 2013).

Hybrid rice development in India has been hampered by several non-trivial scientific and technical challenges: a narrow germplasm base for breeding activities, poor pest and disease resistance in early-generation hybrids, and difficulties in managing large-scale seed multiplication efforts (Xie and Hardy, 2009; Janaiah and Hossain, 2005 and 2003; Janaiah

[2] Recommended seeding rates ranging from 15–30 kg/ha for transplanted hybrid rice, depending on agroecological conditions and other management practices. These seeding rates are generally substantially lower than rates for inbred rice. See Virmani, Siddiq, and Muralidharan (1998) and Xie and Hardy (2009) for further discussions.

2003, 2002 and 2000; Janaiah et al., 2002). These challenges were exacerbated at the farm and household levels by grain quality issues that affected consumer acceptance, low market prices offered for the inferior grain, and the relatively higher costs of seed and fertilizer inputs, and limited availability of quality seed (Janaiah, 2010, 2003, 2002; Chengappa et al., 2003; Ramasamy et al., 2003). Although many solutions to these problems have since been found or are under development, hybrid rice still represented just 6 percent of India's 44 million hectares under rice cultivation as of 2008–09 (Baig, 2009; Francis Kanoi, 2009).

Somewhat surprisingly, the proportion of area under hybrid rice has grown at a rate of about 40 percent per year since 2005, with the majority of this growth attributable to cultivation in northern and eastern states such as Jharkhand, Bihar, Uttar Pradesh, Uttarakhand and Chhattisgarh (Viraktamath, 2011; Viraktamath and Nirmala, 2008). Francis Kanoi (2009) reports that 24 percent of surveyed rice farmers in Bihar and 15 percent in Uttar Pradesh have tried cultivating hybrid rice at some point in the past. Likewise, according to data from the CSISA baseline survey, 53 percent of surveyed farmers in selected districts of Bihar and 15 percent in selected districts of eastern Uttar Pradesh have cultivated hybrid rice.[3] These northern and eastern areas are characterized by limited irrigation infrastructure, less vibrant input markets, lower modern rice variety adoption rates and lower rice yields when compared to India's irrigated cropping systems in the northwest and south. Thus, they may also be areas where farmers are most likely to observe and appreciate the yield gains associated with hybrid rice when compared against their current yields.

According to Francis Kanoi (2009) data, farmers' awareness of hybrid rice is higher in northern states (Uttarakhand, Uttar Pradesh, Haryana, and Punjab) and central states (Chhattisgarh and Madhya Pradesh) than in southern states (Karnataka and Tamil Nadu) or eastern states (Jharkhand, West Bengal and Bihar) – figures that correlate with regional adoption patterns. These data also suggest that while a lack of awareness and the high cost of seed are primary constraints to hybrid rice cultivation among surveyed farmers (and not poor grain quality or lower market price for hybrid rice grain), there is significant regional variation.

Data from the CSISA survey similarly suggest that a wide variety of issues are influencing hybrid rice adoption in India, ranging from information constraints to production constraints. In terms of the distributional aspects of hybrid rice adoption, data from the CSISA survey indicate that hybrid rice adoption is concentrated among relatively wealthy farmers. Nearly 75 percent of all hybrid rice adopters in the CSISA survey have incomes above the poverty line and more than half of all adopters fall in the upper-middle or upper income quintiles. See Spielman et al. (2013) for further details.

These figures suggest that the market for hybrid rice seed in India is growing even despite the rocky start. However, prolonged growth of the hybrid rice market will require further

[3] Given the high rates of hybrid rice adoption reported in the CSISA baseline survey relative to other sources, it is worth noting possible issues relating to data quality and accuracy. One issue is that although the CSISA baseline survey specifically asked farmers about their familiarity and experience with hybrid rice, it is possible that farmers, enumerators, or both did not accurately distinguish among hybrid rice, high-yielding (modern inbred) rice varieties, and traditional (land race) rice varieties. Alternatively, it is possible that the districts covered by the CSISA baseline survey were characterized by progressive farmers or more vibrant seed and input markets relative to all-India figures, thus resulting in high rates of hybrid adoption. That said, the CSISA baseline survey data are not implausible in light of state-level adoption rates reported by Francis Kanoi Marketing Research (2009).

investment to ensure that hybrid rice is both a productivity- and profit-enhancing venture for India's smallholder farmers.

Next, we turn to Bangladesh's experience with hybrid rice. Hybrid rice research began at the Bangladesh Rice Research Institute (BRRI) in 1993 but expanded as a result of national crisis rather than strategic product development. Hybrids were first distributed widely in Bangladesh in 1998/1999 when floods caused a shortfall in domestic seed supply, in response to which the government allowed private companies to import 2,000 metric tonnes of hybrid seed (Azadi et al., 2008). These first hybrids were introduced for the dry-season, irrigated *boro* rice crop, and were sourced primarily from China.

Encouraged by the yield gains offered by hybrid rice, the government expanded its research program with funding and technical support from several international organizations and donors (Ar-Rashid et al., 2011). Since about 2010, several companies expanded beyond bulk seed imports and began importing parental lines from China to conduct seed production in Bangladesh. Several firms have also invested in their own adaptive research and product development programmes for hybrid rice, as has BRAC, a large non-governmental organization (NGO).

The area under hybrid rice cultivation in Bangladesh peaked in the 2007-08 *boro* (winter) season, Bangladesh's main rice-growing season, at 22 percent of total *boro* cultivated area, or 9 percent of all rice-cultivated areas in the country, and has been concentrated in the northern districts where small-scale irrigation enables *boro* season cultivation (Kürschner et al., 2010; Hossain, 2010). A study conducted in 2004-05 by Azad et al. (2008) reports that hybrid yields beat inbred varieties by 15–30 percent, little change in production costs, increases in the prices offered for hybrid rice grain, and adoption spreading from larger-scale farmers (farms of greater than 2.0 ha) to medium-scale farmers (0.5–2.0 ha).

Notably, Bangladesh has relied more on technology transfers in the form of hybrid rice seed and breeding material from China than it has on own, in-country R&D (Ar-Rashid et al., 2012). This approach is significantly different from India's approach, where more concerted investments in public and private breeding have led to the homegrown development of rice hybrids for the Indian market. But while hybrids may represent a greater proportion of area under rice cultivation in Bangladesh than in neighboring India, despite India having more developed and well-funded hybrid rice research programmes, there is some inherent risk in Bangladesh's approach. First is the risk associated with the distribution of seed that may be poorly adapted to Bangladesh's agroecological context, crop management practices, farming systems and consumer preferences.

This last aspect appears to be especially troublesome for a heterogeneous product like rice grain, because grain not suited for the tastes and preferences of consumers often results in a thin output market and lower prices. Given higher seed costs (compared with conventional inbred varieties), higher expenditures on complementary inputs, and lower output prices, margins between returns and costs become increasingly narrow. We do not have adequate data to state unequivocally that this mechanism has contributed to the decline in area under hybrid rice cultivation in Bangladesh, but prior studies and feedback from many key informants suggest that grain quality has been the major issue impeding widespread adoption of hybrid rice in Bangladesh (See Azad et al., 2008).

The second risk relates to the issue of market concentration emerging in the hybrid seed market, a concern described earlier that seems to accompany emerging markets for hybrid seed in many countries. At present, the issue of market concentration and monopoly pricing is not an in issue in Bangladesh, due primarily to the fact that the Bangladesh Agricultural

Development Corporation (BADC), a parastatal under the Ministry of Agriculture, sells hybrid rice seed at prices well below marginal costs.

The third risk results from the volatile and sometimes unpredictable nature of trade policy: should Chinese exporters or Bangladeshi importers be unable to (or choose not to) ensure a continuous flow of germplasm from year to year due to tariffs, regulations, or other barriers imposed by either trading partner, then the benefits of hybrid rice cultivation could dry up quickly. Although this is not a pressing concern for either country at the moment, China's limited willingness to share its more advanced breeding lines and systems with other countries is an indication of just how significant trade barriers can be.

Data from the more recent BIHS, on the other hand, suggest that farmers with larger landholdings are significantly more likely to adopt hybrid rice than farmers with either medium or small landholdings. Specifically, the BIHS suggests that poor households (those households with per capita incomes lower than $1.25 per day, adjusted for inflation and differences in purchasing power) are less likely to adopt hybrid rice than non-poor households. Rather ironically, it also suggests that households that have adopted hybrid rice do not, on average, have significantly higher incomes than those households that have not adopted. According to these data, there does not appear to be any significant statistical relationship between higher income and a higher adoption rate for hybrid rice. See Spielman (2012) for details.

In Rajshahi and Rangpur divisions, however, where hybrid adoption rates are highest, some evidence exist that suggest household incomes are higher for hybrid rice adopters than for those households that have not adopted (though the income difference is only marginally significant in the Rajshahi sample). It should be noted that the Rangpur division has the lowest per capita income among all of Bangladesh's divisions; thus, if hybrid rice cultivation does lead to higher incomes in Rangpur, increased hybrid rice adoption may prove a viable pathway for addressing poverty alleviation. For the country as a whole, however, fewer than 60 percent of hybrid rice adopters had incomes above the poverty line.

6. Discussion

There are still significant technical, social and economic challenges related to the diffusion of hybrid rice in India and Bangladesh, even despite both governments' strong policy stance and optimistic outlook. Because of its potential for boosting stagnant yield growth, improving national food security and raising incomes, hybrid rice remains high on the agenda of many public policymakers and corporate decisionmakers. Additionally, the sustainable intensification of rice production on a smaller area of land allows for greater diversification into other higher-value crops.

The initial hurdles to accelerating the diffusion of hybrid rice in India and Bangladesh occur at scientific and technical stages of the technology's development. Researchers are still challenged in their efforts to secure high levels of heterosis in tropical hybrid rice – challenges that were overcome in the development of temperate hybrids developed in China. Researchers are also constrained by the limited effectiveness of the hybridization systems currently in use – in particular, the three-line male sterility system that is most commonly used in South Asia, but also the more advanced two-line system that is used in China. Third is the narrow germplasm base from which hybrid rice research is being conducted, which is in part a result of the limiting reliance on the male sterility system and in part a result of the absence of an effective heterotic genetic pool. Solutions include negotiating greater access to breeding lines from China's hybrid rice research programme, greater public and international investment in new breeding lines and public-private research collaboration on improving developing hybridization systems to accelerate hybrid rice research in the long run. See Xie and Hardy (2009) and Virmani (1994) for details.

These solutions require a long-term outlook on hybrid rice development. Most scientists agree that the current stock of scientific and technical knowledge is at a level at which many of these problems can be readily solved with sufficient time, effort and resources. But given the time lag between research investment and product delivery as well as potentially thin markets (at least initially), this also suggests that solutions will not be immediately available or remunerative in commercial markets. Thus, there is a need for both public and private investment in hybrid rice. Long-term commitments and long project funding cycles are needed from the international donor community to ensure that national research systems, the International Rice Research Institute, and the Global Rice Science Partnership (GRiSP) have sufficient resources to invest in hybrid rice development. This can be aided by technical collaborations, joint ventures and licensing agreements between public research organizations and the global cropscience firms that have been investing heavily in hybrid rice breeding in recent years.

Investments in science and technology are only part of the puzzle: product development strategies will be equally vital to the diffusion of hybrid rice. However, product development itself faces several key challenges that need to be addressed if hybrid rice is to generate welfare-improving and yield-enhancing impacts in India and Bangladesh. These challenges include the need for effective regulations to protect intellectual property rights and ensure the growth of a competitive hybrid rice seed industry.

To be sure, private investment in seed-based technologies is partly determined by the existence of a credible IPR policy regime. Although hybrids provide breeders, seed companies and entrepreneurs with a biological form of IPR protection, these biological IPR protections are more effective when backed by some form of legal protection. This is particularly valuable in situations where it is easy for competitors to steal parental lines from foundation seed and production fields, as is the case in both industrialized and developing countries. By ensuring that innovators have legal recourse allowing them to appropriate a portion of their innovation rents, plant variety protection (PVP) laws can incentivize private investment in hybrid rice development. In addition, through related requirements of disclosure, certification, and labeling, PVP laws can help address information asymmetries between farmers and seed retailers. Unfortunately, few South Asian countries have sufficiently credible PVP laws. India's Protection of Plant Varieties and Farmers' Rights Act of 2001 provides the region's highest standard of protection, but other South Asian countries lag behind in this regard.

Private investment also raises the issue of competition and industry concentration. While there are currently many firms operating in the hybrid rice seed market, the number of unique and proprietary hybrids are likely much fewer, and the potential for concentration among the leading cropscience firms is much higher. Continuous monitoring of market concentration backed by effective enforcement of antitrust laws is necessary to ensure that hybrid rice seed markets remain competitive in India and Bangladesh.

While many critics of hybrids cite the high cost of hybrids and the need to purchase new seed every year, the fact remains that private sector development of rice hybrids is a powerful avenue through which technological innovations can reach resource-poor, smallholder farmers. In addition to the evidence that farmers are currently active in replacing seed with new seed on a regular basis, there is also evidence that farmers are generally willing to pay substantial premia for high quality seed that either raises mean productivity or reduced yield variability. And it need not be the case, for example, that improved hybrids crowd out improved varieties. Ward et al. (2014) have demonstrated that the demand structures for drought tolerant hybrids is very different than that for drought tolerant varieties, and have argued that the two products could coexist in the market, each serving a distinct market segment. This presents opportunities for potentially transformative public-private partnerships to develop these improved traits for inclusion in both hybrid and inbred backgrounds to the benefit of large numbers of resource-poor farmers throughout South Asia.

This leads to the challenge of product delivery, possibly the weakest link in the hybrid rice innovation process. Ultimately, the widespread diffusion of hybrid rice will depend on efforts to improve the genetic quality of seed sold to smallholder farmers, customize hybrids to the diversity of agroecological conditions and consumer preferences found in the region, and expand the distribution and marketing channels that reach these farmers. Strong feedback mechanisms between scientists and sales agents can facilitate this, as can economic and social science research designed to provide insights on determinants of heterogeneous adoption patterns.

At the delivery/adoption end of the spectrum, careful thought needs to be given to the use of public resources to subsidize hybrid rice seed and complementary inputs. Although subsidies have strong historical precedence in encouraging the adoption of new technologies in both India and Bangladesh, such interventions may ultimately work against widespread adoption and the growth of a competitive hybrid rice seed industry. These countries' experiences with input subsidies suggest short-run gains in use and adoption of modern technologies often lead to long-run and intractable rent-seeking behavior and elite capture that can ultimately impede market growth, efficiency and innovation.

7. Conclusion

While farmer-saved seed and in situ conservation of rice biodiversity are noble sentiments and key elements of a diversified crop management and livelihood strategy for smallholder rice farmers in Asia, sole reliance on these elements is limiting because they constrain smallholders' access to technological improvements embodied in seed. Commercial seed markets are one among several mechanisms through which farmers can access these technological improvements – access that they might forgo if they were to depend solely on own-seed savings or exchanges with neighbors.

The diffusion of hybrid rice in India and Bangladesh will depend acutely on the combination of growth in commercial markets for seeds and traits and the expansion of scientific knowledge and expertise on hybrid rice. This paper examines the innovation process surrounding hybrid rice in India and Bangladesh, and identifies the roles played by various organizations involved in advancing hybrid rice development and delivery. It suggests several policy innovations that could accelerate the discovery, development, and delivery of hybrid rice technology. First and foremost is the recommendation for further public investment in the upstream research on hybrid rice to develop the tools and technologies needed to advance national breeding programs and address issues related to yield, pest and disease resistance, and grain quality. Second is the need to improve the innovation incentives that may ultimately encourage more private investment in hybrid rice development, for example, public-private research collaborations and effective intellectual property rights regimes.

In sum, hybrid rice has the potential to transform rice cultivation in India and Bangladesh despite significant challenges. The basic outcome of stable, better adapted, and commercially accessible hybrid rice could translate into a range of positive impacts: enhanced rice productivity; increased on-farm incomes for smallholders; and reductions in the land required for intensive rice production, which in turn allows for reallocation to other agricultural and nonagricultural activities. Significant scientific, technical, and policy challenges exist at each stage of the innovation process – discovery, development, and delivery – and repeated iterations of research and development need to be pursued. The ability of public policymakers, corporate decisionmakers, scientists, entrepreneurs and farmers to understand these challenges and anticipate solutions is fundamental to the long-term success of hybrid rice in India and Bangladesh.

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Hybrid Rice Development in Bangladesh: "Assessment of Limitations and Potential"

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1. Overview of rice production in Bangladesh

Geographically, Bangladesh occupies one of the biggest deltas in the world, with an area of about 147,570 square kilometers and a total population of about 160 million. Every year, the population is increasing by 1.40 percent, with density of population at 980 per square kilometer. Its cultivable land is about 10 million hectares. Cropping intensity is about 190 percent. Bangladesh enjoys a sub-tropical monsoon climate and experiences annual average of 2,300 mm precipitation, varying from as little as 1,400 mm in the west to over 4,500 mm in the east. In Bangladesh, the major cereal crops are rice and wheat, but the main focus is on rice production. The rice growing environment is classified into three major ecosystems based on physiographic and land types. These are: irrigated, rainfed and floating or deepwater. Under these three rice ecosystems, three different rice crops, namely, Boro, Aman and Aus are grown. The coverage of Aman rice is around 48.46 percent, Boro rice is around 42.71 percent and Aus rice is 8.83 percent. Bangladesh is a rice country. Rice is more than food. It is life. Per capita consumption is 188.4 kg. Seventy percent of their calorie needs come from rice.

Rice is a major staple food for the people of Bangladesh like millions of people in the Asia-Pacific region. Almost 75 percent of the total cultivable land is covered with rice in Bangladesh. Rice is therefore not only a staple food but also a way of life and a cultural heritage of the people of Bangladesh. Rice is a pivotal source of livelihood for millions of resource-poor farmers of the country. The country's population is increasing each day. On the contrary, agricultural land is decreasing by about 0.75 percent every year for non-agricultural purposes. An additional 2.5 million births per year require production of additional 0.5 million tonnes of rice per year. Considering the population growth, urbanization, industrialization and growth of economy, the future projection will need to be focused on vertical improvement with the help of frontier technologies. Climate change is a big challenge for Bangladesh agriculture to grow more food. As land area cannot be increased horizontally, we need to focus on hybrid rice technology. The available option as we can foresee is to use molecular technology and hybrid rice technology to overcome the limitations of conventional breeding of rice.

Spectacular gains in productivity of rice have been achieved with the adoption of hybrid rice technology in Bangladesh. Being inspired from the success story of China, the Government of Bangladesh for the first time allowed the private sector to import and commercially market four exotic rice hybrids in 1999-2000 during the Boro season. A total of 115 hybrid rice varieties were released and registered by the National Seed Board (NSB) of the Ministry of Agriculture (MoA). With the introduction of hybrid rice, production has increased to cope with the foodgrain demand; thus, the country is now at the gateway of food self-sufficiency. Rice production has increased to 30.5 million metric tonnes.

The private seed sector is playing a pioneering role in hybrid rice seed production locally by minimizing the import of hybrid rice seed. The Government of Bangladesh (GoB) from 1998 encouraged the private sector through favorable seed policy and regulatory support to improve their capacity and capability in hybrid rice technology development.

2. Progress of hybrid rice development in Bangladesh

2.1 History of hybrid rice development

In the wake of the big flood in 1998, the Government decided to introduce hybrid rice technology with the encouragement from the Honorable Agriculture Minister Ms. Motia Chowdhury (who is also the Minister at present) and strong participation from private sector. In 1999, after a one-year brief trial, four varieties were released: three from India and one from China. Indian varieties performance was not well at that time but performance of the Chinese variety was better and was accepted by the farmers.

Hybrid rice is a key technology for maximizing yield as well as raising the productivity, and correspondingly increasing the income of rice farmers. In Bangladesh, hybrid rice research was initiated at the Bangladesh Rice Research Institute (BRRI) in 1983, but it was only for academic purposes. In 1993, a few female parental lines (CMS-lines) and experimental rice hybrids from the International Rice Research Institute (IRRI) were evaluated at BRRI research farms. Systematic efforts were initiated in BRRI in 1996. The commercial hybrid rice technology was evaluated by four private seed companies during the 1997-98 Boro season with four exotic rice hybrids. Hybrid rice was officially released and registered from MoA during the 1998-99 Boro season. The condition was imposed that the concerned private seed company or public organization will have to take initiative to produce hybrid rice seed locally within three years of approval of the candidate hybrid and gradually this imposition has been increased to eight years for import permission of hybrid rice seed. After eight years, the F_1 hybrid rice seed needs to be produced locally.

2.2 Status and trends of hybrid rice development

The hybrid rice technology has gradually gained its popularity with the area under hybrid rice also increasing from around 10,000 hectares of lands to as many as 650,000 to 700,000 hectares until the 2013-14 rice crop season. The use of hybrid rice seed has increased from 150 tonnes in 1999-2000 to above 8,000 tonnes during the 2013-14 crop season. Initially four hybrid rice varieties were registered in 1998, which now increased to 115 hybrid rice varieties released and registered for commercial cultivation. Among the 115 hybrid rice, 108 varieties were for Boro and 7 varieties were for Aman crop season. The yield heterosis of released rice hybrids are from 6.50 tonnes per hectare to 8.50 tonnes per hectare, which were performing 15-20 percent higher yield heterosis compared to the most popular inbred rice varieties being cultivated in the Aman and Boro seasons, respectively. The progress of hybrid rice varietal development is shown in Table 1 below.

Table 1. List of hybrid rice released and registered in Bangladesh

Sl. No.	Crop Season	Number of Released Hybrid Rice	Country of Origin				Category of Organization		
			Bangladesh	China	India	Philippines	Public	Private	NGO
1	Boro	108	8	87	12	1	4	95	9
2	Aman	7	2	2	3	-	1	5	1
3	**Total**	**115**	**10**	**89**	**15**	**1**	**5**	**100**	**10**

2.2.1 Progress of hybrid rice research

Rice research in Bangladesh

Bangladesh rice research has a long history. In 1908, an experimental station (known as Dhaka Farm) of about 161 hectares of land was established in Dhaka. In 1911, the rice improvement programme was for the first time started in the Dhaka farm. In 1934, a rice experiment station was established at Habiganj district as the first outpost for the purpose of improvement of deepwater rice and irrigated Boro rice. In the 1960s, the green revolution was started by introducing IRRI- developed the high-yielding varieties (HYVs) of rice, namely IR 8, IR 20 and IR 5. The organized rice research was started in Bangladesh through the establishment of Bangladesh Rice Research Institute (BRRI) in 1970. Over time, the rice research strategies for advancing knowledge and technologies have changed in response to changing demands, perceived opportunities, available knowledge and resources. The total HYVs released from BRRI had exceeded 65 and from BINA, 4 varieties had been released which had sustained food requirements of 160 million people. Rice production technology has been digitalized by BRRI and the Rice Knowledge Bank. BRRI developed 15 high-yielding rice varieties which were drought tolerant, where one is a diabetic rice variety. BRRI also developed Vitamin A-enriched and zinc-enriched rice variety. Besides this, they also developed submerged and saline-tolerant high-yielding rice variety.

Hybrid rice research in Bangladesh

The hybrid rice is almost a new technology in Bangladesh. In the public sector-organized hybrid rice research started in 1996, BRRI has developed four rice hybrids from 2001 to 2010, including three hybrids for the Boro season and one hybrid for the Aman season. Four exotic rice hybrids introduced by the private sector were officially released and notified in 1998 for commercial cultivation in the 1999-2000 Boro season. Hybrid rice research and development activities in the private sector started in 2000-2001 with the production of 27 tonnes of hybrid rice seed locally. In the meantime tremendous progress has been achieved in hybrid rice research and seed production by the private sector due to Government policy and support.

Earlier, only 150 tonnes of hybrid rice seed were imported, but now it has been increased to 8,000 tonnes, of which 7,400 tonnes were locally produced. A total of 115 rice hybrids were officially released and registered for commercial cultivation. Among them, four hybrids released from Bangladesh Rice Research Institute and six hybrids released by the private seed companies. The rest, 105 hybrids are exotic hybrids introduced from abroad. The import and local production of hybrid rice seed is shown in Table 2 below.

Fig 1. Hybrid rice breeding in Bangladesh

Table 2. Year-wise quantity of hybrid rice seeds import and local production in Bangladesh

Year	F$_1$ hybrid rice seed imported and local production				
	Import (MT)	Local production (MT)	Total (MT)	% Import	% Local production
2000-2001	406.25	27.00	433.25	94	6
2001-2002	244.33	106.00	350.33	70	30
2002-2003	458.42	262.89	721.31	64	36
2003-2004	674.42	212.40	886.82	76	24
2004-2005	797.83	490.80	1 288.63	62	38
2005-2006	1 489.05	681.14	2 170.19	69	31
2006-2007	5 336.18	2 171.29	7 507.47	71	29
2007-2008	7 848.00	2 500.00	10 348.00	76	24
2008-2009	8 148.00	2 800.00	10 948.00	74	26
2009-2010	3 472.00	3 200.00	6 672.00	52	48
2010-2011	4 000.00	3 600.00	7 600.00	53	47
2011-2012	3 400.00	4 800.00	8 200.00	42	59
2012-2013	3 500.00	6 500.00	10 000.00	35	65
2013-2014	600.00	7 400.00	8 000.00	7.5	92.5

(Source: Seed Wing, Ministry of Agriculture, Bangladesh)

2.2.2 Status of hybrid rice production

Area, yield and production

The use of hybrid rice seed and grain production has increased significantly over a period of 15 years from 1999-2000 to 2013-2014. In 1999-2000, the use of hybrid rice seed was only 150 tonnes while the area coverage was only 10,000 hectares. In 2013-2014, the use of hybrid rice seed has increased to 8 000 tonnes while the area coverage increased to 670 000 hectares. The local production of hybrid rice seed has increased from 27 tonnes (6 percent) in 2000-2001 to 7 400 tones (92.5 percent) in 2013-2014. The use of hybrid rice seed, area under hybrid rice and hybrid rice grain production are shown in Table 3 below.

Table 3. Commercial area under inbred and hybrid rice and production of Bangladesh during the last six years (2008-2014)

Year	Area under inbred and hybrid rice							
	Area under total rice crop (Boro, Aman & Aus)				Production of total rice grain (Boro, Aman & Aus)			
	Inbred (in lac ha)	Hybrid (in lac ha)	Total (in lac ha)	% Hybrid	Inbred (in lac MT)	Hybrid (in lac MT)	Total (in lac MT)	% Hybrid
2008-09	113.14	9.39	122.53	8.08	299.06	43.12	342.18	12.60
2009-10	108.00	10.00	118.00	8.47	294.44	47.90	342.34	13.99
2010-11	111.50	8.00	119.50	6.69	315.72	38.00	353.72	10.74
2011-12	108.16	7.12	115.28	6.18	307.33	31.81	339.14	9.38
2012-13	107.78	6.60	114.38	5.77	308.53	29.8	338.33	8.80
2013-14	111.76	6.70	118.46	5.65	312.18	30.00	342.18	8.76

(Source: Department of Agricultural Extension, Ministry of Agriculture, Government of Bangladesh)

Technologies transferred and applied in hybrid rice

Hybrid rice technologies have been standardized by doing adaptive trials and farmers' participatory trials at different agro-ecological zones of Bangladesh. Hybrid rice has varietal trial and evaluation conducted by Seed Certification Agency under the technical guidance of the Technical Committee of NSB. The Department of Agricultural Extension (DAE) is responsible for conducting various demonstrations of the released and registered hybrid rice varieties to popularize the hybrid rice crop production technologies to the farmer level. In addition to the demonstrations conducted by DAE, BRRI and the Bangladesh Agricultural Development Corporation (BADC), private seed companies have been conducting demonstrations and adaptive trials on hybrid rice to popularize their own hybrid rice. Appropriate training on hybrid rice production technologies has been given to farmers. Considering 15-20 percent yield advantage of hybrid rice over most popular modern inbred rice varieties, farmers have been motivated and well adapted to the hybrid rice in their cropping pattern, Aman and even in Aus. The print and electronic media in Bangladesh have been playing positive and pragmatic roles to popularizing hybrid rice technologies keeping in view of the economic benefit and promoting growth of food grain production with the ultimate objective of helping the country achieve food self-sufficiency and food security.

Hybrid rice seed production

Hybrid rice seed production was started in 2000-2001. The quantity of F_1 hybrid rice seed was 27 tonnes in 45 acres of land and average production was 600 kg per acre. The production has gradually been increased to 6,500 tonnes in an area of 5,100 acres. The seed yield was about 1300 kg/acre in the year 2012-2013. The efficiency of F1 hybrid rice production depended on the potentiality of parent lines, seed setting/out-crossing rate, environmental conditions, synchronization capacity and capability, capacity of technical human resources, row ratio of A-lines and R-lines, application of GA3 and other factors. Over time, BRRI, BADC and different private seed companies had improved their hybrid rice varietal improvement, maintenance breeding and F_1 hybrid rice seed production efficiency. Most of the public and private seed industries have been availing of the technical support of their principal seed industries in the field of varietal improvement, maintenance of parent lines, and improvement of productivity of F_1 hybrid rice seed production in the country.

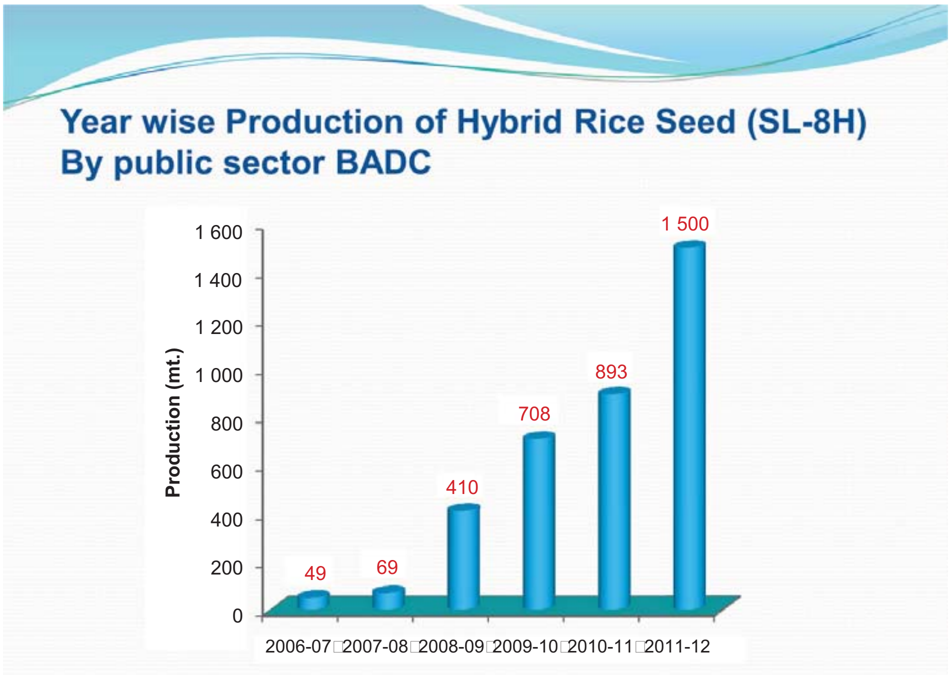
Hybrid rice seed supply and trade

Hybrid rice seed is distributed and marketed by the public sector BADC and private seed companies. BRRI has been supplying parent line seeds of A-line and R-line as well as F_1 hybrid rice seed mainly to the public sector BADC. Some private seed entrepreneurs who don't own a hybrid rice variety are taking some quantities of F_1 hybrid rice seed of BRRI-developed hybrid. There are two different sources of hybrid rice seed supplying BADC and private seed companies. About 30 seed companies are doing business with hybrid rice seed, Supreme seed, Lalteer seed, ACI seed, Isphahani seed, Aftab seed, BRAC seed, Syngenta & Getco seed, etc.

Fig. 2. Hybrid rice fields

The Ministry of Agriculture officially approves the annual quantity of F_1 hybrid rice seed to be produced locally and to be imported from abroad including parental seed. The MoA also monitors and evaluates the performance and quality of local production, import and marketing of F_1 hybrid rice seed all over the country.

For the first time, the Ministry of Agriculture has opened a new avenue for the public sector BADC and private seed companies to explore the opportunity of exporting F_1 hybrid rice seed from Bangladesh. In 2013, it had given permission for exporting 500 tonnes of hybrid rice seed. If this new venture is successful, then Bangladesh can increase its production of F_1 hybrid rice seed locally and can be able to trade the excess quantity to the global market. It has been observed that cost of hybrid rice seed production in Bangladesh is comparatively lower due to cheap agricultural labor rate.



ig. 3. Year-wise production of hybrid rice seed (SL-8H) by public sector BADC

Hybrid rice intellectual property rights

Bangladesh is a signatory of the World Intellectual Property Right Organization (**WIPRO**). The plant variety and farmers' rights protection (**PVFRP**) Act of Bangladesh is now in the pipeline to get verdict and enact into law in the National Parliament of Bangladesh. After enacting the **PVFRP Act-2014**, the hybrid rice intellectual property rights will be incorporated into the PVFRP Act.

Impact of hybrid rice adoption

The hybrid rice technology was introduced in Bangladesh to fulfill the increasing demand for food grains by the growing population. Encouraged by the success story of PR China, the Government of Bangladesh has taken a positive initiative to avail of the road map of higher per unit production by promoting hybrid rice. Hybrid rice was obviously selected as an alternative because of its high yielding ability and wide adaptability. Hybrid varietal development, seed production and hybrid rice crop cultivation technologies have been appropriately developed by BRRI, BADC and the private sector. Farmers' demands are being fulfilled not only through supplying improved hybrid rice seed but also providing proper training and packages of hybrid rice production technologies. Our agriculture-friendly Government of Bangladesh has taken positive initiatives through policy support and extension activities with the involvement of Department of Agricultural Extension. DAE as well as different public and private industries have undertaken programmes for creating farmers awareness by conducting field demonstrations, training, advertisement, promotional activities and disseminating packages of technologies on hybrid rice cultivation.

The rice area under hybrid rice has been maintained to around 5-8 percent for the last five years due to the successful adoption of hybrid rice technology by the farmers. The positive impact on adoption of hybrid rice and its popularity to the farmers has made the success of hybrid rice in increasing local production, decreasing import and increasing the area under hybrid rice cultivation. At present the important indicator is 15-20 percent yield advantage of hybrid rice over inbred rice, further initiatives have been taken to improve the quality of hybrid rice particularly higher amylose content (above 25 percent amylose), better cooking and keeping quality. These will create more impact to improve the taste of rice and get premium selling price of hybrid paddy for farmers. Consumers preference will also help get premium price of rice (husked rice) to the traders. Hybrid rice has a positive contribution towards achieving self-sufficiency in rice production in Bangladesh.

3. Constraints and gaps in hybrid rice development

Bangladesh is an agrarian country. The hybrid rice technology dissemination has encountered some technical, agro-ecological, social and marketing constraints. There are three systems of hybrid rice seed production being followed in Bangladesh. These are the land lease system, contract growing system and seed multiplication farm. The widely practiced system is land lease system followed by contract growing system. In selecting land for hybrid rice seed, difficulty arises as it needs all farmers and their lands under a selected area to be brought under hybrid rice seed production. But it is very difficult to bring all farmers and their lands under the selected blocks for hybrid rice seed production due to variable socio-economic conditions of farmers. It is also difficult to get suitable and potential lands for hybrid rice seed production because there are 30 agro-ecological zones in Bangladesh, and their soil, land and climatic conditions are varied. The most important barrier is to maintain isolation for hybrid rice seed production. There is one essential chemical, namely GA3 needed in hybrid rice seed production, which is fully import- dependent and demands a high cost. The other socio-economic constraints are the availability of seed sun-drying facilities at the field level as well as seed processing and preservation facilities after post-harvesting of seed. At the field level, seed producing companies used to hire sunning floors of local rice millers on seasonal rental basis which was very costly. The establishment of seed processing and preservation centers, dehumidified storage, internal quality control and packaging facilities are essential for hybrid. However, these facilities involve very high financial investment. The public sector BADC and some seed companies have their own seed processing, preservation, storage and packaging facilities. Other seed companies who don't have such facilities have been availing these on a rental basis.

3.1 Technological constraints

In Bangladesh, only the three-line hybrid seed production system is in practice. The hybrid rice research, varietal development, parent line development, maintenance breeding, F_1 hybrid seed production methodologies, scientific and technical support have been provided by IRRI to BRRI, principal companies of China and India are providing to private sector seed industries while the Philippines is providing to public sector BADC. The public research institute BRRI, public sector organization BADC, and private sector seed industries including NGO (BRAC and Ayesha Abed Foundation) have also developed their own breeding, research and hybrid development and maintenance technologies.

The technological constraints in the field of hybrid rice in Bangladesh are as follows:

- The CMS line, R-line, and B-line potentiality and purity, out-crossing/seed setting rate, synchronization, and F_1 hybrid seed production efficiency have not yet been achieved to the extent of international standards.

- The high amylose content (above 25 percent) and good cooking quality desirable hybrids have not yet been developed.

- The marker-assisted selection (MAS) breeding and varietal improvement technology have not yet reached satisfactory level.

- The molecular technology by using DNA finger printing has not yet been developed for characterization and identification of genotypic traits.

- Local OP variety, due to superior taste, gives higher market price compared to hybrids.

- Chinese hybrid rice is sticky and soft, which is disliked by most consumers.

- Chinese hybrid seeds quality and yield performance have not reached satisfactory level.

- No new varieties have been introduced which really gives much higher yield than existing Chinese common hybrid varieties.

3.2 Social and economic constraints

The hybrid rice seed production at different locations in Bangladesh is facing some social and economic constraints mainly in following the land lease system and contract growing system. Most important constraints are listed hereunder:

- Availability of potential and suitable land for hybrid rice seed production.

To produce hybrid rice seed, the requirements of suitable land, fertile soil, sufficient sunlight, irrigation water, isolation, sunning floor for seed drying, sufficient human laborers are essential.

- Attitude of farmers

Farmer's attitude and their economic conditions are most important for getting lands for hybrid rice seed production. If all farmers at the selected locations are not interested to offer their lands for hybrid rice seed production, it is difficult to properly maintain the purity of F_1 seed. In this regard, it is found that land lease system is comparatively better than contract growing system. In land lease system although the land cost is higher but the productivity and seed purity could be better and improved through controlled management system by the seed producing agencies, but in contract growing system productivity and purity of seed maintaining is very difficult because all management activities are fully depends on the attitude and financial capabilities of the contract farmers as well as their efficiency and capabilities.

- Availability of sunning floor for seed drying and post harvest operation

Since the hybrid rice seed is very environment sensitive, proper facility for seed threshing, cleaning and drying on the sunning floor are most essential. But these facilities are not adequately available at different locations of Bangladesh. The seed producing public and private industries need to hire these facilities for a period of 15-30 days or more in a particular crop season. The owners of the sunning floor used to take undue advantage by charging very high rent for a period of postharvest operation.

- Availability of GA3

GA3 is an essential chemical needed for hybrid rice seed production. This chemical is traded by different local agencies and made available through import from abroad. It involves high costs as it depends on 100 percent import.

- Market price of hybrid rice grain

The market price of hybrid rice grain has not yet gained its positive impact in comparison to inbred rice grain. Consumers prefer comparatively higher amylose content (above 25 percent) and better cooking quality. Although farmers are getting comparatively 15-20 percent higher yield advantage over the inbred rice but due to sticky rice (low amylose content, below 20 percent) and bold grain, the consumers openly show their negative preference because general consumers in Bangladesh preferred long slender grains with high amylose percent and better cooking and keeping quality.

3.3. Capability constraints

Hybrid rice seed production involves research, breeding, varietal improvement, maintenance breeding, seed production, processing, internal quality control, preservation, packaging, distribution and marketing capacity and capability. BRRI and BADC have gradually developed their facilities with the financial support from the Government of Bangladesh; however, in the case of private sector seed industries, they manage their own finance. Some private seed industries have been gradually developing their facilities. The other private seed industries who don’t have such facilities are availing through bilateral agreements with the private companies or availing facilities from BADC on a rental basis. Mechanical drying, dehumidified storage and internal quality control are most important factors which have been developed by a limited number of private seed industries.

3.4. Environmental constraints

Climate change is a major threat to Bangladesh Agriculture. Natural disasters like drought, flood and salinity have an adverse impact on cultivation of hybrid rice. Rice varieties with high yield potential, short life cycle, increased tolerance to biotic and abiotic stresses and superior grain quality are needed to combat climate change challenges.

Sunshine, temperature, rainfall are important for hybrid rice seed production as well as commercial cultivation of hybrid rice all over country. But in case of the two-line system of hybrid, no academic research and field trials have been conducted by BRRI and BADC. In case of the two-line hybrid seed production, climate is not favorable because in July-August, temperature is more than 25 percent but due to heavy rainfall rice, pollen are usually washed out. The three-line hybrid rice seed production needs favorable temperature and relative humidity, particularly the difference of day and night temperature during seed setting time. This environmental condition is varied at different locations in Bangladesh because there are 30 agro-ecological zones in Bangladesh. Considering these wide ecological variations the public and private sector seed industries have selected environmentally favorable locations for hybrid rice seed production.

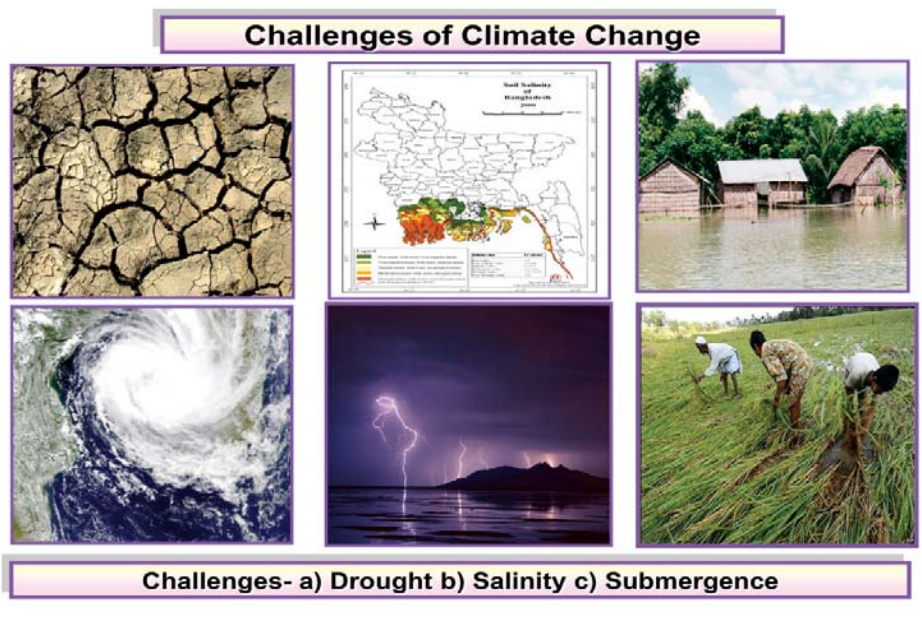


Fig. 4. Challenges of climate change

3.5. Policy constraints

In Bangladesh, the seed sector and seed system are regulated by an apex body - the National Seed Board (NSB) - under the Ministry of Agriculture. The MoA is functioning as a Secretariat of NSB. It regulates the seed sector and seed system through the National Seed Policy, the Seeds Act and the Seed Rules. The seed sector and seed system are implemented by public sector research institutes under the National Agricultural Research Systems (NARS), public agricultural universities, Department of Agricultural Extension, the public sector seed industry and the private sector seed industry. Seed quality control and seed certification are performed by the Seed Certification Agency (SCA). The seed quality control and seed certification are regulated by the NSB particularly focusing on the six notified kinds and varieties of crops, namely, rice (paddy), wheat, jute, potato, sugarcane and *kenaf and mesta*. The other 73 kinds and varieties of crops are declared as non-notified crops. The seeds of non-notified kinds and crops are not under official seed certification. The quality control and certification for these non-notified kinds and crops are declared as "Truthfully Labelled Seed" by the seed producers, who are officially registered with NSB.

There are two committees under the NSB: the Technical Committee and the Seed Promotion Committee. The functions of the Technical Committee are variety evaluation and release. The functions of the Seed Promotion Committee are national seed planning, programming, requirement, production, supply, extension services, evaluation and monitoring of all notified and important non-notified kinds and varieties of crops. The Seed Promotion Committee also performs the function of assessing the quantity of quality seeds of notified crops needed to be imported and recommend to the NSB for formal official approval.

As per the above mentioned regulatory system, the hybrid rice for the first time was released by the Technical Committee and officially notified by the NSB in 1998 in Bangladesh. The National Seed Board initiated and developed a separate **"Hybrid Rice Variety Evaluation and Registration Procedures"** in 1998. The 'procedures' was modified in 2003 and again in 2007. As per the procedures, hybrid rice varieties introduced from abroad or developed locally are evaluated through two years of performance trials at different agro-ecological locations and agro-climatic conditions of the country. The trials are conducted by the SCA under the control and guidance of the Technical Committee. On the basis of the two-year field performance evaluation trials, the candidate hybrid found with 20 percent higher standard yield heterosis over the best and popular inbred modern rice check variety, is released by the Technical Committee and officially notified by the NSB.

In pursuance of the 'procedures', the following conditions are imposed in releasing and notifying on a hybrid rice variety:

The qualified hybrid rice variety is released and notified only for the specified region(s) where the candidate hybrid performed 20 percent higher standard yield heterosis over the best and popular inbred rice modern variety.

The F_1 hybrid rice seed of the notified hybrid variety is allowed to be imported for a maximum period of 8 years. After that period, hybrid rice seed will have to be produced locally and beyond this period the hybrid seed will not be allowed to be imported.

The hybrid rice seed of released and registered variety is allowed for commercial marketing and distribution only to the region(s).

The Ministry of Agriculture has undertaken an initiative to modify and upgrade the above mentioned hybrid rice policy, hybrid rice evaluation trials, and release and notification procedures. The conditions for locally developed rice hybrids in both the public and private sector which may be more favorable such as joint venture investment, custom hybrid rice seed production for exporting to global market, molecular plant breeding, marker-assisted selection, DNA finger printing for genotypic characterization of hybrid variety in addition to Distinctness, Uniformity and Stability (DUS) test for morphological characterization of hybrid variety are under active consideration. Initiative will be taken by the Government of Bangladesh for better plant material transfer agreement (MTA) with parental line exporting countries.

4. Lessons learnt

Achieving self-sufficiency in rice production and maintaining price stability are important objectives of Bangladesh like other developing countries of the world where rice provides food security and generate employment and income of the rural people. Rice production has tripled during the last three decades to 34 million metric tonnes. Favorable policies supported by irrigation made it possible to achieve this production.

Lessons learnt on hybrid rice may be categorized into: Hybrid rice variety development and seed production and Dissemination and adoption of hybrid rice technology to the field.

4.1 Hybrid variety development and seed production

- Hybrid rice research and varietal development;
- Hybrid rice seed production, processing, preservation;
- Hybrid rice seed distribution and marketing'
- Farmers knowledge; and
- Human resources.

The F1 hybrid rice seed production efficiency of BRRI, BADC and different private seed industries have shown varied performances. The efficiency of F1 hybrid rice seed production is varied from 600 kg per acre to 1 300 kg per acre, with an average level of 1 200 kg per acre. The seed setting/out-crossing performance is also varied at different locations and organizations. The use of GA3 chemical is different from organization to organization. The row ratio for R:A lines is also different among organizations. The isolation practice is varied at different organizations.

The hybrid rice seed marketing and distribution have been well developed by BADC and by most private seed industries across the country through their own seed marketing network as well as through the seed distributors, seed dealers and seed retailers.

The farmer's knowledge on hybrid rice production technologies is not well organized and institutionalized. The BRRI has been educating farmers and officials in the Department of Agricultural Extension (DAE), and field level officials of different private seed industries and seed enterprises through BRRI's annual action plan program. The public sector BADC and individual private sector seed industries are educating farmers informally, conducting field demonstrations and distributing leaflets and booklets on hybrid rice crop production technologies.

4.2 Dissemination and adoption of hybrid rice technology to the fields

-The cost of hybrid rice seed is comparatively higher for farmers, although it is cheaper than China and India.

- Farmers need to procure hybrid rice seed on a regular basis because they can't retain seeds of hybrid rice like seed of inbred variety.

- Hybrid rice crop needs high management and high-input.

- Hybrid rice is demonstrating only the higher yield advantage but does not guarantee resistance to important insect pests and diseases like wide-area tolerance and resistance of inbred modern rice varieties and landraces.

-Hybrid rice grain quality and cooking quality are very much a concern to the consumers.

5. Opportunities for hybrid rice development

The regular evaluation trials at minimum six different agricultural regions out of ten regions conducted by SCA during Boro (irrigated ecosystem) and Aman (rain-fed ecosystem) seasons under the guidance of the Technical Committee of the NSB had clearly shown that there is enormous potentiality and economic opportunity to large-scale adoption of hybrid rice in Bangladesh. The standard yield heterosis as observed during field performances evaluations trials that the hybrids are performing above 8 to 9 tonnes yield per hectare during the Boro season and 6.5 to 7.5 tonnes yield per hectare during the Aman season indicates more than 20 percent yield heterosis over best performing inbred HYV/Modern varieties of rice. About 50 hybrids in each Boro season and about 25 hybrids in each Aman season are under the field evaluation trials by SCA. Out of these trials, 4 to 5 best performing hybrids during the Boro season and 2 to 3 best performing hybrids during the Aman season are getting release approval by the Technical Committee and finally being notified by the National Seed Board of Ministry of Agriculture.

Honorable Prime Minister Sheikh Hasina visited BADC stall in the International SAARC Seed Congress & Fair 2011 & talking about Hybrid Rice Seed

Fig. 5. Prime Minister of Bangladesh discusses hybrid rice seed

F_1 hybrid rice seed production has also been successfully increased from150 kg per acre to 1 300 kg per acre with an average of 1 200 kg per acre. The seed setting/out crossing rate has also been increased to 60 percent. The average commercial yield of farmers cultivating hybrid rice has also increased over time to above 7 tonnes per hectare in Boro season and above 6 tonnes per hectare in Aman season. Major numbers of released and notified hybrid rice have gained their popularity among farmers across the country. The scientists, researchers, planners and policy makers are looking forward to developing hybrid rice by local plant breeding or through introduction of higher yield of above 10 tonnes yield per hectare in Bangladesh. Promising hybrids with a higher magnitude of heterosis, better grain and cooking qualities, and resistance to major biotic and a-biotic stresses are in the pipeline of strategies of BRRI, BADC and private sector seed companies. Bangladesh needs expansion of hybrid rice cultivation to meet the growing demand for food due to increase population and reduced cultivable land.

6. Key strategies and policy options to promote hybrid rice development in Bangladesh from 2020 to 2030

The Ministry of Agriculture, in collaboration with BRRI, BADC and private sector seed companies, is looking for developing a mid-term 5-year and a long-term 10-year well-defined strategic action plan from 2015-16 to 2025-26 for hybrid rice research, variety development, variety release, seed production, distribution and marketing. Under the strategic action plan priority will be given to the following issues:

- Strengthening of hybrid rice research programme at BRRI and the private sector;

- Developing hybrids with more stable and adapted CMS & R lines that also possess good combining ability and satisfactory out-crossing rates;

- Developing hybrids with desirable amylose (>25 percent) content and long slender variety;

- Developing hybrids with resistance to diseases (BLB) and insect pests;

- Developing hybrids having adaptability to a specific ecosystem, particularly stress prone areas (biotic and a-biotic stresses);

- Refining hybrid rice seed production techniques and hybrid rice production practices;

- Expeditious and effective transfer of the hybrid rice technology already generated;

- Short-duration varieties for Amon, Aus & Boro seasons with high amylose content;

- Aromatic hybrid rice variety for all seasons;

- Increase hybrid rice cultivation area from10 percent to 20 percent;

- Enhancing international cooperation regarding hybrid rice seed technology; and

- Harmonization of hybrid rice seed technology.

7. Concluding remarks

The Government of Bangladesh is very much pro-hybrid and pro-hybrid rice seed industry development for the better interest of attaining food security and food self-sufficiency. To maximize the potential and achieve higher yield, hybrid rice technology would be an alternative tool in genetic mapping of rice technology. To achieve this vision of the Government of Bangladesh, the following strategic plans and action programmes need to be undertaken and implemented with the participation of public and private sectors through level-playing opportunities:

- Hybrid rice technology has the potential to raise the yield of rice and thus overall rice productivity and profitability. Successful deployment of hybrid rice requires more effective cooperation between public research institutions and the private sector research to overcome current constraints.

- Hybrid rice offers higher income opportunities for farmers due to 15-20 percent yield increase than inbred rice production. This increase in rice grain production that hybrid rice offers can help minimize most of the importation that the country resorts to annually. In fact, a one-tonne increase in rice productivity per hectare even in only 20 percent of the country's 4.6 million hectares or 0.92 million hectares of land under hybrid rice particularly in Boro rice ecosystem (irrigated) area and at least 5 percent of 5.6 million hectares or 0.28 million hectares under hybrid rice in Aman rice ecosystem (rain-fed kharif) by 2020, would help produce an additional 2.964 million MT of paddy (achieving at least 2.47 tonnes additional yield per hectare due to 20 percent yield heterosis).

- To realize the maximum yield potential of hybrids, the maintenance of genetic purity of at least 98 percent of parental lines is essential.

- It has been known that yield increase of rice through replacement of tall inbred cultivars with semi-dwarf varieties is due to increase of harvest index (HI), while the yield advantage of hybrid rice is attributed to increase of biological yield. Further increase in biological yield in hybrid rice will require use of DNA marker-assisted selection of parental lines, most importantly CMS lines.

- Maintenance breeding need to be strengthened for upgrading the present level of 15-20 percent yield heterosis so that adoption of hybrids rice could be economically much more viable and profitable to the farmers in comparison to inbred rice.

- The hybrid technological advancement may be evaluated through conducting performance and adaptability trials on the "two-line hybrid technology" in addition to the present commercial basis adoption of the "three-line hybrid technology."

- To cope with the increased food requirement for population growth as well as declining impact of potential land and natural resources due to industrialized economic growth of the country, there is need for the development of **"super hybrids"** which will help increase productivity of 10-15 percent higher yield heterosis against traditional hybrids and 25-30 percent higher yield heterosis than inbred rice.

- The development of region-specific hybrids is needed to cultivate in the abiotic stress- prone regions of the country, particularly in saline, drought, submergence, flood-prone areas of south-western, south-eastern, north-western, north-eastern regions of the country.

- The National Hybrid Rice Strategic Research Plan (NHRSRP) is needed under the NARS umbrella - the Bangladesh Agricultural Research Council (BARC) - to help the Bangladesh Rice Research Institute (BRRI), public agricultural universities, the Bangladesh Agricultural Development Corporation (BADC) and private seed industries to develop and strengthen their own hybrid research, hybrid varietal development and hybrid rice seed production.

- The people of Bangladesh prefer high amylose content rice and better cooking quality rice, so research dimension needs to be intensified to develop hybrid rice variety having amylose content above 20 percent with good cooking quality.

- Level playing fields must be created to develop hybrid rice seed production capacity and capability, infrastructure capacity building for seed processing, preservation, and internal quality control, packaging, and improving supply chain for hybrid rice seed marketing across the country.

- Worldwide and regional research collaboration is needed to be developed with many international partners, including the International Network for Genetic Evaluation of Rice (INGER), in the exchange of germplasm and associated intellectual property, quarantine, bio-safety requirements, exchange of scientists and information as well as multiplications testing of new parents, hybrids and breeding lines.

- The development of inter-institutional technical cooperation networks with international rice research institutes, international hybrid rice research institutes and also development of standard material transfer agreement (**SMTA**) are needed for strengthening public and private sector hybrid rice research.

Hybrid Rice Achievements, Development and Prospect in China

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Rice is one of the main crops in China, playing great significant roles in China's food security. In the past decades, China became self-sufficient in basic food for the first time in modern history. This is a tremendous accomplishment when one considers that China, with more than 1.3 billion people, has 22 percent of the world's population but contains only 7 percent of its arable land. Hybrid rice is one of the greatest innovations and miracles in the world, which contributed much to Chinese food security in the past 30 years.

1. Overview of rice production in China

In China, the annual cultivated area of rice has reached 30 million hectares, accounting for one third of the sown area of main crops. During the past decade, the cultivated area of rice dropped at first and then went up: before 2000, the cultivated area of rice kept at 30 million hectares and more and in 1980 (33.879 million ha). From 2001 to 2003, both cultivated area and production of rice were decreasing progressively, to 26.508 million hectares. Under the strain of food security, China has introduced many encouragement policies, contributing to restorative growth in rice planting since 2004. In 2012, rice planting area climbed to 30.35 mil ha (Fig. 1). It is estimated that, in terms of rice planting area, 30 million hectares serves as the security cordon to ensure food security in China

On the production side, the total output of rice presents a wave mode for the last 20 years. In 1997, the total output of rice made a breakthrough with 200 million tonnes. However, with the decrease of rice planting area, the total output of rice remained hovering under 200 million tonnes (Fig.1).

Until recently, due to the consistent rise in per unit yield of rice, from 6.16 tonnes in 2001 to 6.78 tonnes in 2012, the total yield realized a sound momentum of consistent growth (the ninth consecutive year of grain harvest) during the time when rice planting coverage recovered progressively, and the total output of rice returned the high level up to 200 million tonnes.

In recent years, China's rice import and export began to show an inverse growth, the total volume of rice import kept growing, while that of export was decreasing (Fig. 2). From 1980 to 2011, there was less than 1 million tonne rice imported annually except the 1.64 million tonnes in 1995. The huge surge of rice import in 2012 and 2013 set the import records in recent years. In 2012, the total volume of rice import sharply rose to 2.3446 million tonnes, an increase of 305.4% compared with that of in 2011. The figure remained high at 2.244 million tonnes in 2013. Simultaneously, in the past decade, China's total volume of rice export was dropping year by year to 279,000 tonnes and 478,000 tonnes in 2012 and 2013, respectively. The main reason for this phenomenon is that rice prices in domestic markets are comparatively higher. However, the lower rice prices in some south-east Asian countries contributed to the soar in rice export and fall in rice import.

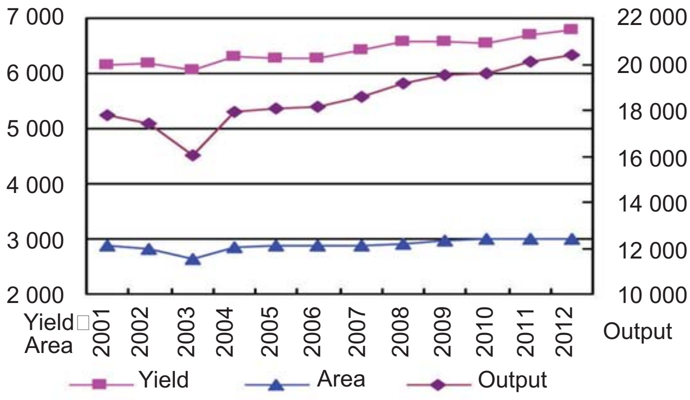


Fig 1. The varlution of growth area, output and yield

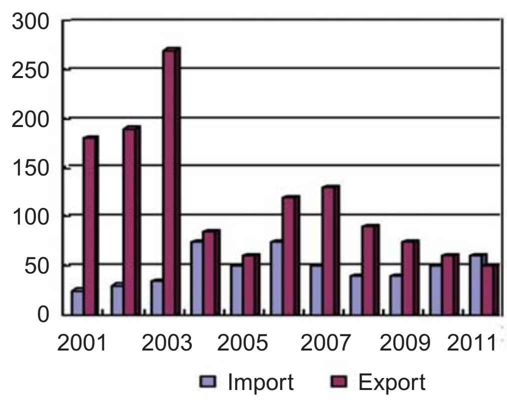


Fig 2. The varlution import and export

2. History of hybrid rice in China

2.1 Completion of the three-line hybrid rice system within 10 years

Hybrid rice research was begun by Professor Yuan Longping in 1964. After nine years of hard work, three genetic lines were successfully developed in 1973, i.e., a cytoplasmic male sterile line, a maintainer line and a restorer line. This research resulted in the realization of "three-line system" to produce commercially viable hybrid rice. In 1974, the first hybrid combination was developed with good heterosis and high yield. In 1975, technology for large-scale hybrid seeds production was completed, and One year later, hybrid rice was released for commercial production in1976. Thus, China became the first country to put hybrid rice technology to real mass field production.

Based on the theory of he t"three line system", WA Type CMS line, Zhenshan 97A, bred by Prof. Yan Longan was widely used, and the hybrid rice variety of Shanyou 63 (Zhenshan 97A/Minhui63) had been developed by Prof. Xie Huaan in 1980. The growth area of Shanyou 63 was the largest one in 1980's in China. In addition, the hybrid rice of Honglian type and Gang D type invented by Prof. Zhu Yingguo and Prof. Zhou k.d, respectively, were also widely applied in production and enriched the theory of rice hybrid in China.

2.2 The theories and techniques of two-line hybrid rice succeeded in 1995

The first natural male sterile rice plant was discovered by Chinese scientist Shi Mingsong in Hubei in 1973. He developed the rice male sterile line Nongken 58S with a dual purpose in 1981. The dual-purpose line is also called photoperiod- and thermo-sensitive genic male sterile (PTGMS) line because its fertility expression is regulated by day length and temperature. The discovery of the dual-purpose line or PTGMS line indicated a new way to use heterosis in hybrid rice with the two-line system.

With the discovery of the PTGMS gene and the discovery of a wide compatibility (WC) gene by Japanese scientists (Ikehashi, et al.) in 1984, Professor Yuan put forward the strategic breeding idea on of using heterosis in hybrid rice breeding. The approach was to use heterosis by means of the systems from the three-line, two-line, and one-line methodology and from intervarieties to improve the level of heterosis by means of intervarietal, intersubspecific to distance hybrids.

In 1987, Professor Yuan was elected the principal investigator of the national key project of the "two-line system hybrid rice". He developed a comprehensive array of theories and techniques and finally succeeded in 1995. In recent years, the two-line hybrid varieties are grown in the field of 3 million hectares. It has been proven that the two-line system hybrid yields 5-10 percent more than the three-line system hybrid. The grain quality has also been improved.

3. Progress in hybrid rice development in China

3.1 The commercial hybrid rice production and its release of varieties

The development of Chinese rice production has generally been divided into three stages (Fig. 3): the traditional varieties growth stage (before 1964), semi-dwarf and double cropping stage (in 1965~1976), and hybrid rice development stage (in 1976 to now).

In the first stage, the traditional varieties yielded about 2 t/hm^2 , wherein the plant height of the varieties was very high. In the 1960s, China started to grow semi-dwarf rice varieties resulting in yields increasing from 2 tonnes per hectare to 3.5 t/hm^2 in 1975. Because of the innovation of hybrid rice, the successful commercialization of three-line hybrid rice in the late 1980s brought another revolution in rice production. The rice yields had risen to more than 5 t/hm^2 (Fig. 3). With the technology of hybrid rice seed production basically developed, hybrid rice was rapidly and widely extended in China. In 1991, hybrid rice area reached 17.6 million hectares, accounting for 54 percent of total rice area. By 1995, with further development of hybrid rice technology, nationwide rice yields averaged above 6 t/hm^2. The average yield of hybrid rice is 7.5 t/ha while that of other inbred varieties is 5.3 t/ha. From 1976 to now, the accumulated planted area of hybrid rice was 380 million ha and increase of the yield with a total of 600 million tonnes.

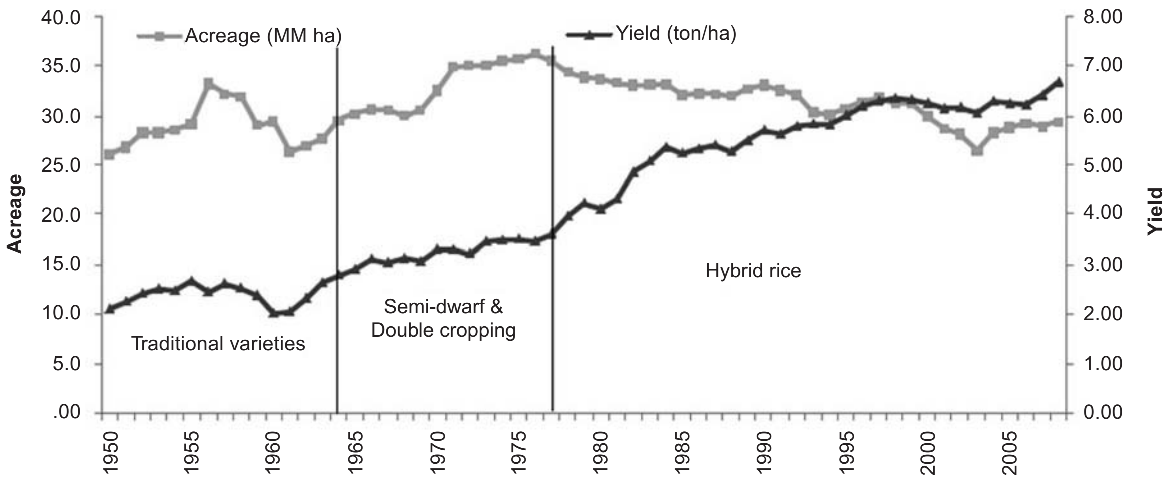


Figure 3. The changes of rice yield and rice planting area (1950-2008)

Meanwhile, during 2001 to 2013, there were 5 883 rice varieties officially released and certified by the national and provincial levels in China, and now with a yearly increase of about 400 new varieties of hybrid rice released. For instance, there are 446 and 494 varieties released in the whole country in 2008 and 2010, respectively. The *indica* hybrid rice varieties accounted for an absolute majority by 65.25 percent and 63.36 percent, respectively (Table 1). Among those released varieties, there are 80 varieties where each variety covered a planting area under 66,667 hectares, and 700 varieties with the planting area of each variety under 6,667 hectares. In the past five years, top five in growth area of hybrid rice varieties are the two-line hybrid rice Y-you No.1, Yangliangyou No.6 and Xianliangyou No.6, with about 1,000,000 hectares, and the three line hybrid rice Yueyou 9113, Gangyou 188 with about 533,333 hectares.

Table 1. Numbers of rice varieties released and the percentages of inbred & hybrid in 2008-2012

Types of rice variety	2012		2011		2010		2009		2008	
	N	R%	N	R%	N	R%	N	R%	N	R%
Indica inbred	30	7.63	33	8.64	32	6.48	36	7.58	25	5.60
Indica hybrid	247	62.85	257	67.28	313	63.36	303	63.79	291	65.25
Jalonic inbred	102	25.96	77	20.16	122	24.70	107	22.53	113	25.34
Japonic hybrid	14	3.56	15	3.92	27	5.46	29	6.10	17	3.81
Total	393	100	382	100	494	100	446	100	446	100

N: numbers of variety; R%: percentage of varieties released

3.2 Development of the super hybrid rice

In order to meet the food requirement for all Chinese people in the 21st century, a super rice breeding programme was launched by the China Ministry of Agriculture in 1996. The yield targets for hybrid rice are listed in Table 2 below

Table 2. Yield standards of super rice in China

Phase	Hybrid rice[a]			% Increase
	First Cropping	Second Croppin g	Single cropping	
1996 level	7.50	7.50	8.25	0
Phase I (1996-2000)	9.75	9.75	10.50	More than 20%
Phase II (2001-2005)	11.25	11.25	12.00	More than 40%
Phase III (2010-2015)	/	/	13.50	More than 60%

[a]*In t ha^{-1} at two (2) locations with 6.7 ha each in two (2) consecutive years*

Following the super rice breeding programme, Prof. L.P. Yuan put forward the theory of Super Hybrid Rice, emphasizing on the plant morphological improvement and utilization of the inter-subspecific heterosis. According to the basic principles of hybrid rice breeding, it has to make full use of the dominant complimentary effects of the two parents to improve morphological characteristics of the hybrid; This ideal plant type with the characteristics: taller canopy with long, erect, narrow, V-shaped uppermost 3 leaves, medium to large, uniform and droopy panicles and high lodging resistance as shown below (Fig 4). It has to extend the genetic diversity of the parents to increase the heterosis level by means of utilization of inter-subspecific heterosis and the favorable genes from wild rice.

Through the work of Chinese rice scientists, the Phase I objective (10.5 t/ha) was achieved in 2000, the Phase II objective (12 t/ha) was achieved in 2004, the Phase III objective (13.5 t/ha) was achieved in 2012, with yield increases of 25-50%, over the best hybrid checks before 1996. For example, the first two-line super rice hybrid, Liang-You-Pei-Jiu, had high commercial yield across multiple years and locations in large-scale rice production because of the good plant type and the remarkable level of interspecific heterosis that was the first hybrid rice variety to reach the Phase I yield level goals.The Phase II two-line hybrid Liang You-0293 and three-line hybrid Ming-You 8 yielded more than 12 t/ha in Hunan province and

Fujian province, respectively, surpassing the Phase II yield target. And the research team of Prof. Yuan set a stunning super-high-yield record of 13.90 t/hm^2 in the 7.2 hectares demonstration base in Longhui, Hunan Province in 2011. The team again achieved an average yield 13.76 t/hm^2 in the 6.87 hectares demonstration base in Xupu, Hunan Province in 2012, marking the achievement of the goal for the third-phase super hybrid rice in China.

Fig. 4. The real ideal model of plant morphology of hybrid (Pei'ai)

In the utilization of hybrid heterosis, some other breeding theories/models for super hybrid rice have been put forward, such as the "heavy panicle type" hybrid rice breeding by Prof. Zhou Kaida and the "physiological functional type" by Prof. Cheng Shihua. The super hybrid rice II You 162 and Xieyou 9308 bred are the representatives supervised by those theories.

By 2013, the MOA certified 73 rice hybrids as "super rice"(Table 3). Among them, 52 three-line hybrid rice varieties, such as Fengyuan You 299, Xie-You 9308, Luo-you No.8 and Ⅱ-you-hang No.1, etc., and 21 two-line hybrid rice varieties, Lian-you-pei-jiu, Y-You No.1, Yang Liang You No. 6, etc.

In March 2013, the Minister of MOA announced, on the spot in Sanya, Hainan to start the Phase 4 super hybrid rice e with large-scale yield objectives of 15 t/ha. Prof. L. P. Yuan and his research group have made a breakthrough with 14.82 t/hm^2 (two-line hybrid, Y-You No.900) in the 7.87 hectares demonstration base in Longhui, China in 2013.

Table 3. The number of super hybrid rice certified by MOA (2005~2013)

Year	2005	2006	2007	2008*	2009	2010	2011	2012	2013	Total
3-line	20	7	3	0	4	4	3	6	5	52
2-line	2	5	2	0	3	2	3	3	1	21
Total	22	12	5	0	7	6	6	9	6	73

3.3 The research of the mechanism in heterosis, fertility and molecular breeding of HR

3.3.1 Heterosis mechanism of hybrid rice

The utilization of heterosis has been proved to be effective way to improve the crop production, but its molecular mechanism has not been demonstrated clearly for a long time and lack direct evidence. Through the cooperation with Institute of Genetics and Developmental Biology and Chinese Academy of Sciences, the high-throughput screening technique (EST-Expressed Sequence Tag label and DNA chip) and mRNA differential display are applied to demonstrate genetic mechanism, evolution and molecular biological basis of heterosis with the genome sequence of two super hybrid rice parents- 9311 and Pei ai 64. Recently, with hexaploid wheat, molecular mechanism on heterosis caused by unbalanced hybrid between different ploidy species has been displayed, which provide important evidence for heterosis formation.

3.3.2 Fertility mechanism of hybrid rice

- Cloned cytoplasm male sterile gene- WA352, which was applied widely in the three-line hybrid rice and 2 restoring genes- Rf3 and Rf4, and found that same WA352 exist in different types sterile lines. WA352 can interact with COX11, an inhibitor related to programmed cell death, which can release the active oxygen. Through interrupting the function of COX11, start the degradation of tapetum and cause the loss of fertility.

- Cloned cytoplasm male sterile gene- orfH79 and its restoring gene Rf5, and demonstrated its fertility restoring mechanism; Rf5 encode a Pentatricopeptide repeat (PPR) protein, interact with GRP162 to form the complex to stop the transcription of orfH79.

- Cloned Photo-Thermo-Sensitive genic male-sterile gene-pgms3, a long noncoding RNA (lncRNA), referred to as long-day-specific male-fertility-associated RNA (LDMAR), and regulates PSMS in rice.

3.3.3 Molecular breeding of hybrid rice

Hybrid between *indica* rice and *japonica* rice can produce strong heterosis, an important way to improve rice production further. However, its related phenomena including half fertility, late maturation limit its utilization in practice. Following the cloning of growth regulating genes-DTH8、DTH2 and Ehd4, fertility control gene-pss1, plant height regulating gene-D53, it will cause hybrid between *indica* rice and *japonica* rice more effective.

Furthermore, with marker-assisted breeding and exogenous DNA introducing technique, high-yielding gene and resistance genes from wild rice have been transferred into parents of super hybrid rice, such as Y-you No.1, Y-you 900, in which production of Y-you 900 has reached 14.82 t/hm2 on the spot base at area of 7.8 hm^2 in 2013. These achievements in rice breeding display the prospect of heterosis utilization.

3.4 HR seed production

When the first hybrid rice was released in 1975, the technology of hybrid rice seed production was the key problem for commercialization because the yield of hybrid rice seed production was very low, and the average yield in China was only 274.5 kg/hm2 in 1975. Fortunately, many agronomists shifted their focus to that problem and technology package for high-yielding seed production was developed within a few years, resulting in the yield of hybrid rice seed production increasing greatly and rapidly (Fig. 5). In 1985, the national average yield increased to 1.66 t/hm2, then up to 2.25 t/hm2 in 1990. In Hunan Province, yield on a large scale increased to 3.0-4.5 t/hm2 in the 1990s from 324 kg/hm2 in 1976 and the highest recorded yield of 7.4 t/hm2 was made on a small plot (0.113 ha) at Zixing City, Hunan

Province in 1993. With the yield increase in multiplication and seed production, the area ratio of A line multiplication to F1 hybrid seed production to F1 hybrid commercial production has changed from 1:30:1,000 in the 1970s to 1:50:6,000 in recent years, which greatly lowers the cost of hybrid seeds.

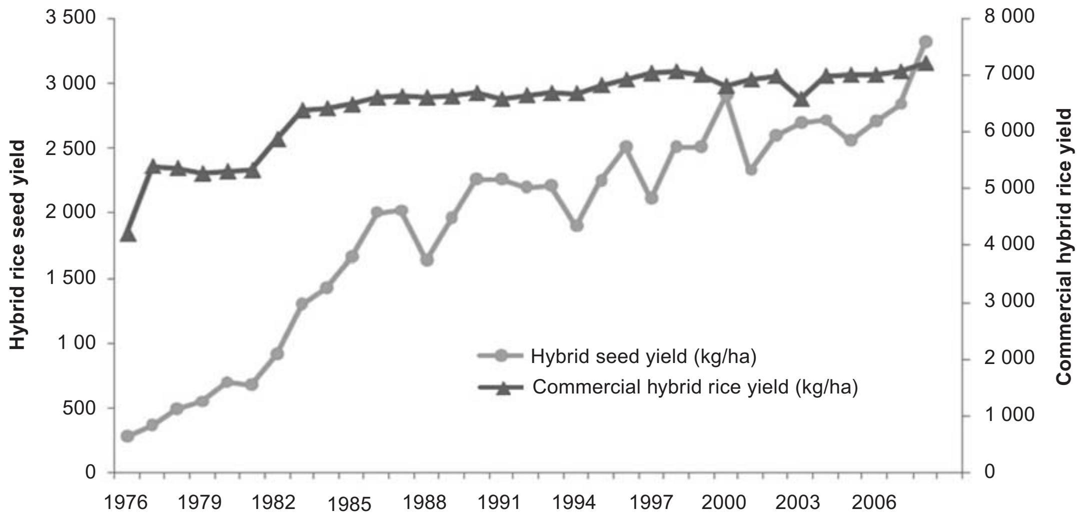


Figure 5. Commercial hybrid rice yield and hybrid rice seed yield in China

The yield increase of hybrid seed production ensured sufficient quantity for commercial hybrid rice production, lowered costs for seed businesses and farmers (Zhou and Peng 2005), and promoted the fast and steady expansion of hybrid rice production in China. After years of demonstrated yield advantage of hybrid rice and a commercially viable hybrid seed production system, the Chinese government established many large and effective hybrid rice seed businesses in the late 1970s at all levels from county to state. This was the first time in Chinese history for crop seed businesses to be financially sound.

Because of the labor cost increase, it is hard for seed companies to use the techniques of the hybrid rice seed production such as artificial pollination, transplanting parent's lines, and harvest. Therefore, some seed companies have initiated the research of techniques mechanized for hybrid rice seed production. Longping Hightec has used unmanned aerial vehicle (UAV) rotor instead of artificial pollination and GA spraying, modified the ratio of R:A as 6~8 rows to 40~80 rows, and combining with mechanical transplanting parent lines separately and harvesting. This techniques mechanized and optimized perform higher outcrossing seed setting rate (about 45%) and high yield by 2.7～3.0t/hm^2 on large scale in hybrid rice seed production. it finds a way out for hybrid rice seed production in large scale China that is conducive for Chinese seed industry enterprises to attain healthy development.

3.5 Field management of HR

Fig. 6. The pollination, GA spraying and the ration of A:R lines by the unmanned aerial vehicle (UAV)

Hybrid rice technology revolutionized rice farming practice because unlike inbred rice, hybrid rice requires different degrees of agronomic management depending on its stage of growth. Therefore, it was important to develop optimum field management practices to manipulate yield components such as plant population and canopy structure to realize the maximum economic yield of hybrid rice. Chinese hybrid rice agronomists accomplished this by developing systematic methods for high-yielding field management such as the Rice Precise and Quantitative Cultivation Technique for High Yield (H.C. Zhang, et al., 2008), the Improved system of rice intensification (G.H.MA, Jun, Ma, et al., 2007), “3-ding”Cultivation Technology for Super Hybrid Rice (Y.B Zou et al., 2010) and the Nitrogen-saving and lodging resistant cultivation (G.H.MA et al., 2012).

The "3-ding”Cultivation Technology for Super Hybrid Rice, proposed by Y.B Zou from Hunan Agricultural University: The “3-ding” cultivation method involved one of the cultivation methods to quantify the target yield, population indexes and technique procedures, namely, to plan target yield based on the yield level in growing regions, to quantify population indexes (e.g., panicle number) based on the yield components, and to fix technique procedures (e.g., nitrogen rate) based on soil yield potential and LCC readings.

The Rice Precise and Quantitative Cultivation Technique for High Yield: This technique, which is created by Yangzhou University, improves the quantification and precision of cultivation programme design, crop development dynamic diagnosis and cultivation measures implementation, with “three types of quantification” including quantitative course of growth and development, quantitative dynamic indexes of population and quantitative cultivation techniques and “three types of optimizations” including optimum operating times, optimum adjustment time and optimum input quantity at the core. The technique was widely used in the primary rice production regions in China with more than 10 percent increasing in yield and 20 percent increase in efficiency generally. In 2013, the yield of mechanical transplanting rice in Xinghua City set the record of 1.44 t/hm2 with more than 6.7-hectare field in wheat-rice rotation system.

The Improved System of Rice Intensification (MSRI) based on the System of Rice Intensification (SRI), which originated from Madagascar: The Improved SRI, absorbed some of the technical idea of SRI, but the overall copy of this technique is obviously not suitable for super hybrid rice super high-yielding cultivation. Therefore, with the support of the MOA, many Chinese agronomists are engaged in the research and technical improvement on SRI to establish a modified SRI. The main technical features: (i) transplanting suitable age seedlings (3-5 leaves age) instead very young ages (only 2.1 leaves); (ii) being of reasonable density (19-22 hills/m2) instead of super sparse (9-14 hills/m2); (iii) transplanting double seedlings instead of single one; (iv) to apply the formula component fertilizer instead of large numbers of organic fertilizer, and (v) intermittent irrigation and moisture field management instead of the stress irrigation. In the practice of super hybrid rice demonstration, the MSRI yielded 13.5 t/hm2.

Nitrogen-efficiency and lodging resistance cultivation technique which is created by Hunan Hybrid Rice Research Center: In view of super hybrid rice production in large quantity of nitrogen application, serious lodging, and non-point source pollution, this integrated technique consists in the reduction of nitrogen quantity (about 20 percent) with the increase of planting density (about 10 percent), slow release nitrogen application, promoting regulation combining inhibitory control to the stems of plant, that greatly increase the nitrogen use efficiency by 20 percent more, shorten the basal internode length by about 20 percent, but not significantly reduced plant height and biomass. The practice on large scale shown that, compared with the conventional cultivation, reducing the total amount of nitrogen by 20 percent, effectively prevents the lodging, and increases yield by 3-9 percent.

4. The intellectual property and seed industry of HR in China

4.1 The development of hybrid rice seed industry

The Chinese rice seed industry is growing rapidly. By the end of 2012, altogether, there were 520 rice seed enterprises that have acquired business certificates. Among these 520 enterprises, there were 43 whose registered capital was more then 100 million yuan (100 million included), accounting for 8.3 percent. However, among these enterprises, only 21 of them have acquired the qualification of the integration of breeding, multiplication and commercialization, taking up 4% of rice seed enterprises And among such many seed enterprises the cover rice seed business, top 5 are: China National Seed Group Co., Ltd, Longping High-Tech, Hefei Fengle Seed Co.,Ltd, Beijing Kings Nower Seed S&T Co., Ltd and Hainan Shenlong Dafeng Seed S&T Co.,Ltd. Longping High-Tech takesup about 30 percent in the hybrid rice market.

The Chinese rice seed industry is full of promises. According to incomplete statistics, 1.167 billion kg rice seed were sown in 2012 with hybrid *indica*, hybrid *japonica,* inbred *indica* and inbred *japonica* accounting for 23 percent,1 percent, 26 percent and 50 percent, respectively. The rice seed for commercialization was weighed at 855 million kg, among which are 283 million kg hybrid rice seed and 884 million kg inbred rice seed with commercialization rate of 100 percent and 64.76 percent, respectively.

4.2 Intellectual property right (IPR) of hybrid rice

Hybrid rice has contributed greatly to Chinese food security and farmers are direct beneficiaries. In 1980, China's hybrid rice was transferred to USA as the first agricultural patent technology, which received extensive concerns from international community. However, it was a regret that the patenting of plant varieties were forbidden in the then Patent Law of People's Republic of China, resulting in very low transfer fee given by USA. This situation did not alter until in 1999 when China joined the The International Union for the Protection of New Varieties of Plant （UPOV). The Chinese government implemented the Patent Law of People's Republic of China and Regulations for the Protection of New

Varieties of Plants. The two-line sterile line P64s, developed by CNHRRDC, became the first variety enjoying the Protection of New Varieties of Plants and was numbered as CNA1999001. Among 3,632 rice varieties, 1,459 have received authorization with hybrid rice varieties and parent accounting for 80 percent.

Though hybrid rice varieties and technology are the most dynamic part of agricultural IPR protection, there remain many parts that are not in line with hybrid rice development. IPR infringements sometimes occur, and it is difficult and expensive to safeguard IPR. The protection fee and safeguard cost of IPR of hybrid rice new varieties and safeguarding cost shift to profit, leading to an increase of farmer's cost of production.

5. Constraints in HR development

5.1 Area has been at a standstill for years

In 1991, the hybrid rice area reached its peak at 17.6 million ha, but after that the area decreased and has stayed at about 15.5 million ha. The main reasons are considered to be a decrease in the area of double cropping of early hybrid rice and *japonica* hybrid rice. Another reason is that 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.

5.2 Lack of *japonica* hybrid rice with strong heterosis

The planting area of japonica hybrid rice has been limited to around 100,000 ha, accounting for only 1-2 percent of total japonica rice in China for many years because of its relatively poor heterosis (about 10 percent over conventional japonica rice), the sterility of its CMS lines is not stable enough to produce high purity of F1 seeds, and it has poorer grain quality.

5.3 Super high yield with great yield gap for super hybrid rice

The super hybrid rice in test area has shown the yield potential of 14.82 t/ha in Hunan province but the average yield of single-cropping rice in Hunan was only 6.84 t/ha during the last 5 years. There is a great yield gap of 5.16 tonnes per hectare. The country has to develop adaptable package techniques to gradually shorten the yield gap step-by-step for super hybrid rice.

5.4 Too many new hybrid rice varieties yearly but very few breakthrough combinations

Hybrid rice Shanyou 63 was bred In 1981, with the planting area ranked as No 1 nationwide for 15 consecutive years. The largest planting area of this hybrid reached yearly up to more than 6.7 million hectares. In contrast, now there are hundreds of new hybrid rice combinations officially released very year. Of that, there are 381 hybrid rice varieties, the planting area of each variety is only about 10 000 hectares. Although Y-you No 1 is the top one in the planting area in China, it is only by 377 000 hectares in 2012.

5.5 Need of the breakthrough for the mechanized technology of HR seed production

In the past 40 years, China's hybrid rice seed production techniques had not much mprovement, hybrid rice seed production process is complex and strict, with lower efficiency and high labor cost. Hybrid rice seed production, relying on the traditional labor-intensive, became the key obstacle to develop HR in China. So that it is urgent to mechanize the technology of hybrid rice seed production.

6. Reasons for the success of hybrid rice in China

First of all, the Chinese government paid much attention to developing hybrid rice and the heads of the Government at all levels were very much committed to and supportive of hybrid rice research and development, such as special budget and policy support provided when needed.

Second, a very efficient organization and coordination had been established in 1970s-1980s such as the National Hybrid Rice Advisory Committee (NHRAC) and the hybrid rice leading group or office at different levels. The NHRAC coordinated the relations between technology development and dissemination activities. At the same time, frequent conferences on hybrid rice were held to discuss and solve the serious problems encountered in the initial stages.

Third, targeting the real technical problems, financially supported by the Government and organized by the networks, applied and strategic studies, extension activities were conducted in each 5-year period. Training, yield trials, on-farm demonstration, study tour and propaganda for hybrid rice were extensively organized in the initial stage in the entire country. The Government put large efforts into producing a large amount of hybrid rice seeds at Hainan Island in the off-season to widely demonstrate hybrid rice in the whole country. Hybrid rice technology was immediately incorporated into a textbook for agricultural education in the early 1970s.

Last, the policy dealing with hybrid rice development played a very important role also such as the subsidy in the initial time, the national standard of hybrid rice seed quality and the hybrid seed law implemented.

7. The prospect of hybrid rice development in the future

Based on the rice breeding practice, there are only two effective ways to further increase rice yield. One is the morphological improvement; another is the utilization of heterosis. The yield potential is limited only by morphological improvement and it could also not achieve the further high yield only by heterosis without combining with morphological improvement. Whatever advanced technology we use, such as molecular techniques, all of that will eventually founded on excellent morphology and strong heterosis in order to further increase the yield. Grain yield would be the harvest index by the biomass. Therefore, Prof. L.P. Yuan puts forward a new idea of super high yield breeding (Fig. 7):

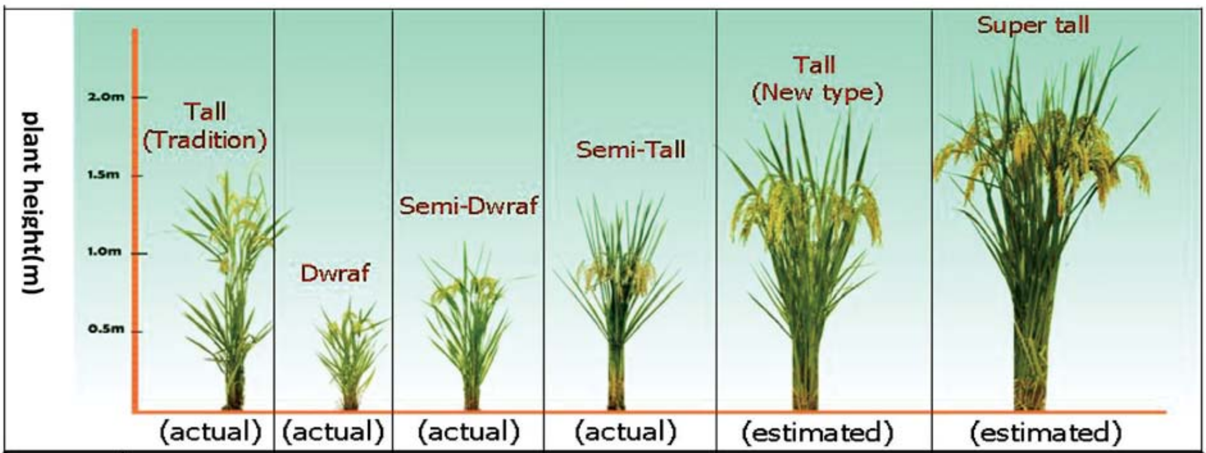
- Increase the biomass by efficiently increasing the height of plant from semi-tall, tall to super tall for the yield increase from 12-14 t/hm^2, 15-16t/hm^2 to 18 t/hm^2 more;

- Morphological improvement to establish the highly efficient photosyntesis populations;

- Further utilize heterosis by exploitation of *indica/japonica* heterosis, favorable genes (QTLs);

- Enhance the lodging resistant; and

- Maintain the higher harvest index with 0.5~0.55.



	Tall (Tradition)	Dwraf	Semi-Dwraf	Semi-Tall	Tall (New type)	Super tall
HI	≈0.3	0.5	0.5	0.5	0.5	0.5
Yield level	3-4t/ha	6t/ha	8-10t/ha	12-14t/ha	15-16t/ha	>18t/ha

Fig. 7. The model of plant types for further yield increase of rice (L.P. Yuan, 2009)

Hybrid Rice in India

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1. Introduction

Rice is the staple food crop of India, providing 43 percent of calorie requirements for more than 70 percent of the population. The area covered under rice is 43.95 million hectares with an annual production of 106.29 million tonnes and productivity of 2,416 kg/ha^{-1} (http://eands.dacnet.nic.in/). In the last six decades, rice production has steadily kept in pace with the population growth rate, mainly due to gains derived from the technologies of the green revolution era.

Rice, besides being the staple food for majority of the Indian population, has also become an item of commerce during the last two decades. Rice production recorded commendable growth with three-fold increase from 30 million tonnes (1965) to 93 million tonnes (2002) helping to achieve self-sufficiency and enabling India to become a rice exporting country. Now with an annual rice production of around 106 million tonnes (2013-14), India has become the largest global rice exporter. During 2012-13, India exported 34,600 metric tonnes (MT) of basmati rice, worth US$ 3,560 million to countries like Iran, Saudi Arabia, United Arab Emirates, Iraq and Kuwait. During the same year, the country also exported 66,800 MT of non-Basmati rice worth US$ 2,650 million to countries like Nigeria, Senegal, Benin, Cote D'Ivoire, South Africa and the United Arab Emirates. Of the several agricultural products exported from India, rice alone constituted nearly 30 percent of the quantum and 29 percent of the foreign exchange (US$ 6,210 million) in the year 2012-13, indicating the importance of rice in the Indian export scenario and in the Indian economy (www.apeda.gov.in/).

Keeping in view the annual average population growth rate of 1.8 percent and estimated per capita consumption of about 250 g of rice per day, the demand for rice is expected to be around 130 MT by 2025. This projected demand can be met only if there is a steady increase in productivity and production. Furthermore, the increase in production has to be achieved under conditions of declining and deteriorating land, soil and water resources and at the same time preserving the environmental quality. Among the available genetic options, increasing yield by exploitation of heterosis is very promising and feasible. Large-scale commercial cultivation of hybrid rice has been successfully demonstrated in the People's Republic of China.

2. Progress in hybrid rice development in India

2.1 History of hybrid rice development

Realizing the potential of hybrid rice to increase the production and productivity, the Indian Council of Agricultural Research (ICAR) launched a mission mode project on hybrid rice in December 1989. The International Rice Research Institute (IRRI) provided the needed germplasm and technical backstopping. This project was further strengthened with financial support from United Nations Development Program (UNDP) and technical support from Food and Agriculture Organization (FAO) of the United Nations (UN) during 1991–1996.

During the first phase of the project, the UNDP support was mainly for providing consultancies, overseas training and need-based equipment.

A national network approach was adopted since 1989 by including all the concerned research institutions, public and private seed agencies and departments of agriculture of target states. Appropriate international organizations were also the part of the network for consultancy and training purposes. Effective linkages were established among all the partner institutes and the project was implemented by the Directorate of Rice Research, Hyderabad.

During the second phase (2000-2004) of the UNDP project, emphasis was given for fellowship training, in-country training and transfer of technology. During the same period, the research activities of the project were supported by the World Bank-funded Indian Council on Agricultural Research/National Agricultural Technology Project (ICAR/NATP) on "Development of Hybrids in Selected Crops" including rice (1999-2005). Mahyco Research Foundation (MRF), now popularly known as Barwale Foundation, provided financial assistance to the hybrid rice project from 1996 to 2002 to fill critical gaps, which is a good example wherein a private foundation supported a public sector research.

The project was implemented through a well-organized national network composed of 12 centres located across the country (Fig.1). This national network has another 30 voluntary centres represented by public, private and NGO sectors.

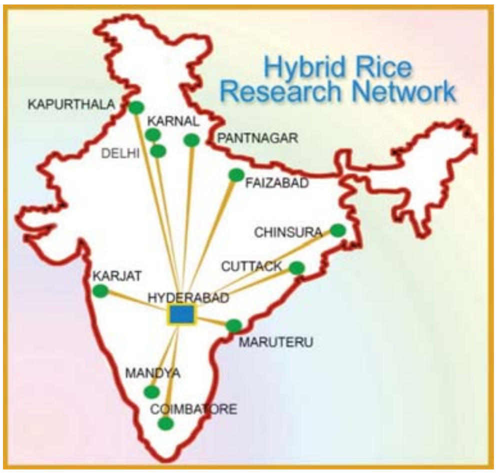

Fig. 1. Hybrid rice research network composing of 12 centres across the country

2.2 Status and trends of hybrid rice development

The strong foundation laid for hybrid rice research and seed production through the consultancy missions of chief consultants Prof. Yuan Long Ping, Dr. S.S. Virmani and Dr. Ikehashi and other Chinese consultants, study tours and fellowship trainings of a large number of Indian scientists in reputed institutes in China and other countries as well as at IRRI, Philippines helped in accelerating the research work on hybrid rice. The visionary approach of the policy makers and research managers, the generous and timely funding from the ICAR and other donors and the effective and efficient implementation of the programme by the project personnel helped India to achieve the distinction of becoming the second country in the world after China to develop and commercialize hybrid rice in a big way. So far, 69 hybrids have been released for commercial cultivation in the country. Out of

69 hybrids released, 31 are from the public sector and 38 are from the private sector (Tables 1 and 2 shown at the end of this paper). The private sector is playing a very important role in hybrid rice research and development in the country.

2.2.1 Large scale cultivation of hybrid rice

The adoption of hybrid rice in the initial years has been rather slow but a steady one. From the initial level of 10 000 hectares in 1995, the area under hybrid reached 1 million hectares in 2006. It has picked up during the last nine years, mainly because of increasing popularity of hybrid rice among rice farmers of Eastern Uttar Pradesh, Bihar, Jharkhand, Madhya Pradesh and Chhattisgarh. As a result, the area under hybrid rice is increasing steadily. In the year 2013, the area under hybrid rice exceeded 2.5 million hectares (Fig. 2), which is about 5.6 percent of the total rice area in the country.

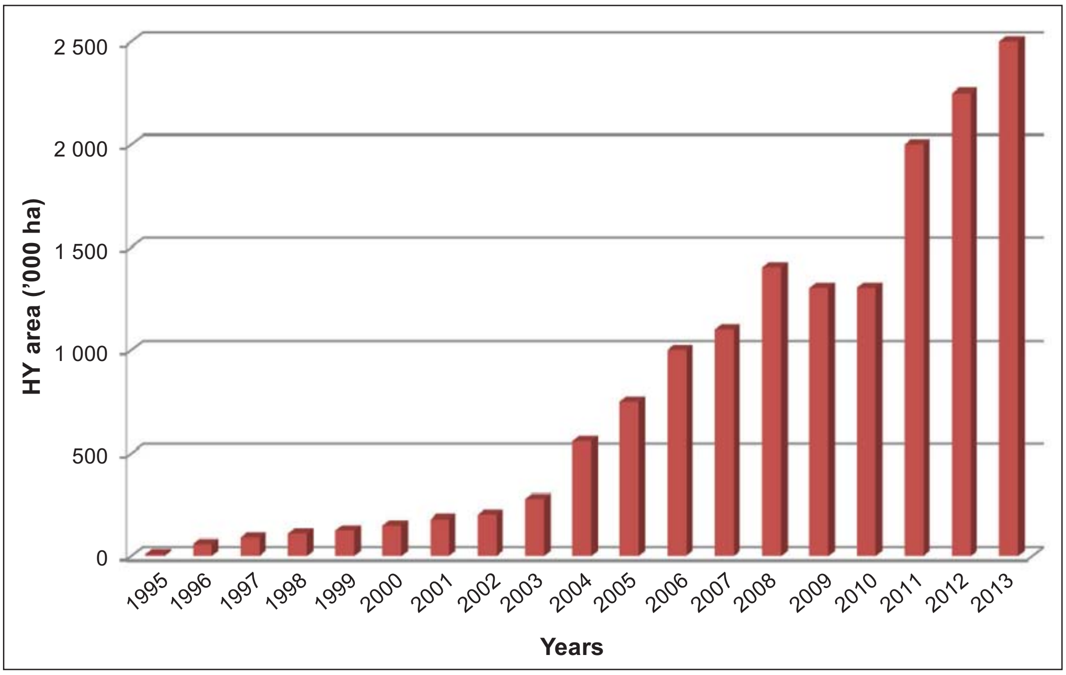

Fig. 2. Hybrid rice cultivation in India over the years

2.2.2 Hybrid seed production

For economic and commercial viability of the hybrid rice technology, the development of an efficient and economic seed production package is a pre-requisite. The extent of adoption of this innovative technology depends primarily on magnitude of realizable heterosis at field level and availability of pure seed at a reasonable cost. Seed production is the most crucial link between the breeders developing the hybrids and the farmers cultivating them. Hybrid rice seed production involves several technical steps which have to be managed satisfactorily to obtain an acceptable seed yield of 2 tonnes/ha. Obtaining proper synchronized flowering between parental lines, determining the optimum row ratio, identifying the critical out-pollination promoting factors, determining the appropriate dosage and stage for application of GA3 and finding out the frequency and precise timing for supplementary pollination, etc. are some of the aspects which were required to be standardized for different hybrid combinations and locations. Extensive trials were conducted on various aspects of seed production technology at different locations under the hybrid rice network project. The optimum package for hybrid seed production and CMS multiplication has been developed (Table 3). By adopting this package, the farmers were able to realize the seed yields in the range of 1.5-2.5 tonnes/ha.

Table 3. Optimum package for hybrid rice seed production and CMS multiplication

Activity	Particulars		
Seed rate	"A" line or female Parent: 15 kg./ha "B" or "R" line or male parent: 5 kg/ha		
Nursery	Sparse seeding (20 g/m2) to ensure multi-tillered (4-5) seedlings in 25 days.		
Row Ratio	2B:6A for CMS multiplication 2R: 10A for hybrid seed Production		
Number of seedlings/hill	2 seedings/hill for female parent 3 seedlings/hill for male parent		
Spacing	Male : Male = 30 cm Male : Female = 20 cm Female : Female = 15 cm Plant : Plant = 15 cm or 10 cm		
GA3 application	60-90 g/ha in 500 litres of water at 5-10% heading in two split doses on consecutive days		
Supplementary pollination	Four to five times a day at peak anthesis with 30 minutes interval during flowering phase		
Roguing	At Vegetative phase	--	Based on morphological characters of leaf and plant type
	At flowering	--	Based on panicle characteristics
	At maturity	--	Based on grain characteristics and percent seed set.
Seed yield	1.5-2.5 tonnes/ha		

Fairly good progress has been made on hybrid rice seed production, by achieving the seed yield of over 2.0 tonnes/ha. However, for successful large-scale seed production programmes, maintenance of purity of parental lines and their regular supply particularly to the public sector seed agencies, economizing the seed production cost and imparting training to large number of seed production personnel are some of the crucial requirements which were provided by the hybrid rice network. Like in other crops, in rice the private seed sector has taken a lead in hybrid seed production and more than 95 percent of the hybrid rice seed production in India is being taken up by this sector. The leading private sector seed companies are: Bayer Bio-Science Pvt, Ltd; PHI Seeds Ltd., Pioneer Overseas Corporation; Seed Works International; Bio-seed Research (I) Pvt. Ltd; Mahyco; Syngenta India Ltd.; Advanta India Ltd.; Nuziveedu Seeds; Nath Biogene Ltd., Indo-American Hybrid Seeds; J.K. Agri Genetics; Metahelics Life Sciences Pvt. Ltd and Ganga Kaveri Seeds Ltd. Among the public sector seed agencies, State Seed Corporations of Maharashtra, Karnataka and Uttar Pradesh and National Seed Corporation are taking up hybrid rice seed production on a small scale. Initially the seed yields obtained were very low (0.3-0.5 tonne/ha), but with experience over the years, 1.5-2.5 tonne/ha average seed yields are being obtained now.

2.2.3 Hybrid seed supply and trade

The private sector is following the centralized contract farming model for seed production and it works on the agreement between the farmers and a private seed company. Contracting companies provide support to the production of the crop by farmers, purchase the crop from them, and then process, package and market the product, thereby tightly controlling the seed quality. The dry season (*rabi)* is found to be better for seed production than the wet season (*kharif*) as recorded by the seed yields obtained in large-scale seed production in Telangana State (erstwhile United Andhra Pradesh). Telangana State is the hybrid rice seed hub with more than 80 percent of the seed being produced in Karimnagar, Warangal, Nizamabad, Khammam, and Nalgonda districts. Ideal climatic conditions, progressive and receptive seed growers and active presence of the private sector seed agencies in and around Hyderabad are the main reasons for large-scale hybrid rice seed production in these areas. Progressive improvement in hybrid rice seed production in India is given in the Table 4. The volume of hybrid rice seed produced in India, starting with less than 200 tonnes of total production in the year 1995, has crossed 40 000 tonnes from 30 000 hectares in 2013. Sale price of hybrid seed produced by the private sector ranges from US$ 2.73 to 3.91 per kg, whereas that of public sector ranges from US$ 1.56 to 2.34 per kg. At the time of marketing, the companies follow the 'distributor/dealer/retailer' network to make the seed available to the farmers.

Table 4. Progressive increase in area and production of hybrid rice seed

Year	Area (ha)	Seed Production (t)	Year	Area (ha)	Seed Production (t)
1995	195	200	2005	6 800	12 500
1996	1 075	1 200	2006	12 000	18 000
1997	1 485	1 800	2007	13 000	19 500
1998	1 630	2 200	2008	14 000	21 000
1999	1 660	2 500	2009	18 000	27 000
2000	1 630	2 700	2010	20 000	30 000
2001	1 625	2 900	2011	18 000	26 000
2002	1 635	3 100	2012	21 000	30 000
2003	2 865	4 000	2013	30 000	40 000
2004	4 350	8 600	-	-	-

The public sector is strong in technology generation in terms of releasing hybrids and optimizing the technologies for seed production. However, its capabilities in large-scale seed production and marketing are rather limited. On the other hand, the private sector is quite strong in large scale seed production and marketing. Therefore harnessing of mutual strengths of public and private sectors in a partnership mode is the key to popularize the public bred hybrids which are as good or even better in some cases as compared to private hybrids. Public-private partnerships for hybrid seed production have been fructified in India by the signing of memorandums of understanding (MOU) by some companies with few public sector research institutes. Some examples are given below and these MOUs are being signed as per the guidelines issued by the Indian Council of Agricultural Research (ICAR), New Delhi (Table 5).

Table 5. Details of MoUs signed with private seed companies

Hybrid	Developed by	MOU with
DRRH-2, DRRH-3	DRR, Hyderabad	C P Seeds Co. Bioseed Research India Pvt., Ltd Shakthi Seeds Pvt., Ltd Zuari Seeds, Ltd Rohini Seeds Pvt., Ltd J K Agri Genetics, Ltd Namdhari Seeds Pvt., Ltd Siri Seeds Pvt., Ltd Krishidhan Seeds Pvt., Ltd RJ Biotech Pvt., Ltd Ankur Seeds Pvt., Ltd Ganga Kaveri Seeds Pvt., Ltd
Pusa RH-10	IARI, New Delhi	J.K. Agri Genetics Nath Biogene (I), Ltd Devgen Seed and Crop Technology Pvt., Ltd Zuari Seeds, Ltd Advanta India, Ltd Yashoda Seeds Pvt., Ltd Namdhari Seeds Pvt., Ltd Amareshwara Agri. Tech, Ltd Bhavani Seeds Pvt,. Ltd
PSD-1 and PSD-3	GBPUAT, Pantnagar	Syngenta India, Ltd, Pune
CORH – 3	TNAU, Coimbatore	Rasi Seeds (P), Ltd, Attur, T.N.
Ajaya, Rajalakshmi, CRHR-32	CRRI, Cuttack	Vikky’s Agri Sciences Pvt., Ltd PAN Seeds Pvt., Ltd Nath Bio-Gene Pvt., Ltd Sansar Agropol Pvt. Ltd
KRH-2	UAS, Mandya	Namdhari Seeds Pvt., Ltd, Hyderabad
Sahyadri-1	BSKKV, Karjat	Syngenta India, Ltd, Pune
JRH-4, JRH-5	JNKV, Jabalpur	Vikky’s Agri Sciences Pvt., Ltd, Hyderabad

The import of hybrid rice seeds is restricted. Limited quantities for the purpose of testing and evaluation only are being imported while import in large quantities is not permitted. From the export point of view, approximately 5,000 to 6,000 tonnes of hybrid rice seed were sent (during 2013) to different Asian countries, viz., the Philippines, Bangladesh, Vietnam, Pakistan by major private seed companies viz., Bayer Bio-Science Pvt Ltd, Syngenta (DevGen), Seed Works International, Bio Seed Research India, Pioneer Overseas International, Nath Bio-Gene and Nuziveedu Seeds Company.

2.2.4 Hybrid rice - Intellectual property

To protect the interest of the developers of the varieties and also to safeguard the interests of the farmers, who cultivate the varieties, the Government of India has enacted a legislation on the ‘Protection of Plant Varieties and Farmers Act’ (PPV&FR) in 2001, which is a unique and model Act which gives equal importance to the farmers and breeders and treats them as partners in their efforts for sustainable food security. The Central Government, by notification in the Official Gazette, established the Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA) to implement the Act. The PPV&FRA came into force in 2007 and started the registration of plants covering 12 crops including rice from May 20, 2007 (www.plantauthority.gov.in). The PPV&FRA accords registration of rice varieties under different categories viz., new variety, extant variety, farmer's variety and essentially derived variety. The public sector organizations/private seed companies can apply their hybrid rice parental lines/hybrids to the Authority and get them registered to protect them. Details of some of the rice hybrids registered with PPV& FR Authority are furnished below (Table 6).

Table 6. Details of some of the rice hybrids registered with PPV& FRA Authority

S. No	Applicant Name	Denomination Filed	Type of variety as filed
1	MAHYCO	P 1628	New
2	MAHYCO	P 1523	New
3	MAHYCO	P 1524	New
4	MAHYCO	MRP 5401	New
5	Syngenta India, Ltd.	SYN-RI-5251	New
6	Indo-Amercian Hybrid Seeds (I) Pvt., Ltd.	INDAM 100-001	New
7	JK Agri Genetics ,Ltd.	JKRH-401	Extant
8	Pioneer Overseas Corporation	27 PO4	Extant
9	Bayer Crop Science AG	H 6444	Extant
10	Bayer Crop Science AG	H 6129	Extant
11	Indian Agricultural Research Institute, New Delhi	Pusa RH-10	Extant

2.2.5 Impact of hybrid rice adoption

The impact of hybrid rice technology in India was assessed by two reputed independent agencies viz., Indian Institute of Management, Ahmedabad and Society for Management of Agri-Rural Projects, Kanpur (during 2002). An assessment of the impact was carried out in the States of Punjab, Haryana, Uttar Pradesh, Uttaranchal and Bihar in northern India. In southern India, it was carried out in the States of Tamil Nadu, Karnataka and Andhra Pradesh. Maharashtra in the western region and West Bengal in eastern India were also covered under this study.

Salient findings from the impact assessment study in Punjab, Haryana, Uttar Pradesh, Uttaranchal and Bihar

- There is a yield advantage of 1.0-1.5 tonnes/ha in all the five states studied by cultivation of hybrid rice over the highest yielding inbred checks in different states.
- Additional net profit by cultivation of hybrids over the inbred checks ranged from Rs. 2,781 to Rs. 6,291 per hectare.

- The net profit by undertaking hybrid rice seed production was around Rs. 21,000 per hectare, at seed yield levels of 1.0 tonne/ha and the farm gate seed price of Rs. 50 per kg.
- Except in the State of Punjab, farmers, researchers and extension workers were convinced that the hybrids give considerably higher yields than the inbred varieties.
- There is some reluctance on the part of millers to offer similar price for hybrids as for the inbred varieties in Uttar Pradesh and Bihar.
- The prospects of large-scale adoption of hybrid rice are bright, if grain quality of the hybrids is improved and proper policy and institutional interventions are forthcoming.

Salient findings from the impact assessment study in Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka and West Bengal

- Net profit by cultivation of hybrids ranged from Rs. 1,250/ha in Andhra Pradesh to Rs. 6 000/ha in Karnataka, Maharashtra and Tamil Nadu.
- Net profit in hybrid seed production ranged from Rs. 7,500/ha (Andhra Pradesh) to Rs. 30,000/ha (Karnataka).
- Hybrid seed production activity generates additional employment of 65 person days/ha and most of them are women.
- There is no adverse impact of hybrid rice cultivation on the environment.
- In the process of development of hybrid rice, more emphasis should be given for market preferences.

The impact assessment study jointly conducted by the International Rice Research Institute (IRRI) and Acharya NG Ranga Agricultural University in 2010 showed that hybrid rice varieties are indeed superior to the inbred rice varieties for yield and profitability in Chhattisgarh and eastern Uttar Pradesh. Hybrid rice outyielded the existing inbred varieties by about 36 percent in Chhattisgarh and 24 percent in Uttar Pradesh under farmers' field conditions (Table 7). On average, the yield gain of hybrid rice over the existing popular inbred rice varieties in eastern India is about 30 percent in farmers' fields, which is a phenomenal increase under rainfed uplands (Janaiah and Xie, 2010). Hybrid rice cultivation generated an addition3al net profit of about 13 percent in Chhattisgarh and about 33 percent in Uttar Pradesh. Fig. shows farmers harvested bumper hybrid rice crops.

Table 7. Average yield (t/ha) of hybrid and inbred rice varieties

State	Hybrid	Inbred	Yield gain	% Yield gain
Chhattisgarh	4.5	3.3	1.2	36.4
Uttar Pradesh	6.2	5.0	1.2	24

(Ref: Janaiah A and Xie F. 2010. Hybrid rice adoption in India: farm-level impacts and challenges. IRRI Technical Bulletin No. 14, IRRI)

Hybrid rice cultivation (with 2.5 million hectares during 2013) might have contributed an additional 3-4 million tonnes to the total rice production in the country and hybrid rice seed production. Besides being a lucrative enterprise for seed growers, it also generates additional employment of 60-80 days per hectare, particularly for rural women in activities like leaf clipping, supplementary pollination, roguing, etc., thus benefitting rural communities.

3. Constraints and gaps in hybrid rice development

3.1 Technology constraints

Despite very good progress made in hybrid rice breeding in the country, there are still many issues to be resolved.

- Marginal heterosis: In high productive rice growing states, the yield advantage of hybrids over high yielding inbred varieties is up to 10-15 percent only which is not economically attractive to the farming community.

- Narrow genetic base: All the 69 released hybrids are based on single cytoplasmic source (wild abortive <WA>), which may be prone to outbreak of any major biotic stresses.

- Diversified consumer preferences: The grain quality preferences are highly region- specific in India and developing hybrids to satisfy the quality requirements of diverse regions is a daunting task.

- Very few hybrids in late duration and limited choice of hybrids for unfavourable ecologies: Long-duration hybrids for coastal regions, boro ecologies, and suitable hybrids for saline/alkaline soils are not available.

- Susceptibility of parental lines to major pests & diseases: The parental lines and hybrids are susceptible to major biotic stresses and minor diseases like false smut which is becoming a major threat for hybrid rice cultivation.

3.2 Social and economic constraints

- Higher seed cost is a major deterrent for large scale adoption and hence there is a need to enhance the seed yield in hybrid rice seed production to reduce the seed cost.

- Lower market price offered and discrimination against hybrid rice produce by millers/traders is acting as a deterrent for many farmers to take up hybrid rice cultivation. Price discrimination against hybrids is because of apprehended low-percentage head rice recovery.

Capability constraints

- Very low number of breeders (<20) involved in hybrid rice breeding in the public sector in the country as against many folds (>150) in China.

- Lack of strong institutional mechanism for production and supply of quality seed of public bred hybrids and involvement of public sector seed corporations in large -hybrid rice seed production have been minimal.

- Inadequate funding support for public sector research on hybrid rice in recent years is also one of the reasons for slower progress in hybrid rice research.

Policy constraints

- There is no uniform subsidy component on hybrid seed cost, which varies from state to state (0 - 100 percent).

- The condition that notified hybrids alone are entitled for subsidy on seed cost restricts adoption of many good, truthfully labelled hybrids from private sector.

- There is lack of focused extension strategy for popularization of new hybrids of promise.

4. Lessons learnt

- When the hybrid rice programme was launched in the country (during 1990s), the initial target areas for cultivation were high productivity states like Punjab, Haryana, Tamil Nadu and Andhra Pradesh. However, it didn't become popular in these states, primarily because the yield heterosis levels of the rice hybrids (10-15 percent increase) were not that attractive as the inbred varieties in these states. Instead, hybrid rice cultivation has become very popular in the favorable rainfed areas where rice is grown by using ground water, mainly in the eastern parts of the country. The current base yield of different inbred varieties of paddy under rainfed upland is low and the yield of hybrid rice under on-farm testing is reported at 4-4.5 tonnes/ha, with a net yield gain of about 30-35 percent, which will help substantial enhancement in production (Janaiah and Xie, 2013, *Hybrid rice programmes and its experience in India, in innovations in rice production, ISBN: 978-81-87663-70-6*). The present generation hybrids (recently released) have much better yield heterosis levels (26-34 percent increase) as shown in Table 8. Hopefully these kinds of rice hybrids will help in expanding the hybrid rice cultivation in the high productive states, as initially planned.

Table 8. Extent of standard heterosis observed in some of the recently released hybrids

S.No.	Name of Hybrid	AICRIP years of testing	Yield (kg/ha)		Yield advantage over check (%)
			Hybrid	Inbred check	
1	DRRH-3	2005-2007	6 074	4 620	31
2	27P11	2006-2008	7 225	5 613	29
3	Indam 200-017	2007-2009	5 384	4 121	31
4	VNR 202	2008-2010	5 956	4 742	26
5	VNR 204	2008-2010	7 023	5 226	34

Ref.: The respective hybrid release proposals

- Developing rice hybrids in different grain quality segments is proving to be a herculean task. In the country, the grain quality preferences are unique and region-specific, viz., North India (scented Basmati rice); South India (fine grain rice), Kerala State (parboiled red rice).

- Dependence on a single source of Wild Abortive (WA) cytoplasm, in the development of rice hybrids is very dangerous, in the event of its breakdown anytime. There is an urgent need to diversify the CMS sources in the hybrid rice breeding programme of the country.

- The development of hybrids based on the two-line breeding doesn't seem to be a practical alternative. The presently available TGMS lines have very narrow Critical Sterility Temperature (CST) and Critical Fertility Temperature (CFT). To make two-line breeding to work under the country's conditions, we need to have lines with wide window of CST and CFT.

5. Opportunities for hybrid rice development

- New generation hybrids devoid of many of the drawbacks of the earlier released ones already available and many in the pipeline;

- Public policy in favor of increased private sector participation in research and development of new plant varieties/hybrids;

- Large and vibrant seed industry with proven capability to produce and supply quality seed; Increasingly receptive farming community for adoption of hybrid technology;

- Subsidy on seed cost for notified hybrids;

- Availability in abundance of qualified scientific and technical manpower for meeting the expanding seed industry need;

- Breeder strength in multinational companies is at desired level unlike in both public and Indian private sector companies; and

- Priority to hybrid rice research in the Twelfth Five-Year Plan.

6. Key strategies and policy options to promote hybrid rice development in India by 2020 and 2030

6.1 Research Strategies

An expanded network project on hybrid rice will be implemented to intensify the research efforts on hybrid rice development. The major emphasis will be on:

- Development of parental lines that can produce highly heterotic rice hybrids;

- Development of heterotic gene pools (a concept well exploited in corn needs to be explored in hybrid rice development);

- Diversification of CMS sources;

- Identification of alternate sources suitable for hybrid seed production; and

- Human resource development through exposure visits and training programmes.

6.2 Seed production strategies

- Refining the seed production technology to enhance the seed yields, so that cost of hybrid rice seed can be reduced;
- Involvement of seed agencies in the public sector, NGOs, and farmers cooperatives along with the private seed sector which is already doing its best to meet the increased demand for hybrid seed in the years to come; and
- Strengthening the existing institutional mechanism for the production and supply of breeder, foundation, and certified seed. The National Seed Corporation and State Seed Corporations need to be strengthened with competent plant breeders.

6.3 Technology transfer strategies

-Transfer of hybrid rice technology from the research farms to the farmers' field is as important as developing the hybrids. Extension agencies have to play greater role in creating much needed awareness among the farmers about the advantages of cultivating hybrid rice through various innovative strategies.
- Identification and popularization of promising hybrids is needed for different states from the available released and notified hybrids.

6.4 Policy options

- Providing adequate funding support and human resources to the hybrid rice research and development in the country;
- Encouraging the contract farming models involving hybrid rice cultivation in different parts of the country; and
- Providing a strong interface between the public sector and private seed sector for popularization of the technology.

Table 1: Details of rice hybrids in India (which are in seed production chain)- Public Sector

S. No.	Hybrid	Duration	Year of Release	Notification No.	Date of notification	Yield t/ha		Yield adv. over check (%)	Developed by
						Hybrid	Check		
1.	**KRH-2**	**130-135**	**1996**	**401(E)**	**15.5.1998**	**7.40**	**6.10 (Jaya)**	**21.3**	**ZARS, VC Farm, Mandya (UAS, Bengaluru)**
2.	**Pusa RH-10**	**120-125**	**2001**	**1134(E)**	**15.11.2001**	**4.35**	**3.11 (Pusa Bas.1)**	**39.90**	**IARI , New Delhi**
3.	Pant Sankar Dhan-3	125-130	2004	599 (E)	25.4.2006	6.12	4.99 (Pant Dhan-12)	22.6	GBPUA&T, Pantnagar
4.	**DRRH-2**	**112-116**	**2005**	**1566 (E)**	**5.11.2005**	**5.35**	**4285 (PSD-1)**	**24.9**	**DRR, Hyderabad**
5.	**Rajlaxmi**	**130-135**	**2005**	**1572 (E)**	**20.9.2006**	**5.71**	**4.47 (Tapaswini)**	**27.9**	**CRRI , Cuttack**
6.	Ajay	130-135	2005	1572 (E)	20.9.2006	6.07	4.47 (Tapaswini)	35.9	CRRI , Cuttack
7.	CORH-3	130-135	2006	1178 (E)	20.7.2007	6.15	4.90 (ADT-39)	25.5	TNAU, Coimbatore
8.	Indira Sona	125-130	2006	1178 (E)	20.7.2007	6.80	5.45 (Jaya)	24.7	IGKVV, Raipur
9.	JRH-4	110-115	2007	1178 (E)	20.7.2007	4.67	4.14 (Local Check)	12.8	JNKVV, Jabalpur
10.	JRH-5	110-115	2007	1178 (E)	20.7.2007	4.81	4.14 (Local Check)	16.0	JNKVV, Jabalpur
11.	Sahyadri 4	128	2008	454 (E)	11.2.2009	6.79	5.98 (PA 6201)	13.0	RARS, Karjat (BSKKV)
12.	JRH-8	115-120	2008	449(E)	11.2.2009	-	-	-	JNKVV, Jabalpur
13.	**DRRH 3**	**130-135**	**2009**	**211(E)**	**29.01.2009**	**6.07**	**4.62 (BPT 5204)**	**31.0**	**DRR, Hyderabad**
14.	**CRHR-32**	**140-145**	**2010**	**456(E)**	**16.3.2012**	**5.43**	**4.88 (Savitri)**	**11.18**	**CRRI, Cuttack**
15.	**TNAU Rice hybrid co 4**	**130-135**	**2011**	**312(E)**	**01.02.2013**	**6.50**	**5.5 (BPT 5204)**	**17.95**	**TNAU Coimbatore**
16.	Sahyadri-5	140-145	2012			3.62	3.13 (Sashi)	15.45	RARS, Karjat

Hybrids in bold font are released by CSCCSN & RV

Table 2: Details of rice hybrids in India (which are in seed production chain) - Private Sector

S. No.	Hybrid	Duration	Year of Release	Notification No.	Date of notification	Yield t/ha		Yield adv. over check (%)	Developed by
						Hybrid	Check		
1.	PHB 71	120-125	1997	647(E)	9.9.1997	6.25	5.20 (ADT 39)	20.2	Pioneer overseas corp. Hyderabad
2.	PA 6201	125-130	2000	92(E)	19.7.2000	6.18	5.03 (Jaya)	22.9	Bayer Bio-Science, Hyderabad
3.	PA 6444	135-140	2001	1134(E)	5.11.2001	6.11	4.91 (Jaya)	24.40	Bayer Bio-Science, Hyderabad
4.	Suruchi	130-135	2004	122(E)	2.2.2005	5.94	4.97 (Jaya)	19.5	Mahyco Ltd, Aurangabad
5.	JKRH-401	135-140	2006	122 (E) & 244 (E)	6.2.2007 & 24.1.2014	6.22	5.48 (Jaya)	13.5	JK Agri Genetics Ltd, Hyderabad
6.	PA 6129	120	2007	1703 (E)	5.10.2007	6.58	5.46 (Local check)	20.0	Bayer Bio-Science, Hyderabad
7.	GK 5003	128	2008	454 (E)	11.2.2009	6.79	5.98 (PA 6201)	13.0	Ganga Kaveri seeds Pvt Ltd, Hyderabad
8.	DRH 775	125-130	2009	2187 (E)	27.8.2009	4.77	3.86 (Regional check)	23.0	Metahelix Life Sciences Pvt. Ltd., Hyderabad
9.	HRI-157	130-135	2009	2187 (E)	27.8.2009	6.51	5.49 (Regional check)	19.0	Bayer Bio-Science, Hyderabad
10.	PAC 835	130-135	2009	2187 (E)	27.8.2009	6.51	5.35 (PA 6201)	22	Advanta India Ltd. Hyderabad
11.	PAC 837	130-135	2009	2187 (E)	27.8.2009	5.62	5.12 (KRH 2)	9.8	Advanta India Ltd. Hyderabad
12.	NK 5251	125-130	2012			6.81	6.12 (PA 6201)	11.6	Syngenta India Ltd, Secundrabad
13.	US 312	125-130	2010	2137(E)	31.8.2010	6.07	5.47 (Hybrid)	11.0	Seed Works International, Hyd
14.	Indam 200-017	125-130	2010			6.20	5.0 (IR64)	25.0	Indo American Seeds, Hyd
15.	27P11	135-140	2011	632(E)	25.3.2011	5.67	4.55 (BPT 5204)	25.0	PHI Seeds Private Ltd, Hyd
16.	VNR 202	130-135	2011	456(E)	16.3.2012	5.96	5.32 (KPH 2)	12.0	VNR Seeds Pvt Ltd, Raipur
17.	VNR 204	120-125	2011	456(E)	16.3.2012	7.02	6.24 (PA 6201)	12.59	VNR Seeds Pvt. Ltd., Raipur
18.	US-382	120-125	2012			6.72	5.78 (PA 6201)	16.3	Seed Works International Pvt. Ltd. Hyderabad
19.	27P31	125-130	2012			6.17	5.49 (PA 6201)	12.0	PHI Seeds Private Limited, Hyderabad
20.	HRI 169	120-125	2012			6.73	5.98 (PA 6201)	13.0	Bayer BioScience Pvt. Ltd., Hyderabad
21.	RH 1531	120-125	2012	312(E)	01.02.2013	6.06	5.54 (PA 6201)	9.5	Devgen Seeds & Crop Technology Pvt. Ltd. Secundarabad

22.	**PNPH-24**	**125-130**	**2012**			**5.54**	**4.98 (PA 6201)**	**11.1**	**Prabhat Agri Biotech Ltd. Hyderabad**
23.	**25P25**	**115-120**	**2012**			**6.55**	**6.18 (PA 6129)**	**6.0**	**PHI Seeds Private Limited, Hyderabad**
24.	**27P61**	**130-135**	**2012**			**5.76**	**5.32 (DRRH-3)**	**5.0**	**PHI Seeds Private Limited, Hyderabad**
25.	**JKRH 3333**	**135-140**	**2012**	**312(E)**	**01.02.2013**	**5.98**	**4.88 (BPT 5204)**	**22.68**	**JK Agri Genetics Ltd. Hyderabad**
26.	**NPH-924-1**	**135-140**	**2012**			**6.27**	**5.06 (IR 64)**	**23.8**	**Nuziveedu Seeds Pvt. Ltd. Hyderabad**
27.	**27P52**	**130-135**	**2013**			**5.73**	**5.31 (KRH 2)**	**8.0**	**PHI Seeds Private Limited, Hyderabad**
28.	**27P63**	**130-135**	**2013**			**5.79**	**5.45 (DRRH-3)**	**6.0**	**PHI Seeds Private Limited, Hyderabad**
29.	**KPH-199**	**125-130**	**2013**			**6.80**	**6.01 (DRRH-3)**	**13.10**	**Kaveri Seed Company Limited, Secunderabad**
30.	**KPH-371**	**125-130**	**2013**			**6.24**	**5.61 (PA 6201)**	**11.28**	**Kaveri Seed Company Limited, Secunderabad**
31.	**US 305**	**130-135**	**2013**	**244 (E)**	**24.01.2014**	**6.54**	**5.89 (DRRH-3)**	**10.9**	**Seed Works International Pvt. Ltd., Hyderabad**
32.	**US 314**	**115-120**	**2013**			**5.38**	**4.31 (PA 6129)**	**25.0**	**Seed Works International Pvt. Ltd., Hyderabad**
33.	**VNR 2375**	**130-135**	**2013**			**5.85**	**4.95 (KRH 2)**	**18.2**	**VNR Seeds Pvt Ltd, Raipur**
34.	PAC 801	120-125	2014						Advanta India Ltd. Hyderabad
35.	PAC 807			244 (E)	24.01.2014				Advanta India Ltd. Hyderabad
36.	ARRH-7434		2014	244 (E)	24.01.2014				Ankur Seeds Pvt. Ltd.

Hybrids in bold font are released by CSCCSN & RV

Hybrid Rice Development in Indonesia

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Introduction

Increasing rice production to support food security of the increasing population has a high priority in agricultural development in Indonesia. Agricultural land for rice cultivation is limited to meet the challenge of producing 70 million tonnes of rice for the estimated population of 265 million by the year of 2025 from the present 240 million people. Rice yield during the last decade with the available varieties and cultivation technologies have exhibited plateauing trend. Hybrid rice technology which has been commercially used to increase rice yield by 15-20 percent over the high-yielding inbred varieties in China and India (Mishra et al., 2003), Vietnam (Hoan et al., 1998), the Philippines (Redona et al., 2003), Bangladesh (Yulfiqnar et al., 2003) and some other countries (Mackill and Rutger, 1994; Moon et al., 1994) has been selected as an option in integrating the efforts to increase national rice production in Indonesia.

1. Rice production in Indoensia

At present, more than 80 percent of the rice area is planted with improved varieties and most of it (54 percent) is irrigated low-land rice. IR64 and Ciherang have been the two major varieties for two decades, wherein the decade of 1980s and 2000s respectively covered 60 percent of total planted area. The average yield of rice in Indonesia in 2013 was 5.152 t/ha with the total production of 71 291 494 tonnes (BPS, 2013). This yield actually has increased to 3.25 percent from the previous year (2012). Yield increase was estimated at about 2.93 percent caused by the increase in harvested area (Table 1). Boosting rice production, while conserving the environment to secure sustainable food availability, is a high priority in Indonesia. This is as a consequence of increasing population and on the contrary diminished agricultural resources, mainly land and water resources. Hybrid rice would be among the options to achieve the goal. In order to achieve the target of the 2011-2014 period of increasing rice production by 5 percent per year and surplus 10 million milled rice in 2014 (Directorate General Food Crop, 2012), the development of high-yielding rice varieties was considered as a strategic programme. Hybrid rice technology has been selected as an option in the integrated efforts to increase national rice production in Indonesia. There are four technical reasons for developing hybrid rice technology in Indonesia: (i) yield levelling-off of modern inbred varieties, (ii) Indonesia has the potential as a tropical country to develop hybrid rice, (iii) good possibility of developing *indica x javanica* hybrid and (iv) good opportunity to develop hybrid rice for specific tropical adaptation (Satoto, et al., 2006).

Table 1. Rice Production in Indonesia during the past ten years

Year	Harvested area (ha)	Increase (%)	Productivity (t/ha)	Production (t)	Increase (%)
2004	11 922 974	-	4.536	54 087 468	-
2005	11 839 060	-0.71	4.574	54 151 097	0.12
2006	11 786 430	-0.45	4.620	54 454 937	0.56
2007	12 147 637	2.97	4.705	57 157 435	4.96
2008	12 327 425	1.46	4.894	60 325 925	5.54
2009	12 883 576	4.32	4.999	64 398 890	6.75
2010	13 118 120	1.79	5.030	65 980 670	2.45
2011	13 203 643	0.65	4.980	65 756 904	-0.34
2012	13 443 443	1.81	5.136	69 045 141	5.00
2013	13 837 213	2.93	5.152	71 291 494	3.25

(Dir. FC)

2. Progress in hybrid rice development in Indonesia

2.1. History of hybrid rice development

Research on hybrid rice in Indonesia was initiated in 1983 with the evaluation of hybrids and introduction of breeding materials as the major activities. The success of the commercial use of the hybrid rice technology in India, Vietnam and the Philippines has encouraged the Government of Indonesia to intensify the research and development of hybrid rice in the country since 1999. The activities were not only evaluating the materials from IRRI but also developing hybrid rice by using local genetic materials. The main target was to obtain hybrid rice that was more adaptive to the Indonesian environment and yielded about 20 percent higher than the existing rice varieties. More intensive activities involving various disciplines were done since 2001, with the main target of increasing heterosis level, providing cultural technologies suitable for the particular hybrid rice and developing technology packages for hybrid rice seed production. The adoption of hybrid rice in Indonesia has been increasing gradually since the year 2005 through both government programme and non-government programe. .

2.2. Status and trends of hybrid rice development

2.2.1. Progress in hybrid rice research

Hybrid rice varieties released in Indonesia were developed by using the three-line method. By using such method, hybrid rice variety resistant to pest and diseases can only be developed if, and only if, resistant parental line CMS and/or restorer line are available. There are three approaches that can be used to get resistant parental lines, namely improvement of the resistance of parental lines, development of resistant parental lines and introduction of resistant parent from abroad. The first approach can be done by crossing among maintainers, among restorers, or between maintainer or restorer and resistant donor varieties. The second approach is done by selected breeding materials so that the lines used in the parental lines development program were the lines having resistant gene to bacterial leaf blight (BLB) only. The third approach has been done by introducing a number of CMS and restorer lines from IRRI. The result of the hybrid rice parental lines improvement were 15 CMS lines developed in ICRR (Table 2), some improved restorer lines (Table 3 and 4), and some improved maintainer lines (Table 5).

Table 2. Some CMS lines with their important traits

CMS lines	Important traits	CMS lines	Important traits
GMJ1	MR RTV	GMJ6	R BLB
GMJ2	Tol Al, Blast	GMJ7	R BLB
GMJ3	R Bph, BLB	GMJ11	OCR
GMJ4	R Bph, BLB	GMJ12	Combining Ability
GMJ5	R Bph, BLB	GMJ13	R BLB3, MR BLB4, OCR
GMJ8	R Bph	GMJ14	R BLB3, MR BLB8, OCR
GMJ9	-	GMJ15	R BLB3, MR BLB4, MR BLB8, OCR

From test cross nursery, six moderately resistant restorer line candidates have resulted (Table 3). In addition, from the parental lines improvement programme, ten restorer lines have been improved (Table 4). Eleven populations of F6-7 generation have resulted as well from the maintainer lines improvement programme (Table 5).

Table 3. Restorer line candidates and their reaction to Bph3, BLB IV, BLB VIII, and RTV

	Restorer lines	Important traits
1	BHS-792	Bph, RTV
2	BHS-469	BLB, RTV
3	BHS-481	RTV
4	BHS-508	BLB,
5	BHS-512	BLB
6	BHS-184	BLB

Table 4. Reaction of some improved restorer lines to Bph, BLB, and RTV

Restorer lines	Bph3	BLB4	BLB8	RTV
BH21B	9	5	5	5
BH25B	3	5	4	5
BH3D	7	2	2	3
BH5D	-	4	4	4
BH6D	1	5	5	4
BH8D	5	4	4	4
BH9D	3	5	5	4
BH9D	3	4	4	4
BH12D	3	5	4	5
BH12D	1	5	4	5

Table 5. Some improved maintainer populations

Crosses	Generation	Objective
IR58025B/BP1778	F6	Bph, BLB
IR58025B/BP1766	F6	RTV
IR58025B/BP1790	F6	BLB
IR58025B/T.Balian	F8	RTV, Bph
IR62829B/BP1778	F6	Bph, BLB
IR62829B/BP1766	F6	RTV
IR68885B/BP1778	F6	Bph, BLB
IR68885B/BP1766	F6	RTV
IR68885B/BP1790	F6	BLB
IR68888B/T.Unda	F7	RTV, Bph
IR68897B/T.Unda	F6	RTV, Bph

The present and future research programmes on hybrid rice are focusing on (i) improving the hybrid and parental lines resistance to major pest and diseases, (ii) enhancing the level of heterosis through *indica* x tropical *japonica* hybrids, (iii) improving grain quality of hybrids by appropriate breeding and selection of parental lines and (iv) improving cultivation and pest management strategies for consistent performance of hybrids. Recently in ICRR hybrid rice, research was emphasized to increase and stabilize yields of seed production, enhance yield heterosis in both and dry season to >20 percent, improve grain quality (reduce chalk and increase head rice recovery), improve resistance to biotic stresses and develop hybrid for unfavorable environments.

2.2.2. Development of Hybrid Rice Resistant to Bph, BLB, and RTV

Based on the genetic materials available in Indonesia, the strategies applied to develop hybrid rice were: (i) evaluation and selection the introduced hybrid combinations in order to obtain introduced hybrid varieties adaptive to the local climate and preference, (ii) through domestic breeding programme to develop restore lines suitable for CMS introduced from abroad. The expected result was hybrid rice obtained from crosses between the introduced CMS and domestic restorer lines, (iii) provide CMS and restorer line obtained from the available domestic gene bank. The expected result was hybrid rice obtained from crosses of genetic materials available in the country, having high adaptability to Indonesian ecosystem and (iv) develop NPT hybrids having yield potentials of 15-20 percent higher than that of the best existing NPT rice, resistant to major pests and diseases, and possess good cooking quality.

To identify hybrids resistant to the major pests and diseases, screening has been conducted in the laboratory and green house by artificial inoculation of BPH, BLB and RTV. Some hybrids resistant to BPH, BLB, and/or RTV have been identified.

The check variety Ciherang is the predominant variety grown by farmers in Indonesia, although it is susceptible to BLB strain VIII and RTV. All of the selected hybrids have better resistance to the major pests and diseases than the inbred check. Among the hybrid rice combinations tested for their resistance, 28 hybrid combinations had resistance to one of the three major pest and diseases. Two the resistant hybrids have been released commercially while the remaining combinations were still in advanced yield trials and multi-location trials. From the above data, it can be said that hybrid rice variety resistant to Bph, BLB, and or RTV would be possible to develop in Indonesia.

Several hybrid combinations resulting from crosses between introduced CMS and local have an average yield of one t/ha higher than the elite rice variety IR64 and resistant to BPH, BLB, and RTV. The hybrids were being further evaluated. Resistant or moderately resistant promising hybrids to BPH, BLB, and RTV have been identified.

2.2.3. Status of hybrid rice production

Area, yield and production

The Government of Indonesia also encouraged private companies to develop hybrid rice variety and produce the seed in Indonesia. Since rice is a strategic commodity, as staple food and source of income for millions of farmers, seed importation should tightly follow quarantine procedures.

Seventy one hybrid rice varieties consisting of 21 developed in Indonesia and 50 introduced hybrid rice varieties have been released officially for commercial cultivation in Indonesia (Table 6).

Table 6. Hybrid rice varieties released in Indonesia

Institution/Company	No	Hybrid rice varieties name
ICRR	17	Maro, Rokan, Hipa 3, Hipa 4, Hipa 5 Ceva, Hipa 6 Jete, Hipa7, Hipa8, Hipa9, Hipa10, Hipa11, Hipa12 SBU, Hipa13, Hipa14 SBU, Hipa Jatim1, Hipa Jatim2, Hipa Jatim3
BISI	4	Intani 1, Intani 2, Intani 301, Intani 602
Bangun Pusaka	2	LP Pusaka 1, LP Pusaka 2
Kondo	5	Miki 1,2,3; Manis 4 & 5
Bayer Crop Sci	4	Hibrindo R1, Hibrindo R2, TEJ, 6444
KNB Mandiri	2	Batang Kampar, Batang Samo
Dupont	2	PP-1, PP-2
Makmur SNT	2	Brang Biji, Segara Anak
TU Saritani	2	Adirasa-1, Adirasa-64
PT SHS and partner	11	SL8, SL11, WM2, 3, 4, 5, DG1 and 2, BSH1,3, and 6
Primasid	2	Mapan-P.02, Mapan-P.05
SAS	6	Bernas Super, Bernas Super2, Bernas Prima, 2, 3, 5
Biogene Plantation	6	Sembada B3, SB-5, SB-8, SB-9, S 101, S168
Agri Makmur Pertiwi	2	Rejo 1, Rejo2
Metahelix	2	DR1, DR2
Advanta	2	PAC801, PAC809
Total	**71**	**21 varieties developed in Indonesia, 50 introduced from China and India**

Under the *P3T* Programme, three released hybrid rice varieties: Maro, Rokan, and Intani 1 were tested in several provinces for at least two seasons (DS 2002 and WS 2002/2003). The demonstration plots were conducted in districts potential for hybrid rice technology adoption based on the following criteria: the district has a wide area of irrigated lowland, it is not the endemic area of BPH, BLB, and RTV and the level of rice yield is high and stable across years. The Government provided seed, fertilizers and chemical pesticides for the demonstration plots which were conducted on farmer field. Workshop training participated by key farmers, extension workers and local agriculture officers were conducted in each district prior to the implementation of the demonstration.

Attainable yield of Rokan was 11.06 t/ha while Ciherang was 9.60 t/ha. Hybrid rice yield was range from 5.52 t/ha to 11.06 t/ha. Hybrid rice technology, therefore, should be planted only to the appropriate suitable locations unless hybrids expressing more stable heterosis and resistance to the major pest and diseases could be developed.

Table 7 showed that at the farmer level, local hybrid Hipa11 and Hipa8 yielded 9.93 t/ha and 9.55 t/ha, respectively, higher than that of inbred varieties Inpari13 (8.62 t/ha) and Inpari10 (6.45 t/ha). In other farmer's fields, Hipa11 yielded 9.21 and 10.87 t/ha, Hipa8 9.36 and 8.11 t/ha, PP1 9.05 t/ha that was higher compared to the yield of the most popular inbred in the location, i.e. Logawa, which yielded 7.83 t/ha.

Table 7. Grain yield of some released hybrid rice varieties in the farmer field, Mernek, Maos, Central Java, CS I, 2011

Variety	Area (ha)	Farmer	Yield (Kg)	Yield (t/ha)
Hipa 11	0.107	Kuswanto	1 030	9.926
Hipa 8	0.07		669	9.554
Inpari 13 (inbred)	0.178		1 540	8.617
Inpari 10 Laeya (inbred)	0.357		2 302	6.448
	0.085	Waluyo	783	9.212
Hipa 11	0.01428		1 552	10.868
	0.357		3 342	9.361
Hipa 8	0.285		2 310	8.105
PP 1	0.017		970	9.053
Logawa (inbred)	0.7		5 482	7.831

Table 8 showed the yield and the increase of farmers' income by planting hybrid rice in West Java as done by some farmers at Cianjur (a regency in West Java, that is suitable for planting hybrid rice). The yield increase reached from 15 percent to 50 percent more than that of inbred from 0.25 ha to 3.5 ha planting area or 33-40 percent income increase that could be reached by the farmers.

The commercialization of hybrid rice in Indonesia is likely bright because some key ingredients for commercialization are already present. These are: (i) food security challenge, (ii) large irrigated areas, low cost of labour, (iii) Government policy support to hybrid rice technology development and promotion, (iv) thirty-five hybrids released, (v) seed production yields of up to 3 t/ha with 1 t/ha being regularly attained, (vi) integrated crop management for hybrid rice, (vii) increased national technical capacity in different sectors and (viii) vibrant private sector participation.

Table 8. Yield and increase farmer income. Cianjur West Java, WS 2010-2011

Yield				
Farmer	**Area (Ha)**	**Hybrid**	**Inbred**	**Yield increase (%)**
Barnas	3.5	24 173	21 000	15
Samsudin	1.25	9 073	6 285	44
Saepulloh	0.15	1 200	800	50
Income				
Farmer	**Area (Ha)**	**Hybrid**	**Inbred**	**Income increase (%)**
Barnas	3.5	26 987 000	20 277 000	33
Samsudin	1.25	22 804 500	16 277 000	40
Saepulloh	0.15	3 000 000	2 240 000	34

Technologies transferred and applied in hybrid rice production

The Government of Indonesia has also encouraged the private sector to develop hybrid rice variety and produce the seed in Indonesia. Since rice is a strategic commodity, as the staple food and source of income for millions farmers, seed importation should tightly follow the quarantine procedure.

An on-the-job training on hybrid rice seed production technology was conducted in Sukamandi during the dry season of 2004. The participants of the training were ten provincial agricultural officers of NAD province. The participants worked together with the technicians of the station to produce hybrid rice seed on about 1 ha area. They practiced all activities of the seed production from land preparation up to harvesting and seed processing. Supervision by hybrid a rice breeder and a seed production specialist was conducted at the critical and important activities such as seed bed preparation, seed sowing, transplanting, roguing, GA3 application, supplement pollination, harvesting and seed processing. Class lectures and discussion were also given by researchers and seed production specialist from ICRR.

The seed system for inbred rice has been established for a long time in Indonesia. The system which includes ICRR, provincial seed farms, district seed farm, public seed companies, and seed inspection and certification officers, has the capability to produce, distribute and market quality seed especially for public varieties. Production and distribution of hybrid rice seed was integrated into the system with some adjustment of seed classes and purity requirement. In order to improve the capacity of the seed farms, training on hybrid rice seed production technology was held for more than 10 times in Sukamandi and other institutes. The training was attended by persons from provincial seed farms with potential for hybrid rice seed production.

Training by doing on hybrid rice seed production was conducted in Tegalgondo Seed Farm (Central Java), Sang Hyang Seri state-owned seed company (West Java), and PT Makmur Sejahtera Seed Company (West Nusa Tenggara). Seed production of hybrid rice was conducted in Tegalgondo seed farm, Pusakanegara research station, Sukamandi research station and Muara. ICRR provided technical guidance and intensive supervision during the critical or important activities including seed bed preparation, seeding, transplanting, selection, supplement pollination, harvesting and seed processing.

The Government of Indonesia selected hybrid rice as one of the technologies to be disseminated for increasing rice production in the country. The Government encouraged public and private sectors to participate in the development and dissemination on hybrid rice technology. Research on hybrid rice was more intensified in 1999 and procedure for release of hybrid rice variety was developed in 2001.

The promotion and dissemination of hybrid rice technology was initiated in 2002 under the integrated program of increasing rice production. The capacity of public seed company, Sang Hyang Seri, and seed farms was improved by conducting group training, on-the-job training, and training by doing on hybrid rice seed production technology.

The Government provided extension services, monitoring of pest and disease incidence, and credit for seed, fertilizers and pesticides for commercial hybrid rice cultivation. However, the development of hybrid rice cultivation area was not as fast as expected due to the constraint of seed shortage, inconsistent heterosis expression and susceptibility of the hybrids to the major pests and diseases. Breeding to develop better hybrids resistant to BPH, BLB, and RTV has been put on high priority in the national rice research and development programme and some promising hybrids had been obtained.

Hybrid rice seed was produced by public seed company and seed farms in limited areas, 5– 15 ha, because of the low seed yield, less than 1/ha. While the capacity of public seed company and seed farms is being improved, the Government offered seed production of public hybrids to private seed companies. Syngenta got the license to produce seed of Hipa-3 and proposed to get license of Hipa-4, Dupont has also licensed to commercialize Maro, and PT SAS for Rokan. The seed production for Hipa3 was initiated in DS 2006 on 5 ha area and 1.2 t/ha seed yield was obtained. Seed production of the Maro variety by Dupont was initiated on area of 50 ha during DS 2007. They proposed to produce 100 ha in this year.

Hybrid rice seed production

The success of hybrid rice technology is dependent on the efficient and economical seed production on a commercial scale. Hybrid rice seed production is a skill-oriented activity, therefore a smooth technology transfer is required to assure high seed yield. Heterosis level and hybrid rice adoption on a commercial level depend on the ability to produce quality and a sizable amount of F1 hybrid seed. Availability, quality and price of hybrid rice seed determine the adoption level.

The requirements for hybrid seed production land are: medium altitude (100-500 m asl); 70 - 80 percent relative , 24-28 ˚C daily temperature with maximum temperature of <32 ˚C and 8-10 ˚C night-day temperature difference, sunny, 10-15 km/h wind velocity, no rain during flowering time, fertile (pH neutral) and responsive farmers. Seed production of hybrid rice is better produced during the dry season (April-September), reminding us of some determining factors, namely dry conditions, no rain during the flowering period, optimum wind velocity, sunny and less pest and diseases. Hybrid rice seed production in Indonesia was done mainly by ICRR with the involvement of local government and private companies.

The synchronization of flowering is one of important factors to produce good hybrid rice seed. Eighty percent synchronization of flowering, achieved through the use of blower or bamboo as supplementary pollination with or without leaf clipping, produced more than 1 t/ha (1.45-1.67 t/ha) F1 seed; on the other hand, 30 percent synchronization of flowering in seed production produced only 0.66 t/ha F1 seed.

The Indonesian Center for Rice Research (ICRR) from 2006 to 2011 had been doing collaboration on licenced hybrid rice seed with private companies for seed production. Muara Bogor, one of ICRR's farm fields, during the dry season in 2006 produced 1.1 t/ha Maro hybrid rice seed. In 2007, the collaboration of Hipa3 seed production with PT. Syngenta took place at Bantul Yogyakarta producing yield of 1.1 t/ha. Seed production of Hipa6 Jete in the dry season of 2008 at Sukamandi field, Subang, West Java Province, yielded 1.8 t/ha. Then in

2009, seed production of Hipa9 yielded an amazing 2 t/ha. In the dry season and wet season 2010/2011, ICRR and AIAT Sumut in North Sumatera collaborated in producing Hipa6 Jete and yielded 0.95 t/ha, but the collaboration with PT. Saprotan Benih Utama (SBU) at Maos Cilacap in producing Hipa14 SBU yielded 1.7 t/ha (Table 9).

Table 9. Seed production of hybrid rice developed by ICRR

Seed Grower	Location	Season	Variety	Seed Yield (kg/ha)
BB Padi	Muara, Bogor	2006 DS	Maro	1 100
PT Syngenta	Bantul	2007 DS	Hipa3	1 057
BB Padi	Sukamandi, Subang	2008 DS	Hipa6 Jete	1 800
PT Dupont	Krebet, Malang	2009 DS	Hipa8	2 000
AIAT SUMUT	Medang Deras, Kab Batubara	2010/2011 WS	Hipa6 Jete	945
PT SBU	Maos Lor Cilacap	2011 DS	Hipa14 SBU	1 700 kg/bahu

F1 hybrid seed rice production of SL8 SHS at Sukamandi, Subang Regency, as presented in Table 10 showed that a 2-ha planting area obtained 2.9 tonnes until 4.5 tonnes. It means that 1 ha of planting area of seed procuction can produce about 1.458-2.272 kg.

Table 10. F1 hybrid seed production of SL8 SHS variety, Sukamandi

Year	Harvest date	Area (ha)	Seed yield	Seed yield (kg/ha)
2008	19-9-2008	2.00	2.916	1 458
		1.00	2.215	2 215
		1.00	2.566	2 566
		1.00	3.919	3 919
		1.00	2.873	2 873
	21-9-2008	2.00	4.544	2 272
		1.00	2.779	2 779
		1.00	2.774	2 774
		1.79	3.460	1 932
		0.50	756	1 620

Hybrid rice seed supply and trade

Though hybrid rice seed is produced in Indonesia, it still imports hybrid seed. Two kinds of hybrid rice seed imported by Indonesia are F1 hybrid seed and parental seed. In 2005, 10.42 tonnes of F1 hybrid seed or about 52.23 percent of Indonesian F1 hybrid seed was imported, while for parental seed about 6.75 tonnes or about 54 percent was imported. In 2006 and 2007, the import of F1 hybrid seed and parental seed increased to 102.14 tonnes and 3,973 tonnes or 23.68 percent and 89.83 percent, respectively, while parental seed increased to 8.05 tonnes and 13.60 tonnes or 48.94 percent and 59.91 percent, respectively. During the period of 2005 – 2010, the highest demand for F1 hybrid seed was in 2009, wherein the country imported 4 868.79 tonnes of F1 hybrid seed. The data are shown in Table 11.

At the commercial scale, seed yield still varied with an average of 1.2 t/ha. A seed system suitable for hybrid rice, including seed production, inspection and certification has been established. Nevertheless, there are still some threats to hybrid rice development in Indonesia such as (i) pests and diseases particularly BPH, BLB, RTV and stem borer, (ii) CMS used to develop hybrid rice varieties were possessing same cytoplasm type, (iii) the environmental temperature fluctuates highly resulting in difficulties in seed production, (iv) expensive seed price, (v) impact of climate change, i.e. high rainfall during flowering stage affecting seed production activity, (vi) habit of some particular farmers to use their own seeds and (vii) limited suitable areas for hybrid rice cultivation as well as seed production.

Table 11. Imported F1 hybrid and Parental seed during the period of 2005-2010

Year	Imported seed			
	F1 hybrid seed		Parental seed	
	Tonne	%	Tonne	%
2005	10.42	58.54	6.75	54.00
2006	102.14	76.08	8.05	48.94
2007	3 973.00	87.03	13.60	59.91
2008	3 321.50	84.61	32.81	82.64
2009	4 868.79	87.87	30.10	53.01
2010	3364.15	66.62	2.13	2.18
Total	**15 640.00**	**81.32**	**93.44**	**38.04**

3. Constraints and gaps in hybrid rice development

The area cultivated to hybrid rice has not increased as fast as expected. Some constraints to rapid development of the cultivated area of hybrid rice were: hybrid rice seed shortage, susceptibility of the most released rice hybrid to major insect and diseases and instability of the heterotic expression. Some programmes to encounter the constraints are in progress, including breeding to develop hybrid rice variety more adapted to local conditions and resistant to major pest and diseases, research on agronomy and pest and disease management to improve technology package of hybrid rice cultivation as well as seed production, and strengthening the hybrid rice seed by involving the private sector.

Several threats in planted hybrid rice are as follows: pests and diseases (BPH, BB, RTV, stem borer, rat), identical cytoplasmic of the CMSs among hybrids, highly fluctuating temperature that affecting seed production, expensive seed price, global climate change (rainfall during flowering period) affecting seed production, habit of using farmers' saved seed and limited suitable area for hybrid rice.

4. Lessons learned

Global climate change has boosted pests and disease outbreaks during the last several years; hence, improving hybrid rice resistance to pest and diseases is important. Reduction of arable land due to shifting in Indonesia has reached 210 hectares per year; hence, developing new hybrid rice with high-yield potential and good rice quality would be important. The potency of hybrid rice seed production is still low (0.5- 1.5 t/ha. The price of hybrid seed rice is still very expensive. Simplicity of seed production of new hybrid rice combination would also be important. Elaborate hybrid rice dissemination across institutions is identified as an important way to encourage hybrid rice adoption.

5. Opportunities for hybrid rice development

IAARD has developed several *indica*-CMS lines. Indonesia has many *javanica* germplasm with potential to be converted into restorer and cytoplasmic male sterility lines, possessing high potency to develop *indica/javanica* HR combination to improve the yield's heterosis. The high population increase in Indonesia (1.5 percent per year) and land reduction will hasten hybrid rice development. Positive support from the Government and private companies is expected to boost the HR's rapid adoption (ICM-FS, seed subsidy).

6. Key strategies and policy options to promote hybrid rice development in Indonesia to 2020 and 2030

Most rice researches in Indonesia are conducted by ICRR which, being a national institute, has the mandate on rice research and development in Indonesia. Hybrid rice research is put as a high-priority programme and still is a high priority in the next five-year programme. The major objectives of the research on hybrid rice are to develop better hybrids with high and stable heterosis, resistance to BPH, BLB, and RTV and good grain quality; to improve seed production technology; and to develop integrated crop management technology.

An inbred variety of a new plant type with higher yield potential has been released in Indonesia. A new plant type breeding material has also been used in hybrid rice breeding to improve the yield potential. Development breeding material trough B x B crosses for B line breeding and A x R and R x R crosses for R line breeding will be continued. A gene pool with recurrent random mating and recurrent selection facilitated by male sterility character has been initiated for R line improvement.

The Indonesian Center for Agriculture Biotechnology and Genetic Research and Development (ICABIOGRAD) has a programme to support hybrid rice breeding by applying biotechnology. The programme includes the development of double haploid breeding lines of B and R through anther culture applied on F1 plants of B x b, A x R, and R x R crosses, marker-aided selection to identify R and B lines and and molecular analysis to study genetics related to combining ability.

The testing of promising hybrids will be conducted in more locations to identify hybrids with more stable heterosis. A network for testing inbred breeding lines has been developed between ICRR, some private companies, and the Assessment Institute of Agriculture Technology (AIAT) present in all provinces. The testing of rice hybrids will be conducted through the network.

Research on hybrid rice seed production with flowering synchronization between parental lines will be conducted in different potential locations. The research will also include a refinement of cultivation technology for seed production. Research on hybrid rice cultivation to develop appropriate integrated crop management suitable for hybrid rice will be continued. Superimposed trials to adjust fertilizer rate, plant spacing, and seedling age suited to locality conditions will be conducted on the demonstration plots in different districts.

Strengthening capacity of public seed farms will be continued by conducting training followed with training by doing on hybrid rice seed production technology. More private seed companies and growers will be offered to participate in seed production of public hybrids. The breeder seed production unit that was established in ICRR for inbred variety is being strengthened to include breeder seed production of parental lines of hybrids rice. The future direction of hybrid rice development: to breed hybrid that are really adapted for Indonesia, resistant to major pests and diseases and have better eating quality and could be developed by utilizations of local germplasm collections or combining of national and introduced lines.

Public-private sector partnership shall be developed on hybrid seed production to accelerate the adoption of HR tech and some companies initiated to produce seed of public hybrids. Breeding to develop hybrid rice resistant to BPH, BLB, and RTV has high priority in the national rice research programme and some promising hybrids were obtained. Breed mat including new developed parental lines and genetic source for desirable characters from IRRI and others are still needed. The Government of Indonesia supports not only research and development but also the dissemination and adoption of hybrid rice technology.

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Hybrid Rice Development in Myanmar

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1. Overview of rice production in Myanmar

Myanmar is one of the largest countries in Southeast Asia in terms of land area, with varied geographic, topographic and climate zones: Coastal Strip, Western Mountain Region, Northern Hilly Region, Central Dry Zone, Ayeyarwaddy Delta, Bago Yoma, Sittaung River Valley, Shan Plateau and Tanintharyi Coastal Strip. With these widely different environments, the Agriculture, Renewable National Resources and Environment (ARNRE) sector in Myanmar is broad and diverse.

Rice in Myanmar grows during the monsoon and summer seasons in four growing zones; the delta, dry zone, coastal zone and mountainous areas. About 50 percent of the total population comes from the delta comprised of the Ayeyarwaddy, Bago and Yangon regions. Twenty five percent of rice is produced in the central dry zone, which includes the Mandalay, Sagaing, and Magway regions. The rest is produced form the coastal and mountainous area. More than 60 percent of the summer season production comes from the delta.

Myanmar/s rice yield and production increased during the period 1990-91 to 2001-02. Much of the production increase comes from the large increase in area under summer paddy from 1992-93 reflecting a major push by the Government to increase the area under irrigated paddy. Prior to this, most of the paddy areas in Myanmar have been under only monsoon (rainfed) paddy. However, average rice yield in 2001-02 also reached 3.3 mt/ha.

Paddy production has grown significantly since, a function of both the increase in area, again particularly of summer paddy, and also in yield.

Table 1. Paddy sown area and productivity

Year	Sown area (,000 ha)	Harvested area (000 ha)	Yield (MT/ha)	Production (,000 MT)
1995-96	6 138	6 033	3.08	18 580
2000-01	6 359	6 302	3.38	21 324
2005-06	7 389	7 384	3.75	27 683
2009-10	8 067	8 058	4.06	32 681
2010-11	8 047	8 011	4.07	32 579
2011-12	7 593	7 567	3.83	29 010
2012-13	7 241	7 208	3.84	27 704

Source: Myanmar Agriculture in Brief. 2013, MOAI.

By 2010-11, the average paddy yield had reached 4.07 MT/ha. However, there was a decline to 3.84 MT/ha in 2012-13, given the season of pulling down the aggregate yield affected by reducing sown area of summer paddy.

In Myanmar, successive Governments endeavored to supply the rice for the country's growing population and surplus of rice based on its different economic policy. Myanmar exported a high of about 3.0 million tonnes under British Colonial rule from 1826-1941. So, Myanmar became the number one exporter and was tagged as the "Rice Bowl of Asia" as early as 1890. After the disruption of the war years, Myanmar became again a major exporter of rice after it gained its independence, in spite of its new focus on food security.

In 2009, there was an important initiative to create a Rice Industry Association (MRIA) and Rice Specialized Companies (RSCs) which are now formed under Myanmar Rice Federation (MRE) and functioning in rice growing, providing farm credit, inputs and service to farmers in the farm of contract farming for poverty reduction and rice development for future plan.

2. Progress in hybrid rice development in Myanmar

2.1 History of hybrid rice development

The agricultural sector of Myanmar contributes 24 percent (2012-2013) of GDP, 24.6 percent of total export earnings and employs 61.2 percent of the labour force. To streamline one of the major economic objectives as "building the modern industrialized nation through the agricultural development, and all-round development of other sectors of the economy", the Ministry of Agriculture and Irrigation (MOAI) set the vision of agriculture as "achieving per capital income and standards of living of rural populace relying on agriculture higher than the neighboring countries and keep abreast with developed nations. Towards this vision, the agricultural sector development objective and strategies are formulated to meet the country's economic objectives.

So, the hybrid rice (HR) seed production of Pearl Thwe and Basmati was carried out at Shwe Taung Farm, Wun Twin Township, Mandalay Region during 2011-2012. Myanmar started the hybrid rice seed production in Northern Shan State in 2002-2003 and on to 2003-04. Now, the country has already A, B and R lines. Hybrid rice in Myanmar can produce more than 200 to 300 baskets per acre. Seed production in MOAI is still carried out not only by private sector but also the Department of Agriculture (DOA).

2.2 Status and trends of hybrid rice development

To increase the country's rice production, Myanmar scientists introduced new rice cultivars, namely IR-8 and IR-5 obtained from the International Rice Research Institute (IRRI) in 1966 and 1967, respectively. These HYVs, having higher yield than local varieties, were adopted and cultivated by farmers rapidly. Consequently, the area of HYV had increased significantly leading to significant rice production increases. At that time, the Agriculture Cooperation introduced the special high-yielding paddy programme which includes the use of HYVs, use of fertilizer and appropriate plant population per acre.

Hybrid rice development in Myanmar was carried out to produce the Pale Thwe F1 seed in rainy and summer seasons in 2011-2012. Especially, in summer season, the farmers, the private company, groups of some farmers had produced above 200 baskets (10 tonne/ha) in 75 townships, 104 village tracts, with 959 farmers and totally cultivation of 1 063 acres.

So, Myanmar HR production had recorded 208 basket/acre in Nay Pyi Taw, 218.57 basket/acre in Waw Township, 248.93 basket/acre in Yesagyo Township and 269.76 basket/acre in Naungshwe Township in 2011-2012. A total of 5,772 education and training programmes were conducted for 406 DOA workers and 536,993 farmers, with10,049 demonstrations and 1,107,471 practical field trips by farmers.

2.2.1 Progress in hybrid rice research

Rice is the daily staple food for Myanmar people. The annual per capita rice consumption of Myanmar is 190 kg (i.e. about 15 baskets of rice), the highest compared to the other rice eating nations. Hence, to cope with the problem of not only self-sufficiency in domestic consumption but also for the export to foreign countries, there have been successive attempts at increasing cultivation and production of rice by various means. So, varietal development is the foundation of any seed supply programme.

There are 56 research and seed farms in Myanmar. Among them, 32 seed farms are under the supervision of Seed Division, Department of Agriculture (DOA) and 24 research farms are under Department of Agricultural Research (DAR). Seeds multiplication and distribution of rice crop are functioning in these seed farms which account for 85 percent of the total seed farm under DOA. Likewise rice research activities performed by DAR are undertaken in 50 percent of the research farms of DAR. The formal seed system is organized by the state agency, MOAI, which monitors the entire process of seed production from breeding to multiplication, processing, storage and distribution to ensure high-quality seeds.

Myanmar's agriculture sector has to progress in hybrid rice research from Nay Pyi Taw to other states and segions. Seed development activities ae carried out by Seed Division of DOA according to the seed flow. DAR produces nucleus seed and breeder's seed while the Seed Division multiplies these as foundation seed and registered seed at 32 seed farms under the Seed Division. Then, the Seed Division produces the certified seed through the Agricultural Extension Division (AED) in cooperation with farmer co-operators.

2.2.2 Status of hybrid rice production

During 2011-2012, Shwe Taung Farm, Wun Twin Township, Mandalay Region, has produced the hybrid rice seed production of Pearl Thwe and Basmati. The average yield (at the time) F1 seed was 922.5 kg/acre (45 basket/acre) in monsoon season, 1004.5 kg/acre (49 basket/acre) for Pearl Thwe and 754.20 kg/acre (36.79 basket/acre) for Basmati in the summer.

Area, yield and production

At different rice ecology conditions in paddy producing areas, the country's paddy cultivation is classified depending on time of sowing as defined by MOAI in 1992-93, based on different rice ecology in the country.

- Paddy planting from May to September is locally known as "wet season paddy" or "monsoon paddy" or "first rice" and
- Paddy planting from October to April is recognized as "dry season rice" or "summer paddy" or "second rice".

The present status and trends over years, comparison to conventional rice production area are as follows:

Table 2. The country's paddy production and surplus condition (2011-12)

Particular	Unit	Production, Consumption and Total Utilization
1. Sown acre	,000 acre	18 761
2. Production	,000 basket	1 390 346
	,000 tonnes	29 005
3. Population	In thousand	60 438
- Rural population	In thousand	41 898
- Urban population	In thousand	18 540
4. Consumption	,000 basket	850 950
5. Seed stored for next planting season	,000 basket	37 522
6. Losses	,000 basket	56 283
7. Total utilization (4+5+6)	,000 basket	744 755
8. Surplus	-	-
- Based on consumption 2/4	%	63 %
- Based on total utilization 4/7	%	47 %

Table 3. The country's hybrid rice Pearl Thwe cultivation

Year	Sown Area (ha)	Yield (mt/ha)	Production (MT)
2011-12 (Summer)	3 046	6.13	23 061
2012-13 (Rainy)	12 618	5.16	78 314
2012-13 (Summer)	11 925	7.31	87 124
2013-14 (Rainy)	17 110	6.18	23.14
2013-14 (Summer)	17 805	-	-

Technology transferred and applied in hybrid rice production

Crop seed production is very important for all agricultural countries not only for food security but also to increase crop production. The main objective of MOAI is to increase crop production. The main functions of DOA are to transfer the agricultural technologies to the farmers by distributing good quality seed (hybrid rice seeds) and to cooperate and coordinate with DAR in research and development activities (R &D).

Seed production should be carried out systematically to get quality seeds. Rice, being a self - pollinated plant, has four seed classes designated by international standardization: Breeder Seed (BS), Foundation Seed (FS), Registered Seed (RS) and Certified Seed (CS).

Therefore, the seed that reaches the farmers would have passed through multiplication cycles. So, there is a need to strengthen the seed production in Myanmar. The real issue is to make quality seed available in the required quality, make seed available in the required quantities at the right time to resource poor farmers. It is very important or one of the factors for seed production area.

The 14 points of Good Agricultural Practices (GAP) including good post-harvest practice will be encouraged among farmers for promoting quality improvement. Quality improvement could further be enhanced through private-public-partnership (PPP) in the near future. Both seed producers and seed growers must respect and follow rules and regulation of the Seed Law in Seed Industry Development in Myanmar.

At present, the seed production industry is being led by the Government sector. But, it is not enough to distribute seed. There is a need for subsequent cooperation by the private companies. Now, the Government sector is encouraging private companies to help in increasing crop production. In these activities, the State sector is also needed to help with the control of policy, laws, regulations and production technologies. Seed certification is an important task in seed production

There are four hybrid rice varieties in Myanmar, namely Chinese Long-8, Long-6, Long -4 and Philippines SL8H (Pearl Thwe 4) at present. DOA uses the 14 points of GAP Myanmar cultural practice with crop management in our country.

In Myanmar, HR seed production is in cooperation with contact farmers and some private companies. Systemic seed programme started in 1978-79; however, seed quality control system requires to be improved in Myanmar.

The Myanmar Seed Law was enacted on 7 January 2011 by the State Peace and Development Council. This law shall come into force commencing from the day of completion of two years of its promulgation. Therefore, the Seed Law came into force commencing on 7 January, 2012. Now, the Seed Law and Seed Regulation is being implemented from 7th January 2013 (DOA).

The DOA extension staff and DAR researchers have been engaged in Hybrid Rice Seed Production farm in Shwe Taung since 2010-2011 production seasons as their in-service training. Shwe Taung Farm trained 165 DOA staff about hybrid rice seed production. Some trained staff from DOA were transferred to a 200-acre Hybrid Rice Seed Production in Nay Pyi Taw.

The technologies applied in hybrid rice seed production are listed below.

- Choice of areas and growing season for seed production: The areas of seed production should be chosen so as to provide the best possible conditions at flowering and the pollen shedding period. The most suitable condition are, 24-28 °C day light average temperature, the relative humidity 70-80 percent , the temperature difference between day and night 8-10 °C and good sunshine. An average day temperature of more than 30 °C or less than 23°C, continuous rains, or strong wind are generally harmful to flowering, pollination and cross-fertilization. As a rule, in high temperature with low humidity or in low temperature with high humidity, some glues will not open. This lowers the seed yields. The growing of hybrid seed crop should be so adjusted that flowering takes place after the end of high temperature period but before the start of low temperature period.

- Selection of seed fields: The selection of prime field plots is necessary. The seed fields should be free of volunteer plants, well levelled, should have fertile soil with good physical and chemical characteristics and well drained.

- Isolation: The hybrid paddy fields should be isolated from the other paddy fields, including commercial hybrid of same variety and same hybrid not conforming to varietal purity requirements for certification at least by 200 meters for foundation seed class (A, B and R line production) and by 100 meters for hybrid seed production (A x R production).

- Brief cultural practices for hybrid (A x R) production nursery: Raising of vigorous seedlings is an important factor for obtaining high seed yields. The root system of vigorous seedlings are flourishing, leaf sheaths have high carbon content and all these contribute to produce green growth and tillering at the lower nodes so that more dry matter is accumulated, leading to more panicles and a high seed setting rate per panicle. It has been observed that tillering at the lower nodes gives more and bigger panicles which helps to achieve the goal of 100 kernels per ear.

- Prepare the seedling bed with basal manure. Seed at 22.2 kg/ha for the female parent and 5 kg/ha for the male parent.

- Sowing time: The proper sowing time is dictated by the number of days required from sowing time to panicle formation. The sowing should be so adjusted that the crop comes to panicle stage soon after the end of high temperature period.

- Transplanting: Seedlings with healthy tillers are the basis for increased panicle size. For hybrid seed production, the seedlings of both parents should be standardized. Seedlings of the male parent for short duration varieties should be 20-30 days old with 5.5-7 leaves and 2-3 tillers.

- Planting ratio: The ratio of female and male lines is generally kept at 2:10-12, and row spacing 10x10 inches for male parent and 66 inches for female parent.

- Row difference: Both parents should receive good aeration and equal amounts of sunlight. Row direction should be nearly perpendicular to prevailing winds at flowering to ensure more cross-pollination.

- Fertilization: Adequate fertilization is necessary. In general a seed field with moderate fertility should be treated with 200 kg N, 50 kg P, and 150 kg K per ha, 90 percent applied as a basal dose and 10 percent after panicle differentiation.

Water management: Good water management is very important for regulating water, fertilizer, air and temperature of soil. Give shallow irrigation at the transplanting and tillering stages. In soils where water permeability is poor, the field must not be allowed to remain under water for too long so that root growth could be drained the booting stage. During heading, if the air temperature is above 35 °C, water should be applied during the day and drained off at night so as too decrease soil temperature.

- Synchronization of flowering: Synchronizing the flowering of both parents is the key to increased yields. Technical measures such as staggering seedling dates of the male and females parents, sowing the male parents three times to extend the time pollen is available, and predicting and adjusting flowering dates may be adopted. Actual practices would have to be standardized for each hybrid and the locations selected for the hybrid seed production. Techniques to adjust the synchronization of flowering are: 1. Seeding by adjusting the day of A and R seeding based on flowering period; 2. To cover the A line flowering date by seeding the R line (2) to (3) times separately; 3. Irrigation and drainage to A and R synchronized,; 4. By applying urea fertilizer to A line to late flowering stage of A; 5. By applying urea and triple-super phosphate for early flowering stage; and 6. By using ‘hormone’ for early and late flowering.

- Supplementary pollination (rope pulling): On calm days during anthesis, supplementary pollination can be carried out. Panicles of the restorer lines are shaken by pulling a long nylon rope (5 mm diameter) back and forth every 30 minutes until no pollen remains on the restore line. This method is often used on even topography and regularly shaped plots. In hilly, uneven topography with small, irregular plots, a bamboo pole may be used.

Leaf clipping: Leaves taller than the panicles are the main obstacles to cross pollination. Clipping leaves 1-2 days before initial heading increases the probability of pollination and outcrossing rate. The blade of flag leaf is cut back 1/2 to 1/3 from the top. GA3 spray.

Spraying seed parent with 75 gm GA3/ha 60 ppm or more two or three times increases panicle exertion and help increased seed setting.

- Rouguing: The seed field should be free of rogues. Remove off- type plants in both the parents first before the onset off flowering stage and then soon after emergence of the panicle. Rogue out the plants of maintainer line, if any and the semi-sterile plants in the seed parent as often as necessary.

- Harvesting of seed crop: Harvest male rows first to avoid chances of mechanical admixture.

Table 3. Hybrid rice (Palethwe) seed production in 2011-2012 (rainy season)

No.	Location	Sown Area (acre)
1.	Shwe Taung Farm	100
2.	Yezin Agricultural University	100
	Total	**200**

Table 4. Hybrid rice (Palethwe) seed production in 2011-2012 (summer season)

No.	Location	Sown Area (acre)
1.	Shwe Taung Farm	200
2.	Yezin Agricultural University	100
3.	Yangon Region (Companies)	500
4.	Mon (Mudon & Thathone)	25
5.	Kayin (Hlaingbwet)	25
6.	Ayeyarwaddy region (Kangyidaunt)	3
	Total	**853**

Table 5. Hybrid rice (Palethwe) seed production in 2012-2013 (rainy season)

No.	Location	Sown Area (acre)	Production (Kg)
1.	Shwe Taung Farm	300	184 800
2.	Yezin Agricultural University	70	52 100
3.	Kachin State (Wine Maw)	10	8 300
4.	Sagaing Region (Watlatt, MyinMu)	50	49 888
5.	Bago Region (Pwe Pyayt Farm)	90	65 950
6.	Magway Region (Pwint Phyu Seed Farm)	25	22 351
7.	Mandalay Region (Patheingyi, Myit Thar)	50	38 800
8.	Yangon Region (Companies)	45	4719
	Total	**640**	**426 908**

Table 6. Hybrid rice (Palethwe) seed production in 2012-2013 (summer season)

No.	Location	Sown Area (acre)	Production (Kg)
1.	Nay Pyi Taw	**55**	
2.	Yezin Agricultural University	35	
3.	CETC (100 days hybrid rice)	20	20 106
4.	Kayin (Hlaingbwet)	50	24 410
5.	Bago (Oattwin)	20	14 379
	Mandalay	**460**	
6.	Shwe Taung Farm	450	
7.	Myittha	10	10 930
	Mon State	**20**	**4 410**
8.	Thathone	10	2 550
9.	Mudone	10	1 860
10.	Rakhine State (Sittwe, Kyauktaw)	10	3 698
11.	Yangon (Hmawbe Farm and Companies)	541	400 486
12.	Ayeyarwaddy (Pathein, Kangyidaunt, Kyankhinn, Pyapone)	40	24 254
	Total	**1197**	**502 673**

Table 7. Hybrid rice (Palethwe) seed production in 2013-2014 (rainy season)

No.	Location	Sown Area (acre)	Production (Kg)
1.	Magway Region	20	18 709
	Mandalay Region	**500**	
2.	Shwe Taung Farm	430	314 545
3.	Pathein Gyi	40	33 837.1
4.	Myittha	24	
5.	Sintkai	30	35 603.15
6.	Southern Shan State (Taungyi, Loilin, Linkhae)	32	27 000
7.	Northern Shan State (Lashio, Kyaukme, Muse, Kwanlon, Loatkai)	12	10 480
	Total	552	429 694.25

Table 8. Hybrid rice (Palethwe) seed production in 2013-2014 (Summer season)

No.	Location	Sown Area (acre)	Production (Kg)
1.	Nay Pyi Taw	200	
2.	Bago	30	
	Mandalay	**500**	
3.	Shwe Taung	100	
4.	Great Wall Co., Ltd	400	
5.	Yangon Region (Hmawbe Farm)	20	
6.	Southern Shan State	31	
7.	Northern Shan State	3	
8.	Eastern Shan State	5	
9.	Ayeyarwaddy Region	20	
	Total	**810**	

The private seed companies engaged in hybrid rice seed production are Anhui Longping Hi-tech Seed Co., Ltd; Royal Panse Co., Ltd; Thiri Myint Myat Co., Ltd; Great Wall International Co., Ltd and Win All Co., Ltd.

A field producing hybrid seeds of the hybrid Palethwe was presented in Fig. 1.

Fig 1. Production of the Palethwe hybrid seeds in Myinmu Township (Sagaing Region)

Hybrid rice supply and trade

It is required that seed demand and supply be balanced by way of a secure seed supply system. This would give the farmers access to adequate quantities of good quality seed of desired type at the desired time and at affordable cost. An effective seed supply (distribution) system is necessary to make good quality seed available to farmers at the right time and low cost.

Given the critical role played by improved varieties (HR seed) in increasing crop production, agricultural decision makers have the challenges of developing an integrated and cost effective seed system that is capable of generating and delivering improved seed varieties to farmers. Such a system would be an important step towards ensuring seed security and enhancing livelihoods.

The objectives of the import policy are to provide the best planting materials available anywhere in the world for the farmers and to increase productivity, farm income and export earnings. It is necessary to ensure that there is no deleterious effect on environment, health and bio-diversity. For the important seed and planting materials, seed banks will be established for stocking seed of required crops/varieties and for contingency during natural calamities, production shortage, etc. Seed storage facilities at the village level will be encouraged to take seed crop insurance, which covers the risks of unforeseen situation.

The export policy should specifically encourage custom production of seeds for export based on long-term perspective. The establishment/strengthening of seed export promotion zone with special incentives from the Government should be facilitated. Myanmar can be divided into nine different natural regions based on the different topography, land forms, climate, natural vegetation and agriculture. For this, seed export promotion zone with special incentives from the Government of Myanmar should be facilitated in the central dry zone region (irrigated area), Ayeyarwaddy delta and Bago Region, Sittaung river valley.

So, seed are key components in the conservation and ownership of biodiversity. Accordingly, sustainable and effective seed supply and distribution are among the major activities required for the development of seed industry but also for the export of seed. May I announce again and again “The Good Seed does not cost; it pays” for the future of mankind.

HR intellectual property

The high-yielding variety of paddy, namely “IR-8” (Miracle Rice) released by International Rice Research Institute (IRRI) was introduced to Myanmar in 1966 and distributed to farmers after adaptability testing rice farms to replace indigenous varieties in adapted areas increase yield. Other high-yielding varieties of IR, namely IR-5, IR-20, IR-22 and IR-24, among others, introduced from IRRI, underwent location adaptability test and manipulated in the state seed farms for distribution.

There is no Intellectual Property Right in Myanmar yet. The rice varieties were released with the approval of National Seed Committee (NSC) in Myanmar. So, the ownership of Hybrid Rice variety should be registered to NSC. Hybrid rice, Pale Thwe (1) is already registered to NSC in 2013.

Impact of HR adoption

Understanding the challenges and opportunities, the vision of Myanmar rice sector is stated as “Food source, competitiveness in trade marketing and benefit for small farmers by sustainable rice farming with environmental friendly and effective resource management by 2030”.

The vision statement is not only important for the country of Myanmar but also the food security of the region since Myanmar is all recognized as “Rice bowl of Asia” with its potential of land and water resources.

Suggested time frame for achieving the stated vision is 2030. The 15-year (2015-2030) time frame starting from 2015 is reasonable to build up capacity and skill of the human capital, develop existing infrastructure and institutional arrangement to achieve modern agricultural (HR production) nation from transition economy. Innovations, including technology, organization and institutions, are envisaged as main mechanisms through which such transformations are to be achieved for increasing farmers’ income with production increase and food security in line with reducing poverty among farmers.

3. Constraints and gaps in HR development

3.1 Technology constraints

The technology constraints are as follows:

- Slow and inadequate investment to develop the technology by seed production and supply;

- Limited yield heterosis in commercial rice hybrid by insect and pest control;

- Inadequate human resources in terms of number and quality of personnel available for HR research and seed production;

- Lack of collaboration among the farmer involved in hybrid rice research and development by extension work;

- Lack of effective coordination between hybrid rice research and seed production systems; and

- Inadequate incentives for development or expansion by the private seed industry of good hybrid rice variety and quality.

Finally, the progress of HR research and development has been determined by the extent of action taken to overcome above constraints.

3.2 Social and economic constraints

The hybrid rice seed production is more than just production of good quality seed, but having balance between supply and demand. The effective demand can be stimulated over time. Reliable information is needed to analyze seed demand. To promote seed demand, farmers should be enlightened on the importance of seed and good quality gain as demanded by local exporter. Farmers can earn more income if there is an increase in offers from local traders, millers and other market participants.

For a sustainable seed market, all participants along the production and marketing should receive a reasonable profit margin. So, effective seed demand should be clearly known by all participants (state and regional government administrations, agricultural universities, plant breeders, seed producers, the seed industry and all other stakeholders) along the production and marketing chain by means of extension service and field survey.

3.3 Capability Constraints

There are capability constraints in the rice production sector in view of weaknesses and hindrances to fully attain the following:

- Greater use of high yielding and good quality seeds (especially HR Seed);

- Shift from conventional to mechanized agriculture;

- Expansion in research and extension with a focus on sustainable development;
- Renovation and maintenance of irrigation system;
- Emphasis on high quality production and improved marketing;
- Protection of farmers' right and ensuring farmers get a fair price on their production;
- Support to rural development and poverty reduction activities through development of the agriculture sector;
- Encouraging both local and international investment in the agriculture sector; and
- Amendment of existing agricultural loans and regulations to bring them in light of the economic reforms.

In December 2012, the Government announced a "Framework for Economic and Social Reforms (FESR)" (Policy Priorities for 2012-2015) towards the long-term goals of the National Comprehensive Development Plan (NCDP).

3.4 Environmental Constraints

Rice is grown in various environments in Myanmar which calls for the development of varieties and crop management options that are suitable to the conditions in the field.

Myanmar has been collaborating with the International Rice Research Institute (IRRI) for more than 30 years which had resulted in the breeding of about 70 rice varieties that are high yielding and suitable for the different rice environments.

Moreover, much needs to be done in making these varieties accessible to farmers. Seed supply is wanting as the Government can only provide less than 5 percent of the total seed requirement of farmers. It is imperative that a seed system and marketing be developed that is inclusive of farmer groups and private seed companies to rapidly remove the environment constraints.

Rice seeding had been strong but research and development of appropriate pre and post harvest crop management options had been lagging behind. The few recommendations for rice are adopted from other countries brought by IRRI to Myanmar through the Irrigated Rice Research Consortium and the Consortium for Unfavorable Rice Environment. As such, there are defined recommendations that should go together with the varieties to be grown in different rice growing environments. They are very important for farmers to optimize the yield benefits that the new rice varieties can offer.

3.5 Policy Constraints

The Myanmar rice sector has various barriers and limitations, which are making delay in its development. There are many worse-off stakeholders along the supply chain, which have not been managed properly.

The private sector's extensive value chains (from producers, farmers, millers to consumers), can lead the emerging economic activities.

However, the capacity of the private sector must be developed to effectively and successfully compete in international market. Myanmar's neighbors such as Thailand and Vietnam have become major rice exporters. Although the private sector is allowed to export rice, the volume of rice exported is unstable due to low production quality, high local consumption and weak export policy. The volume of export rice is occasionally controlled in order to maintain local market price and to ensure local consumption.

There is no constraint for hybrid rice production in Myanmar. The President of the Republic of the Union on Myanmar has provided guidance to produce hybrid rice seed in states and regions at 100 acres, respectively, with support from the Ministry of Agriculture and Irrigation.

4. Lessons learnt

The seed quality control system requires to be improved in Myanmar. A seed bank was established by Japan International Cooperation Agency (JICA). Seed programmes are under the supervision of the National Seed Committee (NSC), which was established in 2004. Myanmar enacted a Seed Law in January 2011. The two main responsibilities of Seed Division are quality seed production and seed quality control.

The Seed Division is to produce and distribute quality seeds of major crops, to conduct systemic quality control activities by maintaining seed with genetic identify, varietal purity and high germination to establish model registered seed growing villages for multiplication of certified seed, to conduct trainings, workshops, seminars and field days, to conduct seed processing activities prior to distribution to seed in order to improve seed quality and to conduct applied agricultural research.

5. Opportunities of hybrid rice development

There are some opportunities for hybrid rice development in the rice industry:

- Natural resources potential;
- Private sector engagement;
- Potential of increased productivity;
- Policy environment towards market economy;
- Large skilled work force with relatively low wages; and
- Skilled staff trained at the Shwe Taung Farm can share hybrid rice seed production to the state and regions.

6. Key strategies and policy to promote hybrid rice development in Myanmar to 2020 and 2030

- Significant increase in investments on research and development;
- Skills enhancement, hybrid rice seed industry facilities and infrastructure;
- Reduction of the gap between real and potential productivity of hybrid rice in a sustainable environment;
- Extension of public and private sector participation for environment-friendly agriculture production;
- Proven technology for hybrid rice seed production and development;
- Development of research work on hybrid rice production;
- Capacity building activities and human resource development for key staff;
- Development of seed processing plants for hybrid rice production;
- Provision of updated information through multimedia; and
- Collaboration with NGO, INGO and other institutions.

7. Conclusion

- Hybrid rice production programme has been carried out by both public and private sectors.

- To supply rice for the increasing population, the requirement of paddy production is 41 million metric tonnes. The paddy yield needs to reach 5.15 metric tonnes per hectare.

- To meet the above mentioned requirements, the Government tried to increase the rice production with two categories: paddy sown area expansion and increase in rice yield per acre by hybridization.

- It is necessary to develop adequate marketing systems of hybrid rice that will create satisfactory hybrid rice seed demand and adequate and timely supply of the required range of varieties, with the desired quality, at reasonable prices and at locations accessible to farmers

Hybrid Rice Development in Pakistan: Assessment of Limitations and Potentials

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1. Pakistan Overview of rice production in Pakistan

Rice holds an important position in food and cash crops of Pakistan. It does not only meet the food requirements of the country but also earns a lot of foreign exchange through exports. In addition, it is an important raw material for manufacturing starch paper, etc. It accounts for 6.4 percent of the value added in agriculture. It accounts for 18 percent valued added of major agriculture crops, 10 percent of the total cropped area and 18 percent of the acreage under food crops. Rice is planted on about 2.7 million ha with the production of about 6.0 million metric tons of milled rice. During 2013-14 Pakistan earned US$ 2.00 billion foreign exchange from the export of rice.

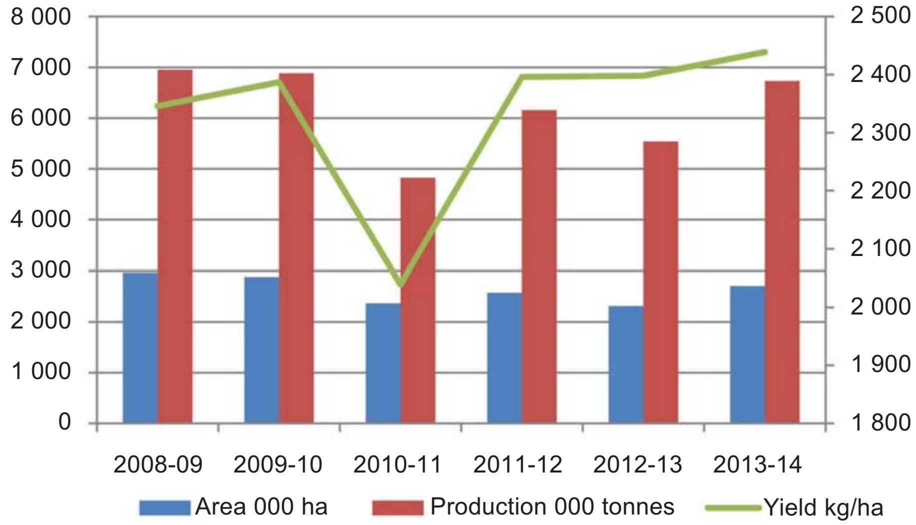

Fig. 1. Trends on harvest Area, Production and Yield of Paddy

Based on a three-year average, 2010-2013, production of rice at country level is estimated at 6 700 thousand tons and area at 2 700 thousand hectares. The provincial shared in area and production of the rice variety are depicted graphically in Figure 2. Punjab is the main contributor in production of rice. Its contribution in overall rice production and area is 63 and 71 percent respectively. The pertinent shares of Sindh, Khyber Pakhtunkhwa and Baluchistan in area under rice crop are 22, 2 and 5 percent respectively and 31, 2 and 4 percent in production

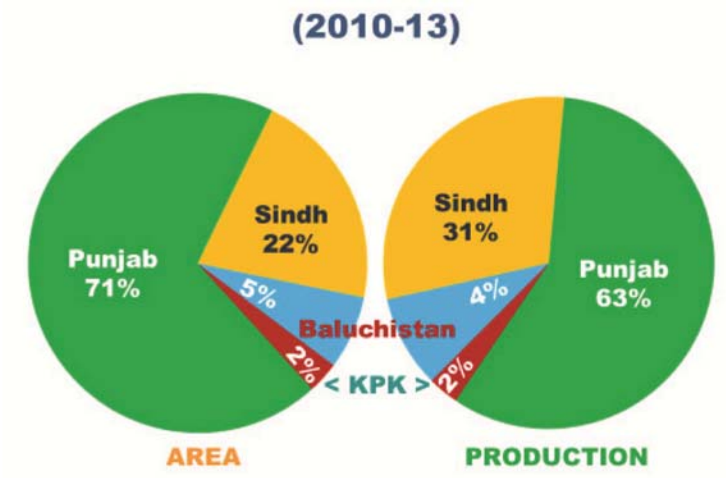

Fig. 2. Province-wise share of area and production

From 2003-04 to 2013-14, the production of rice at country level is estimated to have increased at 2.13 percent per annum due to increase in area and yield at 0.50 and 0.22 percent respectively (Table 1).

Table 1: Average annual compound growth rates of area, yield and production of rice (2003-04 to 2013-14)

Country/ Province	Area	Yield	Production
Pakistan	0.50	2.01	2.13
Punjab	0.22	1.51	1.73
Sindh	0.58	3.32	3.92
KPK	-2.31	-0.97	-3.26
Baluchistan	-6.22	0.30	-4.60

The rice production in Punjab and Sindh is estimated to have increased at 1.73 and 3.92 percent respectively per annum due to increase in area and yield at 0.22, 0.58 percent and 1.51, 3.32 percent respectively. Contrary to this, rice production in KPK and Baluchistan is estimated to have decreased at -3.26 and -4.60 percent respectively per annum due to drastic reduction in area at -2.31 and -6.22 percent respectively.

The total export (Table 2) for the year 2013-14 was calculated to be 3.489 million tonnes, and 3.5 million tonnes on an average from 2009-10 to 2013-14. It has been observed that export of basmati rice is reducing every year due to a number of reasons including high cost of production and improper production technology. However, the total export volume during the last four years was about 3.5 million tonnes with a value of US$ 2 billion.

Table 2. Rice export of Pakistan from 2009-10 to 2013-14

Year	QUANTITY (000 MT)			VALUE (in Million US$)		
	BAS	IRRI	TOTAL	BAS	IRRI	TOTAL
2009-10	1 032	2 700	3 733	1 060	1 156	2 217
2010-11	1 112	2 568	3 680	950	1 206	2 156
2011-12	969	2 755	3 724	844	1 237	2 081
2012-13	630	2 859	3 489	627	1 211	1 838

1.1 Rice Production Zones

Rice can be cultivated throughout the country starting from Southern Sindh up to highest altitude in the North but its cultivation is mainly concentrated in more or less four distinct agroecological zones.

Zone I

It consists of northern mountainous areas of the country. The climate is subhumid monsoon with 750-1000 mm average rainfall, mostly concentrated in summer. Cold tolerant i.e. japonica type rice varieties are recommended for cultivation. Cold damage to rice crop due to cool air temperature and cold irrigation water are the major problems. Areas included are Swat and Khaghan valley.

Zone II

It lies between Ravi and Chanab. The climate is subhumid, subtropical. Average rainfall is 400-700 mm. Rice growing season is fairly long and is suitable for cultivation of basmati aromatic rice. The famous rice bowl called *"Kalar Tract"* of the Punjab lies in this zone. Major districts of this zone are Sheikhupura, Gujranwala, Sialkot and Lahore.

Zone III

It consists of the areas lying on the west bank of river Indus. Climate is subtropical with average rainfall of 100 mm. Temperature is very high during rice growing season, best suitable for growing medium long grain (IRRI type) rice varieties. It comprises Larkana, Jacobabad, Nasirabad, Jaffarabad and Shikarpur Districts.

Zone IV

It is the Indus Delta consisting of vast spill flats and basins. The climate is arid tropical marine with no marked season and is suited for growing of coarse and hybrid rice varieties. Areas included in this zone are Badin and Thatta Districts which are considered with the most favorable environment for hybrid rice production.

Fig. 3. Rice zones in Pakistan according to agro-climatic conditions

1.2 Rice research institutes /setup in Pakistan

- Rice Research Institute, Kala Shah Kaku (Punjab-conventional/molecular breeding, Basmati & coarse rice, submergence)
- Rice Research Station, Bahawalnagar (Punjab-coarse rice, drought and heat tolerances)
- Rice Research Institute, Dokri (Sindh-coarse rice, heat tolerance)
- Soil Salinity Research Institute, Pindi Bhattian (coarse, salt tolerance)
- Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad (mutation breeding)
- National Institute for Biotechnology and Genetic Engg. (NIBGE), Faisalabad (DNA testing and MAS)
- Nuclear Institute of Agriculture, Tandojam (mutation breeding, heat tolerance)
- Agricultural Research Institute (North) Mingora, Swat (KPK-cold tolerance)
- Government Seed Farm, Usta Muhammad (Balochistan, drought & heat tolerances)
- Directorate of Agriculture, Muzaffarabad, AJK (AJK-cold tolerance)

1.3 Brief history of rice research and development in Pakistan

- 1912 Establishment of Rice Research Station at Larkana (Sindh)
- 1926 Rice Station established at Kala Shah Kaku (Punjab)
- 1927 First rice variety Kangni-27 released for cultivation
- 1926-1931Germplasm collection, evaluation continued at Kala Shah Kaku
- 1932 Germplasm divided into 16 agri-cum-commercial groups
- 1933 World famous rice variety Basmati-370 approved for cultivation

- 1973 Rice Stations at Kala Shah Kaku (Punjab) and Dokri (Sindh) were given the status of Rice Research Institute.

-1975 National Coordinated Research Program (NCRP) on rice was started and linkages with IRRI, Philippines were established

-2009 Establishment of Rice Research Station, Bahawalnagar under RRI, KSK

2. Progress in hybrid rice development in Pakistan

Keeping in view the popularity of rice hybrids in neighboring countries, the Government of Pakistan initiated the rice hybrid programs at the national level. Both in public and private sector, the research and development work was started.

2.1 History of hybrid rice development

The Federal Seed Certification and Registration Department (FSC&RD) developed a procedure Hybrid rice is becoming popular in Pakistan due to the yield advantage over inbred varieties. In the public sector, the Rice Research Institute, Kala Shah Kaku, initiated a time-based hybrid rice programme in collaboration with IRRI in the late 1990s. In 2000, this programme was strengthened by the Government with the approval of a research project titled, "Development of Hybrid Rice in the Punjab". Production of Basmati hybrids was also a part of this programme. Under the project, the potential breeders of this institute developed a number of hybrids. These hybrids performed well in station yield trials, however, due to the lack of awareness to the production technology and least interest of the private sector in hybrid seed production, these hybrids could not get popularity among the rice growers.

In the private sector, Guard Agricultural and Services Pvt. imported Chinese rice hybrids for evaluation and marketing in upper Sindh under the technical supervision of Chinese experts. The first ever approved rice hybrids i.e. GNY-50 and GNY-53 were given by this group. These hybrids were *japonica* types and got low market price due to poor quality as compared to inbred varieties i.e. IR-6, KSK-282 and KSK-133. Furthermore, the same company tried to produce hybrid seed in lower Sindh with the help of Chinese experts. However, the yield is just 2.0 t/ha which is quite low and uneconomical. A number of multinational and national seed companies have commenced importing hybrid rice seed in the country from China. A total of 3 000 to 4 000 metric tonnes of hybrid rice seeds were imported every year since the outset of the technology introduction.

for the import and selling of hybrid rice seed in the country. Importers have to provide hybrid rice seed samples for two years testing in the adaptability trials. After two years testing in the adaptability trials, the Variety Evaluation Committee (VEC) gives recommendation to the National Seed Council for the approval of rice hybrids in Pakistan. In the provinces, the provincial seed councils approve the hybrids/varieties in their respective provinces. So far, 85 rice hybrids have been approved by the Committee for General Cultivation in Pakistan (Annexure 1).

2.2 Status and trends of hybrid rice development

In Pakistan, almost all the hybrids are being imported from China. These hybrids have an average yield of 6-8 t/ha. These imported hybrids are not tolerant to high temperature of Pakistan. They have high bursting percentage, poor grain quality, low head rice recovery and mostly susceptible to insect pest and diseases which are not acceptable. Punjab is the leading province for the growing of basmati rice, however in some parts of southern Punjab like Multan, Sadiqabad, Rahim Yar Khan, Dear Ghazi Khan, and Bahawalpur, hybrid rice got penetration. Major areas for hybrids are in Sindh province where coarse rice is grown. Hybrid rice is cultivated in Zone III (upper Sindh). In Baluchistan, it is cultivated in Jafferabad, Nasirabad and Usta Muhammad districts

2.2.1 Progress in hybrid rice research

The development of genetic tools essential for production of hybrid rice, i.e. cytoplasmic male sterile (CMS), maintainer and restorer lines, was initiated. RRI, KSK made following tremendous progress in this respect.

Fig. 4. Research work in farms

The Institute is maintaining and evaluating 19 exotic CMS lines. Three CMS lines also have been developed locally, including two CMS lines in Basmati background. However, all the CMS lines belong to WA source and the outcrossing rate of CMS line ranged from 15 to 46 percent which is quite low for getting good heterotic combination.

- Almost 30 potential restorers have been identified in basmati and non-basmati .

- Thirty maintainer lines were identified for the development of new CMS lines in the local background.

- Eighteen male sterile lines are in the different back cross generations.

- Five rice test hybrids have been developed and they will be evaluated in replicated yield trials.

- The Institute has developed 2 hybrids LH18 (coarse type) and LH 1 (Bas. type). These hybrids have been sent for testing in NURYT and cases also sent for registration to FSC&RD. The seed production technology of these hybrids has also been developed (Table 3).

The CMS lines under study have significant differences among each other regarding the traits plant height, tillers/plant, maturity days and out crossing ratio (percentage) as given in Table 3. Two sets of CMS lines were studied simultaneously, which are Local CMS lines and Exotic CMS lines. In case of local CMS lines, SSMS2A showed maximum plant height (80 cm) followed by KSK 9A (69 cm) and KSK 4365A (69 cm). Number of tillers per plant was observed to be highest in KSK4365A (15). Local CMS line KSK9A had maximum days to maturity which were 98 followed by SSMS2A (89) and KSK4365A (85). Table 3 reveals that local CMS line KSK9A had maximum out crossing ratio (28 percent) followed by KSK4365A (25 percent) and SSMS2A (20 percent).

In Exotic CMS lines, the maximum plant height was observed in line IR68885A (82) and IR73328A (82), minimum plant height was observed in line IR85025A (67). As shown in the Table 3, IR68902A had the maximum number of tillers per plant and IR791565A had the minimum number of tillers per plant. The maximum number of maturity days were observed in line IR68885 (99) and minimum were in IR62829A (79). The out crossing ratio was maximum in line IR68897A (46) and minimum was in IR68902A.

As shown in Table No. 4 it is revealed that locally developed rice hybrid LH-18 (115.3 cm) had more plant height compared with the approved check variety KSK 133 (108.3 cm). The number of tillers per plant were also greater in LH-18 (18.2) which has direct contribution in enhancement of yield than the check variety. The yield obtained from the locally developed LH-18 was 38 percent more than the local check variety. In case of the second rice hybrid which was locally developed LH-1 had 26 percent increased yield.

Table 3. List of hybrids developed by Rice Research Institute under hybrid rice programme

S. No.	Designation	Pl. height (cm)	Tillers /plant	Maturity days	Out crossing rate (%)
Local CMS					
1.	KSK9A	69	14	98	28
2.	KSK4365A	69	15	85	25
3.	SSMS2A	80	14	89	20
Exotic CMS					
1.	IR58025A	67	20	93	30
2.	IR68897A	68	16	85	46
3.	IR70369A	75	17	93	40
4.	IR75596A	75	16	85	30
5.	IR79128A	74	13	85	32
6.	IR70372A	77	13	87	27
7.	IR79156A	78	12	90	26
8.	IR62829A	78	23	79	38
9.	IR68275A	81	16	86	17
10.	IR68280A	68	14	83	20
11.	IR68885A	82	19	99	28
12.	IR68886A	69	21	92	37
13.	IR68888A	68	19	84	32
14.	IR68902A	73	24	90	15
15.	IR69616A	76	19	95	29
16.	IR72788A	80	15	89	23
17.	IR73322A	78	16	92	19
18.	IR73328A	82	14	89	31
19.	IR73794A	81	18	93	25

Table 4. Characteristics of locally developed hybrids at RRI, Kala Shah Kaku

Name of Hybrid	Height (cm)	Tiller per plant	Panicle length (cm)	Maturity days	No. Gr. Per panicle	Yield (tonnes/ha)
LH-18	115.3	18.2	31.3	104.0	189.8	6.607 (38%)
KSK-133 (check)	108.0	16.4	25.9	105.0	126.4	4.804
LH-1	130.0	18.6	35.8	120.0	170.0	5.637 (26%)
Basmati 385 (check)	132	19	33.4	128	155	4.50

Fig. 5. Pictorial comparison of Basmati 385 and LH1 early maturing hybrid

2.2.2. Status of hybrid rice production

Year-wise hybrid rice cultivation data is represented in Figure 6. Data is shown from the 2009/10 to 2012/13. According to the figure it is clearly observed that area and production of hybrid rice production had increased. In the season of 2011/12 the hybrid rice cultivation was more than the area under the local varieties cultivation. In the 2010/11 the area and production of hybrid and conventional (local) varieties were at par, but still the production of hybrid rice was higher. The comparisons of area and production of hybrid rice and traditional varieties in the Pakistan are presented in Fig. 6.

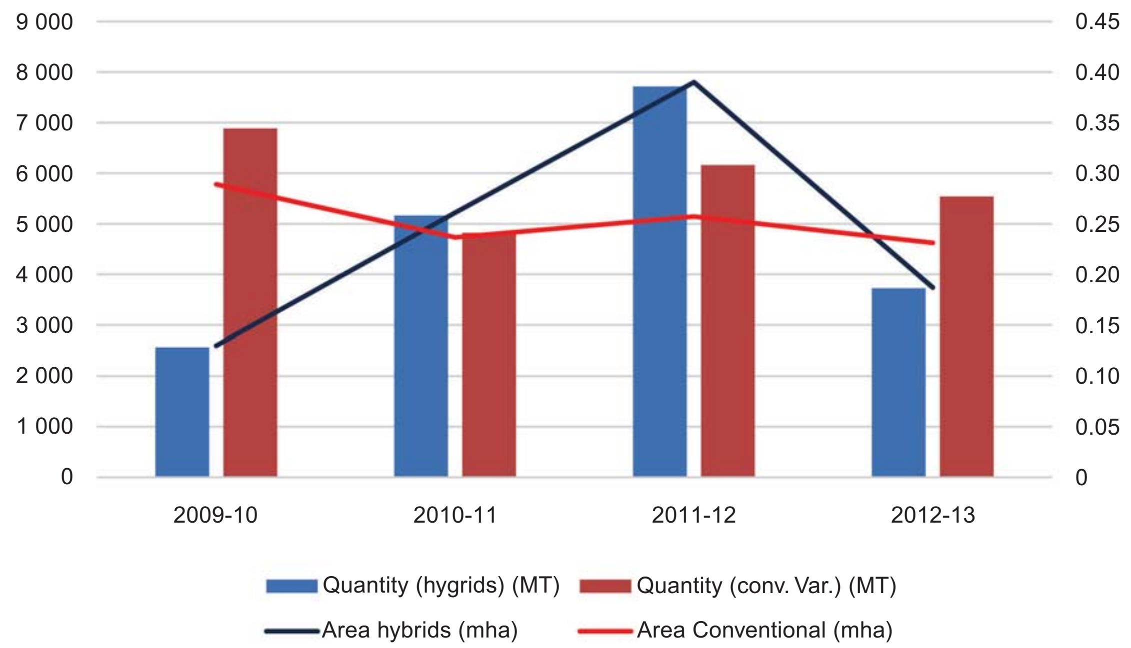

Fig. 6. Comparison of area and production of rice hybrids and traditional rice varieties over the last four years

At present, hybrid rice is cultivated on an area of approximately 202 347 ha in Pakistan where average yield per hectare (2.387 mt/ha) are still lowest in the world (International News, 2012). Rice ranks second among of foreign exchange earnings for the country but achieving self-sufficiency in rice is still the target. Several private companies in Pakistan are currently operating in the production and sale of hybrid rice seeds with tall claims that it would boost the production manifold. A total of 3 000 to 4 000 metric tonnes of hybrid rice seeds are imported every year since the outset of the technology introduction. Farmers have to buy the costly seed every year and that may increase the input cost as compared to conventional rice. The seed availability and dependency on private seed companies could also put farmers on losing side. This situation could lead to disadoption and readoption of hybrid keeping in view the seed prices and availability of seed. Moreover, due to inferior quality of hybrid rice, the marketing problems may also arise as a result of wider cultivation of hybrid rice in the country.

2.2.3.Technologies transferred and applied in Hybrid Rice

Production technology of hybrid rice

In the years to come location- specific specialized seed production technology for the released /commercial hybrids would have to be developed for obtaining maximum seed yields and ensuring good seed quality. Good crop management is necessary for raising a hybrid rice seed production crop. Agronomic management of the hybrid rice is different from the inbred rice varieties.

Hybrid rice seed production using the CMS system, i.e. the three-line system**:** A line (female), B line (maintainer) and R line (restorer) involves three steps i.e., multiplication of A line, multiplication of B and R lines and production of hybrid seed (A x R). In order to obtain the best quality F1 seed in the hybrid seed production programme, high genetic and physical purity of the parental lines is a prerequisite. Impure parental lines lead to variation in plant type, duration, plant height and grain size, and ultimately the quality of the F1 hybrid is affected. It is therefore essential to adopt methods to ensure quality seed production. In order to achieve higher seed yields, rice seed production should be undertaken in the most favorable areas where irrigation is guaranteed, and with adequate and balanced use of fertilizers together with integrated nutrient and pest management. Some standardized seed production practices are described below:

- *Site Selection***:** The land selected for seed production should be fertile, preferably light-textured, with adequate irrigation and a proper drainage system. In order to achieve synchronous flowering, a homogenous plot with an even topography is required. Hybrid rice seed production fields should be isolated as rice pollen can travel longer distances with the wind; negligence leads to impurity of F1 seed. When selecting for isolation of land, the following points must be considered.

- *Terrain isolation:* The selected seed plot is either isolated by mountains or hills or by other natural barriers. Space isolation is the most important factor to be considered for the production of quality seed. Space isolation of at least 100 m from seed production plots to other rice varieties is normally satisfactory for quality hybrid seed production. It is safer to have an isolation distance of up to 200 m for male sterile (A line) multiplication, while for B and R line multiplications in varieties, an isolation distance of 3 to 5 m is sufficient.

- *Time isolation*: When space isolation is not possible, time isolation of about 30 days is satisfactory. This means that the flowering stage of the parental lines in the seed production field should be 20-30 days earlier or later than that of other varieties grown within the area to avoid contamination by pollen.

- *Seeding time:* Seeding of the parental lines should be planned in such a way that flowering coincides with the most favorable climatic conditions listed below:

- daily mean temperature of 24°-30°C
- relative humidity of 70-80%
- differences between day and night temperature of 8°-10°C
- sufficient sunshine with moderate wind velocity
- no 3 days' continuous rain during flowering period

- *Nursery bed preparation and sowing*: Given the high cost of seed, it is essential to raise the nursery in a well-managed field. Optimum seed rate should be used. A sparse well-managed nursery gives healthy seedlings for the main field. The normal recommendation is 1 kg of parental line seed in an area of 40 m2. For 1 ha of main field, 12.5 kg of A line seed and 5 kg of R line seed are required.

- *Determining the seeding interval of parental lines for flowering synchronization*: Time method. The seeding interval is determined by the difference in growth duration between the two parental lines. The one with longer duration must be sown early according to the number of days of difference between the two parents in terms of days to 50% flowering.

- *Leaf number method*: The total leaf number of a variety is relatively stable at the same site and in the same season in different years. The rate of growth in terms of leaf number is influenced by environmental temperature. By observing the leaf number of the early seeded parental line, you could determine the seeding date of the later one because the leaf number difference is rather stable between the two parents.

Hybrid seed set on the female line depends primarily on its flowering synchronization with the R line; the sowing of male and female lines must therefore be planned to achieve this. For example, if the duration of the male line is 10 days more than that of the female line, the male line is sown in 2-3 staggered sowings so as to ensure a continuous pollen supply. In such cases, three sowings of the R line (i.e. 13, 9 and 5 days ahead of the female line) are carried out. However, in countries such as China where the technology has been perfected, only one or two sowings of the male line are necessary.

- Heading date predication

Remaining leaf number method: The young panicle differentiation starts from the reciprocal third-leaf emergence (keeping in the flag leaf as the first leaf and the leaf before the flag leaf as the 2nd leaf and the leaf before the 2nd leaf as the 3rd leaf) and the time taken for complete panicle differentiation is about 30 days from the start to heading. This means that the parental line would head after 30 days, when the reciprocal third leaf emerges.

Stripping the young panicle: The young panicle differentiation could be divided morphologically into eight stages and each stage takes about 3-4 days for developing.

- Transplanting

Conventional high-yielding varieties may be transplanted once the nursery crop is 25-30 days old; but in hybrid seed production plots transplanting may commence (depending on the difference in duration of the A and R lines) when 21-35 days old. Timely transplanting ensures good picking of parental lines. Transplanting of too young or very old seedlings may either delay or accelerate flowering and affect tiller number.

While pulling out the nursery and during transplanting, special care should be taken to avoid mixing seedlings of male and female parents. It is also important to avoid mixing seedlings of different ages of the male parent, which could affect the uniform distribution and availability of pollen. The long- duration parental line must be transplanted first in order to obtain good synchronization at flowering.

Transplanting R lines: Paired rows with 15 cm spacing between plants. Seedlings of different ages transplanted in a sequential order (e.g. I, II, III, then again I, II, III). Single seedlings per hill with row-to-row spacing of 15 or 30 cm (as per recommendation) in the main field.

Transplanting A lines: Six rows with 15 cm spacing between the paired rows of R line seedlings is the normal recommendation in many Asian countries. One seedling per hill with a spacing of 15 x 15 cm. In Pakistan, spacing of 23 cm between A line and R line rows to facilitate bumper male growth and supplementary pollination

Row ratio and layout: Seed parents and pollen parents planted in a specific row ratio and with specific spacing have a marked effect on seed yields. Row direction perpendicular to the prevailing wind direction at flowering stage allows easy pollen dispersal on the seed parent. The optimum row ratio for hybrid seed production is 2-3 males; 8-10 females. Pollen parent seedlings are evenly mixed and planted in three rows, at a spacing of 15x15cm, leaving a space for an TGMS line in between. The TGMS seedlings are planted with a spacing of 30 x 15 cm. The spacing between the TGMS line and the adjacent pollen parent line should be 20 cm. Row direction should be perpendicular to the wind direction.

Fig. 7. Alternative rows of male and female parents for more recovery of rice hybrid seed

- *Synchronization:* For optimum synchronization of flowering, the female parent should flower two to three days earlier than the male parent. If A and R lines have the same growth duration, the A line should flower one to two days earlier than the R line in all panicle developmental stages. If the A line has shorter duration than the R line, the R line should be one stage earlier than the A line during the first three panicle development stages. If the A line is longer than the R line in growth duration, the A line should be two to three days earlier than the R line during the first three panicle development stages.

Adjustment of flowering: If the difference in predicted flowering is more than three days between the parental lines, measures should be taken to synchronize flowering. The application of quick-releasing N fertilizers on an early-developing parent in the early panicle development stages tends to delay flowering. Similarly, spraying phosphatic solution (1%) on the later-flowering parent tends to enhance flowering by 2-3 days. If the pollen parent (R line) reveals a tendency towards heading earlier than the seed parent (A line) after the third stage of panicle initiation, root zone placement of N fertilizer is helpful in delaying panicle development.

- *Leaf clipping:* Leaf clipping of A and R lines is helpful for better out-pollination and seed set. Long and erect flag leaf may obstruct pollen dispersal from the R to the A line and affects the outcrossing rate. Flag leaves should be clipped off in such cases, when the main culms are still in the boot leaf stage. Flag leaf clipping gives uniform distribution of the pollen over A line plants. However, it is not advisable to perform leaf clipping in areas where diseases such as bacterial leaf blight, sheath blight and bacterial leaf streak prevail, as they may spread further and reduce seed yield.

Fig. 8. Practice of leaf clipping in hybrid rice seed production

- *Use of GA3:* Spraying of GA3 is recommended to obtain good panicle exsertion. Female lines with WA cytoplasm have poor or incomplete panicle exertion. Spraying GA3 not only helps exert the panicle but also increases the duration of floret opening, improves stigma exertion and stigma receptivity, and widens the flag leaf angle. Spraying GA3 increases plant height by 10-15 cm and it can also be used to adjust the plant height, in particular of R line in relation to A line. A dose of 40-60 g ha-1 by a knapsack sprayer or 15-20 g ha-1 by a ULV sprayer is recommended for desired results. The spray liquid required is 500 L and 20 L for the knapsack and ULV sprayer, respectively. GA, should be sprayed two times, the first when 15-20% of the tillers have started heading and the second 2 days after the first spraying or when 35-40% of the panicles of the seed parent have emerged. If the male line is no higher than the female line, it is advisable to give one extra dose of GA3 to the R line to increase its plant height. GA3 should preferably be sprayed in the evening (15.00-18.00 hours) and on sunny days.

- *Supplementary pollination:* Rice is basically a self-pollinated crop. At the time of flowering, supplementary pollination is done by shaking the pollen parents with either a rope or bamboo sticks. This operation has to be done 3-4 times daily at peak anthesis and should be continued for during flowering.for 10-12 days. With improved management of parents and effective supplementary pollination, hybrid seed yield can be increased significantly.

Fig. 9. Practice of supplementary pollination

Roguing: Roguing of off-types and voluntary plants at several stages is essential for obtaining physical and genetic purity. Roguing is an important operation in a hybrid seed production. Rogues can be identified as those that are out of their row and early in booting, and based on other morphological characters. Before flowering, roguing is essential, especially in experimental hybrid seed production plots. Roguing at flowering is also extremely important as pollen from off-type plants can cause irreparable damage through cross pollination with male sterile plants. Undesirable plants include off-types (eg. maintainer or B-type plants in A line). B line plants with similar morphological features to A line plants can be identified by their plumpy anthers, completely exerted panicle and 3-4 days earlier flowering compared to the A line. These plants in the A line row must be uprooted as soon as they are identified. Roguing at an appropriate time (flowering initiation) ensures good seed quality. Roguing is normally done from the vegetative to the flowering stage.

Harvesting and threshing: Extreme care should be taken while harvesting and threshing the hybrid rice plots. Just before harvesting, check female rows for left-over pollen shedders (i.e. maintainer plants), off-types and male parent plants (restorers). The male rows should be harvested first and all panicles carefully removed. The female rows which are ready for harvest should be carefully rechecked for left-over plants or panicles of male (restorer) parents. Female plants should then be harvested and threshed on a separate threshing floor. The seed should be dried, processed , bagged and properly labeled.. Before threshing, the threshing machine must be properly cleaned to avoid seed admixture. The bags need to have labels inside and outside, listing all necessary details, such as lot identification or lot number, date of harvest and quantity of lot.

Seed arrivals and processing: As soon as seed arrives at the seed processing plant from seed production areas, lot-wise seed weighing of every bag should be recorded and lot-wise representative samples drawn. These samples should be used for laboratory testing of germination percentage, moisture percentage, physical purity and seed viability. Based on the test results, the seed from good lots should be processed in the seed conditioning plant.

Seed production of A line

For nucleus seed production of A line, the originating breeder hand-crosses true-to-type A/B plants.

For breeder seed production of A line, the breeder plants A/B rows in a ratio of 2 female: 2 male rows with a minimum isolation distance of 200 m. Timely roguing of the plot is carried out at various crop growth stages from vegetative to harvesting.

For foundation seed production of A line, the process is supervised by a foundation seed expert. The seedlings are planted in a ratio of 4 female: 2 male rows with a minimum isolation distance of 150 m. There are normally two sowings of the male line, sowing the B line 3 and 6 days after the female line.

Seed production of B and R lines: Nucleus, breeder and foundation seed of B and R lines are multiplied adopting practices similar to those used for conventional varieties. However, care must be taken not to harvest B and R line seed from A/B or A/R seed production plots. Separate multiplication of B and R line plots helps maintain purity and produce quality seed.

Hybrid Rice Seed Production

Adaptation of hybrid rice technologies in the country helps to solve food security or rice self-sufficiency by increasing the yield of rice crop for farmers. In 2000 when the hybrid rice was introduced in the country all the hybrids were japonica type, susceptible to the abiotic (water lodging saline, drought) and biotic stresses to the crop and inferior in the quality but now according to the present status of the hybrid rice, the situation is much better. All the hybrids are indica type which are resistant to some extent diseases and insect pest. Sterility to high temperature was also serious issue of the hybrids imported in the country but late hybrids are tolerant to the high temperature.

Quality of seed plays fundamental role in high and sustained agricultural production. Though, seed is small, it embodies diversity and freedom to stay alive. The high yielding variety (HYV) of seeds of Green Revolution reached Pakistan's agriculture sector in 1960s. Pakistani farmers continued their seed sharing and exchanging practices. For instance, in case of rice, more than 80 percent seed grown is farmers' own seed. The formal seed sector (public and private) contributes less than 20 percent. As Multi-National Companies (MNCs) dominate the formal seed sector they have been trying to mutate seed situation in Pakistan to make the farmers dependent on them. Hybrid seed was introduced in this regard. This seed grows well but cannot be reproduced. MNCs are also trying to produce hybrid seeds rice.

Table 5. Name of seed companies registered for hybrid rice

S. No.	**Name of seed company with address**
1.	Jullundar Seed Pvt., Ltd, 1-Km Bahawalnagar Road, Arifwala District Pakpatan
2.	ICI-Pakistan Limited
3.	M/S Roghay Sons, B212 Block C North Nazimabad, Karachi
4.	Auriga Seed Corporation, 33 Km Multan Road, Lahore.
5.	Grace Enterprises, Office No. 34 Block E, Opposite Market Committee office Karachi.
6.	Emkay Seeds Pvt, Ltd. Farooq Abad District Sheikhupura.
7.	Kanzo Quality Seeds, 286-H-2 Johar Town, Lahore.
8.	Guard Agricultural Research and Services (Pvt), Ltd. 8th Km Raiwind Road, Lahore.
9.	Hi- Sell Seed Industry, Multan
10.	Mehar Muhammad Din & Sons, Pakistan
11.	Dhoom Seed Corporation, Bahawalnagar Road, Arifwala, Distt. Pakpattan.
12.	Bayer Pakistan Pvt., Ltd., Plot No.23, sector No.22, Korangi Industrial Area, Karachi.
13.	Opal Seed Corporation Pakistan
14.	Arif Traders, Larkana
15.	Wingrow Seed Company 6-B EDEN Value Homes, Main Multan Road, Lahore.
16.	FMC 99E-1 Ghalib Road, Gulberg-III, Lahore.
17.	Syngenta Pakistan, Limited
18.	Hunza Seed Corporation PVT Ltd. 112-Y Commercial area DHA Lahore Cant.
19.	Weal-AG corporation, Suit No1, 3rd floor Shan Arcade new Garden Town, Lahore.
20.	Mount-AG-biotech, Suit No1, 3rd floor Shan Arcade new Garden Town, Lahore.
21.	Vertex Seed Corporation, Chak No. 545-GB Tehsil Thandlian Wala, Faisalabad.
22.	Ch. Khair Din and Sons, Sheikhupura Road, Gujranwala.

Impact of hybrid rice adoption

Hybrid Rice has a distinct yield advantage over the conventional varieties. Its production is higher due to higher cost of seed and high dose of chemical fertilizer. Although the market price of hybrid rice is lower due to poor grain quality yet the profit of hybrid rice was higher than the conventional varieties due to higher yield of hybrid rice. The hybrid rice gave more profit in zone IV as compared to zone III due to favorable climatic conditions. The cost of the hybrid seed is relatively higher than ordinary seed of rice, which discourages the small farmers to take advantage of new technology. Rice growers have to depend on seed companies to buy hybrid seed in every season. Majority of the rice growers were found unwilling to adopt hybrid seed due to its failure. The seed companies are importing hybrid seed from China and there are wide difference in soil and climatic conditions between Pakistan and China. It is suggested that the Provincial Agriculture Department should test such varieties on their research farms to check whether the imported seed is suitable in our soil and climatic conditions. The Agriculture Department should also certify such varieties before cultivation.

3. Constraints and gaps in hybrid rice development

3.1. Social and economic constraints

Hybrid rice technology has not been popularized among the farmers in spite of 20-25% higher yield than the existing rice varieties. It may be due to inconsistent performance of hybrids on farmers' field, lack of understanding of agronomic management, poor grain quality, high cost of hybrid rice seed (Rs. 800/- per kg against Rs. 65/- per Kg of inbred variety) and habits of farmers' using their own seed. Actual farmer's yield of rice in the country is much lower than potential yield under farm circumstances (Figure 6). The yield gap is due to several biological and socio-economic constraints in the adoption of technology.

So far no hybrids have been approved by seed council and only have been recommended by VEC for cultivation. Presently the restriction of hybrid rice cultivation in Basmati area is only due to better profit in extra-long grain (Super Basmati and Basmati 515) cultivation.

3.2. Capability constraints

In case of hybrid rice development in the country, nearly ten scientists are already working to develop disease and insect pest-resistant high-yielding rice hybrids through the three-line system at Rice Research Institute, Kala Shah Kaku, Lahore, Pakistan. However, lack of funds, training and good genetic materials are major hindrances to hybrid development. However, fully equipped labs and vast research area are available for the research and development of hybrid rice technology at RRI, KSK.

3.3 Environmental constraints

Most of the imported rice hybrids are bred in China which are developed for temperate environment. These hybrids are not tolerant to our local environmental conditions and are not tolerant to heat causing high sterility. Most of the imported rice hybrids are the carrier of rice diseases, especially bacterial leaf blight, blast and false smut. All these factors shake the farmer's confidence over hybrid rice cultivation. The performance of these hybrids was not consistent during the past years. Even in most favorable years, the yields of imported hybrids were not better than conventional varieties i.e. KSK 434, KSK 133, and KS 282 (Yield potential up to 110 t/ha). These hybrids have the average yield of 8-10 t/ha. That is why the yield per unit area has not increased. In Punjab, areas under hybrids are expanding at the cost of Basmati area but low paddy price due to unacceptable grain shape inferior cooking quality, high bursting percentage and low head rice recovery has restricted cultivation of rice hybrids.

3.4 Policy constraints

The usual socio-economic constraints (farmers financial problem) encountering the growers include small and fragmented holdings, cumbersome process to obtain credit, interruption in the supply of irrigation water and electricity for tube-wells, non-availability of labor at peak times of transplanting, harvesting and threshing and non-availability of right quality inputs at right time. All of these factors are hampering the rice production in general and farmers' income.

The approval and implementation of Standing Operating Procedures for hybrid rice is needed to be finalized by the Government. Cultivation in non-Basmati zone in Punjab and lower Sindh are needed to be focused. To popularize the hybrids in Pakistan, there is need to properly plan effective production technology and transfer of hybrid technology to the farmers at Government level. This may be achieved by establishing effective mechanism of research, hybrid seed production and technology transfer system.

The Pakistan Government should provide critical support to the hybrid rice programme through funding and policies. Government policies, standards, and investments in human resources and necessary infrastructure will make hybrid rice attractive, profitable, and sustainable. To ensure the continued success of the hybrid rice program, further advances in biotechnology will be crucial for overcoming the challenges from increasing biotic or abiotic pressure, including the ever decreasing water supply and more severe drought from global warming.

4. Lessons learnt

Most of the imported hybrids do not perform well, due to poor quality and susceptibility to insect pests and disease in Pakistan climate. The farmers are also unaware of production technologies of these hybrids. It has been observed due to lack of training of rice scientists regarding new techniques of hybrid rice development. Yields of developed coarse hybrids plateaued. Basmati rice is more preferred in Pakistan and basmati hybrids are difficult to develop due to narrow genetic base. Following recommendations may improve hybrid rice production and adoption in Pakistan.

- A joint venture with Europe, IRRI and China for technology transfer and training of breeders related to hybrid rice;

- To import germplasm form China and IRRI with higher yield and tolerant to biotic and abiotic stresses;

- Strengthening of infra-structure for genomic studies of Basmati rice hybrids;

- A strict quality control regime at every level of production; and

- Awareness campaign among various stakeholders.

5. Opportunities for hybrid rice development

During the past 14 years considerable progress has been made in the development and use of this technology in the country. Achieving self-sufficiency in rice production and maintaining price stability are the important political objectives in the country because of the importance of this crop in providing national food security and generating employment and income for the poor. The future poses more challenging and ambitious tasks. This technology is useful not only due to its higher yield potential but also because of its capability to increase rural employment opportunities through a hybrid seed industry. A survey report data collected from different areas of Pakistan revealed that rice hybrids are giving 20-50 percent more yield than conventional rice varieties, despite all the social as well as policy constraints with hybrid rice development and cultivation. A study in the year 2008-09 revealed increased profit of growing rice hybrids as compared to inbred varieties (Table 6).

Table 6. Economic profit of hybrid rice and other varieties

Location	Hybrid	IRRI-6
1	30 979	17 927
2	59 923	33 337
3	26 284	12 985
Average	36 647	21 138

6. Key strategies and policy option to promote HR development in Pakistan

To promote hybrid rice development in the country, the Government is focusing to provide financial support in the form of projects to enhance the research activities. Training of the hybrid rice breeders in much needed on priority basis. Availability of potential genetic material is also an option to increase the hybrid rice research and development phase. The Government is also encouraging the private sector to promote the imported rice hybrids suited to local conditions by simplified evaluating multi-location yield trials for two years and final recommendation by the VEC.

Key strategies and policy options to 2020 -2030 are:

- The cost of hybrid seed is relatively higher that ordinary conventional varieties, which discourages the small farmers to take advantage of this new technology. Thus, it is of utmost necessity to make necessary amendments to lower the cost of production of rice hybrids.

- Public institutions and private seed companies should be facilitated and encouraged to develop the genetic material of three line and two line super hybrids under local conditions.

- Import of novel genetic material from China and IRRI should be funded to run hybrid breeding program at Rice Research Institutes successfully.

- Moreover, the success of hybrid rice cultivation depends on the success of the hybrid rice seed production program which enables seed producers to produce high quality seed. Therefore, technology dissemination and public awareness through effective extension is pre-requisite for gaining better harvest from rice hybrids.

- Hybrid rice seed production requires specialized techniques, therefore, only highly trained and technically skilled breeders can perform the seed production job locally which will be economical. For this purpose training of rice breeders especially in the field of hybrid seed production technology is needed.

- Hybrid rice technology has not been popularized among the farmers in spite of 20-25 percent higher yield than the existing rice varieties as observed in National Yield trials all over rice growing areas of the country. It may be due to inconsistent performance of hybrids on farmers' field, lack of understanding of agronomic management, poor grain quality, high cost of hybrid rice seed (Rs. 800/- per kg against Rs. 65/- per Kg of local inbred variety) and habits of farmers' using their own seed. Amending these issues can ensure more adoption and cultivation of rice hybrids with effective results.

- More rice hybrids having better yielding ability should be approved by the Seed Council of Pakistan and VEC for cultivation.

- Presently restriction of hybrid rice cultivation in basmati area is only due to better profit in extra-long grain (Super Basmati and Basmati 515) cultivation. Therefore, funding, adequate training and expertise should be provided for development of high yielding and disease, insect pest- resistant basmati hybrids.

- Upgradation and accreditation of DNA labs especially at Rice Research Institute, KSK may facilitate rice breeders to select desirable traits through marker-assisted selection.

- Costs of various inputs especially fertilizer, diesel, and power tariff for tube-wells have substantially increased during the last decade. Additionally, high cost of hybrids increases much the cost of production. Giving subsidies to rice hybrid-producing government as well as private institutes may reduce hybrid prices.

- Increasing susceptibility of rice genotypes for abiotic stresses (drought, salinity, heat, flood and cold) and biotic stresses (insect pests and diseases) may be overcome by incorporating resistant genes from available germplasm from International Rice Research Institute, the Philippines and China, and introgression of these genes into local rice lines to develop hybrids.

- Government of Pakistan must review the unchecked import and cultivation of hybrid rice in the country.

- The yield gap can also be reduced by the approval and implementation of Standing Operating Procedures (SOP'S) for hybrid rice and to restrict its cultivation in non-Basmati zone in Punjab and lower Sindh.

Annexure 1

LIST OF RICE HYBRIDS RECOMMENDED BY VARIETY EVALUATION COMMITTEE (VEC)

No.	Name of Hybrid	Sr. No	Name of Hybrid	Sr. No	Name of Hybrid
1	GNY-50(Guard-50)	31	HR-40(Pukhraj)	61	JS King
2	GNY-53(Guard-53)	32	HS-98	62	JS-777
3	Guard-402	33	Sitara-401	63	GIR-2
4	Guard-403	34	Sitara-402	64	GIR-3
5	Guard-LP-2	35	HR-14(Pukhraj- ii)	65	Roghay 101
6	GuardLP-3	36	CKD-775	66	Y-26
7	Dagha-1	37	CMS-202	67	Grace-1
8	Arize-403	38	MKH-410	68	Winner-06
9	Arize XL94017	39	Maharani	69	Guard LP-18
10	Arize TEJ	40	Prince	70	Sultan
11	Arize H 64	41	Shahanshah	71	Arize 6444 Gold
12	EMKAY H 401	42	Shahanshah 1	72	Red Star
13	CKD-776(Komal)	43	ZY-688	73	NA-1
14	AAS-501	44	ZY-018	74	EN-HY-633
15	S-444	45	TFA-121(Diamond)	75	EN-HY-618
16	HJ-19(Leader)	46	Sc-123	76	FMC-1
17	CJU05(Advantage	47	Global-1	77	NK-5251
18	RA-203	48	Pearl-1	78	Hunza 011
19	RA-204	49	Pride-1	79	Hunza 012
20	PHB-71	50	RCA Rice-202(RS-2)	80	AG-234
21	HS-413	51	RH-257(TAJ-257)	81	SH-123
22	HS-777	52	Winner-05	82	CKD-1355
23	HS-9022(HS-90)	53	Winner-08	83	CKD-1356
24	HS-9393	54	Arize swift	84	Roshan
25	Bravo-958	55	Bravo-9	85	Salaar
26	CMS-303	56	Shahanshah ii		
27	Maharani-ii(PH-5)	57	PARAS(HEV-188		
28	Mehran(HEV-155)	58	Orince-31		
29	Prince-130	59	RA-208		
30	RA-205	60	MKH-411		

Hybrid Rice in the Philippines

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1. Overview of Rice Production in the Philippines

The Philippine rice industry, being among the biggest contributors to the domestic output in agriculture, spans wide across the different levels within the national economy. It has contributed 16.53 percent (2006), 16.76 percent (2007), 16.14 percent (2009), 17.54 percent (2010) and 18.20 percent (2011) to the gross output in agriculture. Land area harvested to rice considering a ten-year period from 2004 to 2013 has gone from 4.07 million ha (2005) to 4.75 million ha (2013) with an annual average of 4.39 million ha. Despite negative increment values for some years, the average annual increase is 1.60 percent. Demonstrating the same growth behavior as that of rice cultivation hectarage, volume of rice produced domestically has increased from 14.50 million mt (2004) to 18.44 million mt (2013), averaging at 16.27 million mt, and with an average annual growth rate of 2.78 percent. The national grain yield, considering data on hectarage and volume of production for the same ten-year period ranged from 3.51 t ha^{-1} (2004) to 3.89 t ha^{-1} (2013), averaging at 3.70 t ha^{-1}, and with an annual increment of 1.16% (BAS).

Considering data covering 2001 to 2010, the value of rice production ranged from 105.32 million pesos (2001) to 238.14 million pesos (2009) averaging at 167.62 million pesos, and with an annual growth rate of 9.53 percent. Using the same ten-year period, supply and utilization of rice as a commodity is presented in thousand metric tons. Year to year, gross supply was 13 648.50, with lowest in 2001 (11 446.00) and highest in 2008 (15 601.00). Beginning stocks (17 percent), production (72 percent) and imports (12 percent) make up the annual figures for gross supply. The average increment for the three components, 2.58 percent for beginning stocks, 2.27 percent for production and 17.65 percent for imports, contribute to the annual increase in supply by 3.34 percent. Behavior for utilization follows that of supply, where there is a positive average increment value year to year. Of the gross supply, 2 percent is utilized as seeds, 5 percent goes to feeds and waste, 3 percent undergoes processing, 73 percent is the net portion for food, and 18 percent lasts as ending stocks. The average annual increase in utilization for each component is at 0.84 percent for seeds, 2.26 percent for feeds and waste, 2.28 percent for processing, 3.17 percent for food, and 5.40 percent for ending stocks. Per capita consumption (kg/year) for 2001 to 2010 ranged from 103.77 (2001) to 128.10 (2008), averaged at 116.15, with an annual growth rate of 1.23 percent (BAS).

The national government has never been more aggressive in its resolve to afford the country self-sufficiency in supply of food staples, with rice being chief among them. With the strengthened efforts and a multi-disciplinary and integrated approach, it is not too distant that such goal would be attained at a sooner time. A clear vision of the challenges at hand and a solid strategy in tackling them would be very instrumental.

Table 1. Figures describing the general area harvested, volume of production and yield level of the Philippine rice industry covering a period of ten years

Components	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Volume of production (million mt)	14.50	14.60	15.33	16.24	16.82	16.27	15.77	16.68	18.03	18.44
Area harvested (million ha)	4.13	4.07	4.16	4.27	4.46	4.53	4.35	4.54	4.69	4.75
Average grain yield (t ha-1)	3.51	3.59	3.68	3.80	3.77	3.59	3.62	3.68	3.84	3.89
Increment (%)	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Volume of production		0.73	4.96	5.96	3.54	-3.27	-3.04	5.78	8.08	2.26
Area harvested		-1.36	2.20	2.72	4.38	1.62	-3.93	4.19	3.38	1.20
Average grain yield		2.12	2.70	3.16	-0.80	-4.81	0.93	1.53	4.55	1.05
Components	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Value of production (million pesos)	105.32	116.52	117.99	136.99	154.06	159.24	182.05	234.07	238.14	231.84
Per capita consumption (kg/year)	103.77	108.03	107.02	116.09	118.8	118.7	126.24	128.1	119.92	114.81
Increment (%)	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Value of production		10.63	1.26	16.11	12.46	3.36	14.32	28.57	1.74	-2.64
Per capita consumption		4.11	-0.93	8.48	2.33	-0.08	6.35	1.47	-6.39	-4.26

2. Progress in hybrid rice development in the Philippines

2.1. History of hybrid rice development

The advent of hybrid rice technology in the Philippines traces back to as early as the 1970s, when shortly after the technology was developed in China, the International Rice Research Institute (IRRI) started looking into the prospects of embedding the hybrid rice technology into the agricultural system in the country. The next decade witnessed more progress as introductions of hybrid rice combinations from China came in and were spread in areas such as Central Luzon, Cagayan Valley, Cordillera Autonomous Region, and Bicol Region, coupled with technical demonstration. In 1989, the country entered into collaborations with various agricultural universities in China for germplasm exchange and development, and sharing of technical information (Gaspar et al., 2007).

In the 1990s, the significant milestones included development of hybrid parent lines adapted to tropical conditions and with a degree of resistance to pest and diseases out of Chinese germplasm, and the development of PSB Rc26H also known as Magat in 1994, both by IRRI. PhilRice, with the assistance of IRRI, also began to explore the principles and technicalities of the technology, and developed and evaluated its first testcrosses. The 1990s saw heavy and large scale testing of tandem technologies and field evaluation of hybrid rice varieties, with the participation of the private sector as well. The Philippine Seed Board in 1997 released PSB Rc72H, also known as Mestizo. This variety was developed by IRRI, tested and promoted in collaboration with the Philippine Rice Research Institute (PhilRice), and is among the hybrid rice varieties with the most significant impacts in the hybrid rice technology history in the Philippines (Gaspar et al., 2007).

The success experienced by the country in its early stages of adopting hybrid rice technology prompted national and international agencies alike to support such development and promote the technology even to the rest of the Asian community. Recognizing the great potential it would contribute to the national agenda of food security, the national government included the hybrid rice technology as a key component in a development plan. In 1998, the hybrid rice technology was officially launched being a national agricultural development strategy to augment domestic rice production. Since then, hybrid rice has always been a major component of national food security programs of various administrative regimes. It paved the way for large-scale importation of F1 seeds and expansive seed production activities done by farmers. One great milestone in the timeline of hybrid rice technology in the country was the forging of the hybrid rice commercialization program (HRCP). Among its provisions was to mandate PhilRice to step up its activities in developing the hybrid rice technology tailor-fit to the country`s conditions and take the role as the lead implementing agency of the HRCP under the Office of the President (Gaspar et al, 2007).

To date, despite the recurring challenges, the national scenario of hybrid rice technology implementation in the Philippines is still getting more interesting and promising with the involvement of more agencies, government and non-government alike, and the opening up of more research avenues to respond to an ever-dynamic, multi-faceted case.

2.2 Progress in hybrid rice research

The sustainability of the rice industry at a global scale is challenged by decreasing land and water resources for rice cultivation alongside a rapidly growing population, posing the need to ramp up domestic production in the years to come. The scenario in the Philippines is no different, perhaps even more challenging as aggravated by more frequent occurrence of natural calamities. Despite such case, the national government has always remained strong in its resolve for self-sufficiency in rice supply and eyes hybrid rice technology as one pillar program towards its attainment. Hybrid rice has demonstrated 15-20 percent yield advantage over conventionally bred varieties. Taking into account the successes of hybrid rice technology adoption and development in the Philippines, there is still a significant need to further strengthen current research thrusts and discover new avenues to complement to the national agenda at hand.

The Philippine Rice Research Institute (PhilRice) with its Central Experiment Station and branch stations strategically located across the country spearheads hybrid rice research, development, and technology dissemination. The broad subjects around which hybrid rice research and development revolves include parent line development and improvement, development of superior hybrids, performance tests, seed production, resilience to biotic and abiotic stress, line and variety characterization, and grain quality evaluation. All components take their niches along the variety development pipeline to come up with ready-to-use technology for the ultimate clientele–the farmers.

Superior parent lines play a great role in discovering superior crosses. Lines that are readily usable in hybrid rice development go through development and improvement. The whole process starts with prospecting. Lines from various inbred breeding programs for the irrigated-lowland ecosystem are prospected to be parents through line-by-tester crossing. The assembled potential parents are crossed to standard testers which are CMS lines. The resulting F1 are then evaluated with respect to spikelet fertility. Male parents of F1 offspring that manifest normal spikelet fertility are forwarded to restorer line development. On the other hand, male parents with F1 offspring that manifest high sterility are forwarded to maintainer line development. Both restorers and maintainers are developed through single and multiple crosses, and selection through single seed descent and modified bulk pedigree method. Corresponding CMS lines of new maintainer lines are developed through backcrossing.

Experimental hybrids are developed by generating testcrosses between restorers, both known and prospected, and CMS lines. F1 development covers both CMS-based and TGMS-based hybrids. Specifically this study aims at identifying superior F1 combinations, determining the combining ability of newly developed parent lines, and developing a cross between cytoplasmic male sterile (CMS) lines, and IL, DH, OPM and TJ lines from the inbred breeding program. Generated hybrids are initially evaluated for standard heterosis and heterobeltiosis prior to getting subjected to field performance testing per se.

Field performances of promising hybrids are evaluated in a series of tests at varied scales. This study aims to evaluate the performance of promising hybrids in different nurseries for grain yield, and other important morpho-agronomic traits, identify hybrids with wide range of adaptation and stable performance across environments and identify location/season specific hybrids. Test hybrids are evaluated in the observational nursery for standard heterosis and heterobeltiosis using augmented design and in the preliminary yield trial for standard heterosis using larger plots arranged in randomized complete blocks, both done at a single-site and for one season each. The multi-location yield trials aim at evaluating the performance of test hybrids at PhilRice branch stations. Entries are planted in larger plots and tested for two seasons. Prior to commercial release, promising hybrids are evaluated in wider scales in multiple sites across the Philippines including branch stations. Entries are evaluated for grain yield potential for two wet and two dry seasons. Simultaneous with grain yield evaluation, merits on reaction to biotic and abiotic stresses and grain quality are also assessed. Data gathered from NCT setups become basis in deliberating for the commercial release of a variety.

Recognizing the importance of an ample supply of planting materials for use in various studies, studies on seed production and enhancing seed production capacities are conducted.

These studies are espoused to the seed production operations which primarily aim to produce sufficient physically and genetically pure hybrid parent lines, and experimental and newly released hybrids for various yield trials and demonstration nurseries, and evaluate and monitor important traits of the CMS, maintainer and reestorer lines of each hybrid. The activities incude multiplication of CMS lines at various quality levels, seed increase of maintainer and restorer lines and production of F1 seeds. As part of quality control measures, the produce are subjected to inspection, testing and certification by both in-house and external agencies at the production and post-harvest stages. As part of standard operating procedures, grow-out tests are also conducted to assess the quality of seeds produced. Aside from being utilized internally, a certain quantity of produced seeds go to branch stations and various cooperators for adaptability tests and technology demonstration.

Given the estabished superiority of hybrids over inbreds in terms grain yield potential, equipping them with more advantage points in terms of resilience to biotic and abiotic stress can make the package more complete. Studies on screening for biotic and abiotic stress reactions, and incorporation of resistance genes with the use of markers primarily aim at evaluating published and functional markers of *Xa23* gene for applicability in marker-assisted selection (MAS), incorporating the *Xa23* gene in the elite hybrid parent lines by MAS, incorporating bacterial blight resistance gene to popular but susceptible public hybrid parent lines, assessing the recurrent parent genome recovery, morpho-agronomic traits and reaction to bacterial blight of improved hybrid parent lines and screening of hybrids and parent lines for tolerance to various abiotic stresses.

The success of hybrid rice breeding depends to a great extent on the quality and diversity of elite lines used as parents in developing new hybrids. Techniques such as *in vitro mutagenesis* (IVM) and *in vitro culture* (IVC) are essential in discovering promising new hybrid parent lines. Mutation breeding can be instrumental in obtaining new cultivars and enhanced variants of existing cultivars and broadening the genetic base of rice breeding materials. This study is conducted to induce mutation in hybrid parent lines using sodium azide/ethyl methane sulfonate (EMS) and gamma irradiation, to utilize in-vitro culture and in-vitro mutagenesis in hybrid parent line development and to generate mutant hybrid parent lines with drought tolerance. The success achieved with mutation breeding techniques, especially for the improvement of the major cereals of the world like rice, would indicate that it is no longer a controversial breeding method and should be considered as an important technique to complement with conventional breeding technology.

The existing modality of breeding hybrid rice varieties is being hampered by the high cost in the segments of F1 development and performance testing where all possible crosses have yet to be generated prior to getting them evaluated for grain yield potential. Handling a large assembly of parents and hybrids is relatively tedious and expensive. Using genetic parameter estimation is one alternate method to obtain grain yield potential estimates without the actual field observation. Among the hybrid performance prediction methods, best linear unbiased prediction (BLUP) which combines field testing of related hybrids and obtaining pedigree information or genetic relatedness, holds great promise (Charcosset et al., 1998). According to Henderson (1986), BLUP is the most appropriate method to predict genetic parameters in hybrids as supported by Bernardo (1994, 1995, 1996a, 1996b). Yield prediction of hybrid performance is a result of good combining ability. The combining ability of the different lines has a major importance in hybrid breeding since it provides information for parent selection and the nature and magnitude of gene action involved. The knowledge of genetic structure and mode of inheritance of different characters helps breeders to employ the suitable breeding methodology for their improvement (Kiani et al., 2007). This study aims to estimate kinship among parent lines using markers, determine the yield performance of tested and untested single cross hybrids through best linear unbiased prediction, measure the general and specific combining ability of hybrid parent lines for yield traits and identify the best performing hybrids and parents through BLUP and combining ability.

2.3 Status of hybrid rice production

The behavior of the figures that describe the status of hybrid rice cultivation and production in the Philippines covering the period 2001 to 2012 resembles that of the country`s general rice industry scenario. Data show that area harvested to rice started very small at 5,000 thousand hectares in 2001 and spiked to 369,000 in 2005, the highest figure to date (DA-MID). The following years saw a downhill pattern despite some recoveries in 2010 and 2012, the only years with positive increment over respective precedent years after 2005. Domestic production of hybrid rice is expressed in thousand metric tons for years considering the same time period. Values ranged from 29 and spiked in 2005 for 2 214, averaging at 1 083.92. The spiking of volume in 2005 could be attributed to the simultaneous peaking of area harvested during the same year. The highest increment occurred in 2002 by about 483 percent with an annual increment average of 75.91 percent.

Recorded data for grain yield potential (t ha^{-1}) of hybrid rice varieties are available for both the dry and wet seasons, as well as that of inbreds. Across years, hybrids demonstrated average grain yield potential of 6.31 for the DS and 5.74 for the WS (DA-MID). The range of values for the DS was from 5.90 (2006) to 6.85 (2002) with an annual increment of 0.02 percent, and from 5.44 (2001) to 6.14 (2012) for the WS, with an annual increment of 1.24 percent. Comparing data for across season grain yield means between hybrids and inbreds, hybrids manifested its superiority by about 52 percent across years for an advantage of 2.02 t ha^{-1}. Average grain yield (t ha^{-1}) for hybrids across seasons (2001-2012) ranged from 5.44 (2001) to 6.45 (2012), averaging at 5.99, while that of irrigated lowland inbreds ranged from 3.59 (2001) to 4.24 (2012), averaging at 3.97.

To date, a total of 53 hybrid rice varieties had been released by the National Seed Industry Council (previously the Philippine Seed Board) for commercial cultivation, bred solely or collaboratively by government and non-government agencies alike (PhilRice). The most number of varieties released was in 2011 (26 percent), followed by 2009 and 2013 (15 percent), then 2010 (9 percent), then 2007 and 2008 (8 percent), 2004 (6 percent), 2002 (4 percent), and lastly by 1994, 1997, 1998 and 2012 (2 percent). National field performance testing data show that the average grain yield recorded among the hybrids released ranged from 4 to 7 t ha^{-1} with entry distribution of 2 percent for 4-tonners, 26 percent for 5-tonners, 60 percent for 6-tonners and 11 percent for 7-tonners. Maximum grain yield on the other hand ranged from 7 to 12 t ha^{-1} with distribution pattern of 6 percent for ≥7 t ha^{-1}, 15 percent for ≥8 t ha^{-1}, 21 percent for ≥9 t ha^{-1}, 40 percent for ≥10 t ha^{-1}, 15 percent for ≥11 t ha^{-1} and 4 percent for ≥12 t ha^{-1}.

As with developing hybrid rice varieties, PhilRice has also taken the lead in disseminating technologies and technical know-how in hybrid rice cultivation and even seed production. The institute hosts trainings for farmers and seed growers that essentially equip them on hybrid rice cultivation for efficient production, enhanced seed production capacities especially with F1 seed production, and on specialized and technical matters.

Recognizing its soundness over conventional methods, integrated approach towards crop management has been infused into the technology as well. As with inbreds, hybrid rice cultivation follow a broad integrated crop management protocol developed by PhilRice- the Palay Check System© for irrigated lowland rice- an integrated crop management system which emphasizes an eight-key practice approach to successful rice cultivation. The key approaches include (i) using quality planting materials, (ii) proper land preparation leaving no high and low spots after final leveling, (iii and iv) synchronous planting after a fallow period using sufficient amount of healthy seedlings, (v) integrated nutrient management, providing ample nutrients especially during early panicle initiation to flowering, (vi) providing just the right amount of water, (vii) avoidance of significant yield loss due to pests and (viii) proper timing for harvest and post-harvest operations (PhilRice 2007).

Location-specific recommendations of tandem technologies are also in place for cultivation components such as establishment, nutrient management, pest management and water management.

Table 2. Figures describing the hybrid rice production scenario in the Philippines in terms of hectareage (thousand hectares), volume of production (thousand metric tons) and yield levels (tons per hectare) over inbred varieties for the irrigated-lowland ecosystem.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Area harvested	5.00	28.00	77.00	204.00	369.00	312.00	239.00	223.00	193.00	204.00	144.00	155.00
Grain yield												
Hybrids (DS)		6.85	6.06	5.98	6.18	5.90	6.23	6.15	6.44	6.61	6.23	6.75
Hybrids (WS)	5.44	5.78	5.93	5.61	5.83	5.81	5.93	5.93	5.50	5.57	5.45	6.14
Inbreds (Season average)	3.59	3.68	3.77	3.92	4.02	4.10	4.21	4.14	3.95	3.99	4.02	4.24
Volume of production	29.00	169.00	462.00	1,173.00	2,214.00	1,830.00	1,463.00	1,349.00	1,179.00	1,265.00	855.00	1,019.00
Increment (%)												
Area harvested		460.00	175.00	164.94	80.88	-15.45	-23.40	-6.69	-13.45	5.70	-29.41	7.64
Grain yield												
Hybrids (DS)			-11.53	-1.32	3.34	-4.53	5.59	-1.28	4.72	2.64	-5.75	8.35
Hybrids (WS)		6.25	2.60	-5.40	3.92	-0.34	2.07	0.00	-7.25	1.27	-2.15	12.66
Inbreds (Season average)		2.51	2.45	3.98	2.55	1.99	2.68	-1.66	-4.59	1.01	0.75	5.47
Volume of production		482.76	173.37	153.90	88.75	-17.34	-20.05	-7.79	-12.60	7.29	-32.41	19.18

Table 3. Morpho-agronomic characteristics of NSIC-released hybrid rice varieties in the Philippines with average grain yield of ≥6.5 t ha^{-1}

Entry	Year released	Average Yield (t ha^{-1})	Maximum Yield (t ha^{-1})	Maturity (DAS)	Height (cm)	Tillers
Mestiso 24	2010	7.3	10.3	108	103	14
Mestiso 30	2011	7.2	11.4	106	103	14
Mestiso 31	2011	7.1	10.3	108	112	14
Mestiso 12	2008	7.1	8.9	112	110	12
Mestiso 29	2011	7.0	11.2	110	104	14
Mestiso 26	2010	7.0	10.7	110	110	14
Mestiso 33	2011	6.8	9.8	108	105	15
Mestiso 36	2011	6.7	9.8	106	103	15
Mestiso 25	2010	6.7	10.6	108	103	14
Mestiso 19	2009	6.7	10.7	110	108	13
Mestiso 7	2006	6.7	10.6	107	108	13
Mestiso 17	2009	6.6	9.7	105	100	14
Mestiso 41	2011	6.5	12.7	115	113	12
Mestiso 37	2011	6.5	10.0	109	107	13
Mestiso 42	2011	6.5	9.8	109	117	12
Mestiso 32	2011	6.5	8.9	109	109	14
Mestiso 27	2010	6.5	9.8	115	119	13
Mestiso 18	2009	6.5	10.6	111	112	13
Mestiso 13	2008	6.5	8.3	113	112	12
Mestiso 10	2007	6.5	10.6	110	107	13
Mestiso 11	2007	6.5	10.5	113	115	14

2.4 Hybrid rice seed

Data on commercial F1 seed production for 2012 and 2013 involve six hybrids (three public-bred and three private-bred). In 2012, a total land area of 1,500 hectares was used for hybrid rice F1 seed production resulting to the production of 107,126 bags (18 kg per bag) of certified F1 seeds. Area utilized in 2013 declined by 23 percent (1,148.81 ha), resulting in the production of 65,002 bags of certified F1 seeds. Data on hybrid rice seed yield for 2002, 2003, 2004 and 2012 suggest that seed production capacity has increased to a certain extent from levels of around 0.7 t ha^{-1} (2002-2004) to >1 t ha^{-1} in 2012 (Hidalgo, et al., 2003; Gonzales, et al., 2007). Such values refer to seed production done by seed growers and public institutions alike.

Seed certification is handled by the National Seed Quality Control Services- the seed quality regulating arm of the Bureau of Plant Industry. The certification procedures are done both on-field and at post-harvest. Entries that pass the standards are then issued certification. F1 seeds that pass quality standards are tagged as Certified Seeds. Parent lines on the other hand, like inbreds, get into a four-tiered classification namely Breeder, Foundation, Registered and Certified seeds, depending on field inspection and laboratory test results.

Although it can be observed that the values for the recorded domestic seed production show a declining trend, the supply of hybrid seeds are augmented by seed imports. Total F1 seed imported was 8,189 mt (2008), 5,783 mt (2009), 8,947 mt (2010) and 4,828 mt (2011) (BPI-

Plant Quarantine Division). Seed export on the other hand was 384 mt (2007), 448 mt (2008), 556 mt (2009), 116 mt (2010), 925 mt (2011) and 732 mt (2012) (NFA).

After several amendments, the existing pricing of seeds for hybrid rice is dictated by DA-Administrative Order 05 Series of 2014. The prescribed buying rates are: PhP 212.00 for F1 seeds, PhP 1 125.00 for breeder CMS line, PhP 750.00 for foundation CMS line, PhP 375.00 for registered CMS line, PhP 187.00 for breeder maintainer line, PhP 100.00 for foundation maintainer line, PhP 50.00 for registered maintainer line, PhP 187.00 for breeder restorer line, PhP 80.00 for foundation restorer line and PhP 40.00 for registered restorer line. For private hybrid rice variety seeds, the price of which being unregulated by government policy, is at PhP 284.00 at the average.

2.5 Policies on hybrid rice and hybrid rice seed production

- Department of Agriculture (DA) Administrative Order No. 4 Series of 2009 – Guidelines on testing and analysis of imported hybrid rice and corn seed

- DA Administrative Order No. 4 Series of 2010 – Seed and Field Standards for the Production of Two-line hybrids

- DA Administrative Order No. 8 Series of 2012 – Revised Seed and Field Standards for the Production of Two-line hybrid

- DA Administrative Order No. 9 Series of 2012 – Revised criteria for accreditation of hybrid rice seed growers/producers

- DA Administrative Order No. 20 Series of 2006 – Revised seed and field standards for the production of hybrid (F1) seeds and hybrid rice parental seeds (A or CMS line; B or maintainer line; and R or restorer line)

- DA Administrative Order No. 18 Series of 2007 – Revised seed and field standards for the production of hybrid (F1) seeds and hybrid rice parental seeds (A or CMS line; B or maintainer line; and R or restorer line)

- DA Administrative Order No. 21 Series of 2007 – Revised guidelines on rice seed certification

- DA Administrative Order No. 29 Series of 2008 – Revising the prescribed buying and selling price of hybrid rice seed (PhP 195/ kg for F1)

- Executive Order (EO) 76 Series of 2002 – PhilRice as the primary government agency responsible for Hybrid Rice Commercialization Program and promoting the utilization of hybrid rice technology

- Presidental Decree (PD) No. 4, Sec. 6 – NFA shall establish rules and regulations governing the export of rice, corn and other grains and/or their substitutes and their by-products/end-products and to collect fees and charges for such exportation at rates to be determined by the Council.

- Republic Act (RA) 7308- National Seed Industry Council, Provision on Seed Industry Development Program, National Seed Quality Control Services, and Restrictions, Sanctions and Penalties (Art. 42, Sec. 1 – prohibit importation of seed varieties which are easy to grow locally under ordinary condition; Art. 42, Sec. 5 – prohibit exportation of rare and indigenous species, varieties, lines, and strains of seeds and planting material, except for scientific of international germplasm exchange purposes)

3. Constraints and Gaps in Hybrid Rice Development

The hybrid rice development in the Philippines has, thus far, afforded the country a certain measure of success in its aim of augmenting domestic rice supply. Even so, the adoption of hybrid rice technology has yet so far to go, with all its exploitable potential in the Philippine agricultural setting. For several years now, some challenges have been persistent, while some have just emerged or evolved from previously existing ones, which were not properly addressed. A clear view of the constraints in hybrid rice development and a working path towards addressing these would be very instrumental in furtherance of hybrid rice technology adoption in the country. Being of multi facets, the challenges that involve seed production, cultivation per se, personnel technical capacity, economics and policy, and politics can be addressed by a multi-disciplinary approach.

To date, although increased participation by the private sector- institutes and individuals alike, has contributed greatly towards increasing domestic F1 seed production, a demand-supply gap still drives for seed importation to go on. In the aspect of seed production, optimization of seed production technology to increase seed yield, identification of additional favorable sites for seed production to increase F1 seed production hectarage and organization of seed producers in the country to build a strong seed supply network are among the priorities. Breeding institutions that are responsible for sending out materials for seed production purposes at larger scales must also ensure the quality of the seeds in terms of physical and genetic purity. Seed production research work will also have to look into curtailing the cost of producing hybrid rice seeds and even multiplying CMS lines to encourage more growers to venture into F1 seed production due to lower costs and entice them with corresponding wider profit margin.

Requiring location-specific tandem technology for greater performance, cultivation of hybrid rice varieties and its practices must also be optimized. The common case with farmers getting bitter losses by cultivating hybrid rice is unmet expectations by looking forward to yield levels recorded in demonstration nurseries. Cultivation techniques have to be developed and be made readily available alongside the varieties during dissemination.

With data on target areas for hybrid rice cultivation and F1 seed production available, key persons per location have to be identified as well for intensive capacity building on effecting the technology and relaying the knowledge to capacitate the farmers as well. There is still a need to review and make training curricula more comprehensive and geared towards application. More technical trainings and hands-on sessions need to be conducted especially for farmers new to the technology. Further, the handling institute can go further and assist the farmer even after the training through visits from time to time and by capability analysis after some time. The handling institute has to be more aggressive in engaging the farmers involved in the adoption of hybrid rice technology.

Given the current market scenario and the expected changes even in the international trade arena, real-time estimates and valuation for economics, profitability, trade risks, and prospects that go with hybrid rice needs to be done. Policy that equally consider all the players in the system such as the farmers, consumers, traders, etc, while eyeing on sustainability at the same time has to be formulated and implemented prudently as well. On the same note, administrative regimes have to be aggressive in seeing to it that the promise of hybrid rice technology as a key tool to attain rice self sufficiency will get to actualization.

While engaging existing bottlenecks with a more comprehensive and more efficient strategy, national research efforts must also look into new and emerging challenges that may have to be dealt with using a very different approach. One great example of this is the manifestations of climate change. In the same way, efforts to get the technology to trickle down to the ultimate benefactors- the farmers have to be re-evaluated and revolutionized. Extension work has to be more aggressive in engaging the farmers.

4. Lessons learned

The success of hybrid rice technology in the Philippines, to date, can be considered significant. With the number and quality of varieties developed, cultivation techniques applied, progress and advancements in hybrid rice research, the reach of extension work, networks and collaborations forged, indeed the frontiers of Philippine rice industry has expanded. Even so, the need to revolutionize the current state the hybrid rice technology is in is imperative. In tackling the multi-faceted constraints, a multi-disciplinary approach can do the trick. It only requires the entities involved to be aggressive towards this end.

5. Opportunities for Hybrid Rice Development

So long as faith in hybrid rice technology still stays strong in the case of the Philippine rice industry, the utilization of the technology will go on. The prospects of hybrid rice include (1) development of new varieties with increased heterosis, expressed as increased grain yield potential and with resilience to biotic and abiotic stress, (2) a revolutionized F1 seed production industry at the national level, (3) human resource with significantly increased technical capacity on hybrid rice technology, (4) well rounded policies, and (5) a well-utilized and well-developed implementation of the hybrid rice technology across the country in general. Further, the role of the public sector may have to be redefined to adapt to the new tasks at hand that could be more important, especially with the joining of more entities into the loop.

Hybrid Rice Development in Thailand

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1. Overview of rice production in Thailand

Rice production has long played as an important socio-economic role in Thailand, making the country the world's largest rice exporter in the last 3 decades. However, as the Thai economy has developed, the role of rice has been declining. A declining of percentage of paddy share in the gross value of agricultural production has been declined form 30.9 percent in 1963 to 19 percent in 2008 (Titapiwantanakul, 2012). However, 65 percent of farmers work in rice sector

1.1 Production

In the last decade, total production increased from 28.5 million tonnes in 2004 to 37.3 million tonnes in 2013 (Table 1). The harvested area grew from 9.9 million hectares in 2004 to 12.9 million hectares in 2013. Total harvested area of rice reached 13.34 million hectares in 2012 because of the paddy pledging policy. The yield per hectare remains less than 3 tonnes. The main reason of average yield stagnancy is water shortage, which become more severe but irrigated area increased slowly. In addition, flooding and outbreak of pest and disease due to increasing cropping intensity also affect yield.

Table 1. Area, Production and Yield of Paddy Rice, 2004–2013

Years	Harvested area '000 ha	Production '000 t	Yield t/ha
2004	9,993	28,538	2.9
2005	10,225	30,292	3.0
2006	10,165	29,642	2.9
2007	10,669	32,099	3.0
2008	10,669	31,651	3.0
2009	10,684	31,508	2.9
2010	12,435	32,396	2.8
2011	12,908	36,004	2.8
2012	13,345	38,102	2.9
2013	12,887	37,337	2.9

Source: Office of Agricultural Economics, 2014

There are two groups of rice varieties grown: modern variety (MV) and traditional variety (TD). Over the last decades, the share of MV production has almost doubled from 86 percent in 2001 to 93 percent in 2010 (Table 2).

Table 2. Varieties of rice grown, 2001-2010

Years	Modern Variety (percent)	Traditional Variety (percent)
2001	86	14
2002	87	13
2003	86	14
2004	88	12
2005	88	12
2006	91	9
2007	90	10
2008	90	10
2009	92	8
2010	93	7

Source: Office of Agricultural Economics, 2013

There are two kinds of rice farming, chemical and organic. Area of organic farming had quite stable about 20,000 hectare in last decade (Table 3).

Table 3. Areas of chemical and organic farming in 2004-2012

Years	Chemical Farming ('000 ha)	Organic Farming ('000 ha)
2004	9,993	0.01
2005	10,225	0.02
2006	10,165	0.02
2007	10,669	0.01
2008	10,669	0.01
2009	10,684	0.02
2010	12,435	0.02
2011	12,908	0.02
2012	13,345	0.02

Source: Office of Agricultural Economics, 2014; Panyakul, 2013.

As organic farming is based on a do-it-yourself, most farmers start with a small piece of land. That normally means they can operate on their own land with their own labour without hiring workers. The production cost of organic farming was 346 dollar per hectare (in term of cash), which was five times lower than chemical farming (Table 4).

Table 4. Cost comparison between organic and chemical farming

	Organic Farming (USD)	Chemical Farming (USD)
Fertilizer	**65**	**208**
Chemical substances	0	208
Seed	0	156
Fuel	65	65
Labour cost (not include owner)	0	541
Harvester rental	108	108
Land rental	0	312
Others	108	108
Total	**346**	**1,706**

Source: http://www.bangkokpost.com/print/396609/

The northeast region, which is Thailand's largest rice production area, has the highest percentage of the poor, followed by the north, south and central regions (Table 5). The central region is Thailand's second largest rice production area, especially for the second crop (irrigated rice). The figures indicate that poverty issues of farmer needed to be addressed.

Table 5. Poverty Statistics for Thailand, 2000–2009

	2000	2002	2004	2006	2007	2008	2009
Total poor	12,555	9,135	7,019	6,057	5,422	5,772	
Share in population (%)	21.0	14.9	11.2	9.6	8.5	9.1	8.3
Percent urban	12.7	13.8	13.3	11.2	11.7	10.0	11.5
Percent rural	87.3	86.2	86.7	88.8	88.3	90.0	88.5
Percent by region							
Bangkok	0.9	1.6	0.7	0.5	1.2	0.7	0.9
Central	9.9	11.9	9.5	8.7	9.2	8.4	7.7
North	20.6	25.1	26.2	23.3	28.0	27.8	25.6
Northeast	58.0	52.8	56.3	59.8	52.2	56.3	57.9
South	10.6	8.6	7.2	7.8	9.5	6.7	8.0

Source: Titapiwantanakul, 2012

1.2 Utilization

Rice is mainly used for food consumption. In 2013, about 96 percent of total rice production was consumed as food. About 60 percent of annul produced paddy had been domestic consumption and the rest had been exported. Rice seed required for growing was about 1.4 million tons per year or 4 percent of total production. Broken rice was used for industrial such as rice flour, noodle, snack and feed. Rice bran was used for feed and rice bran oil (Figure 1).

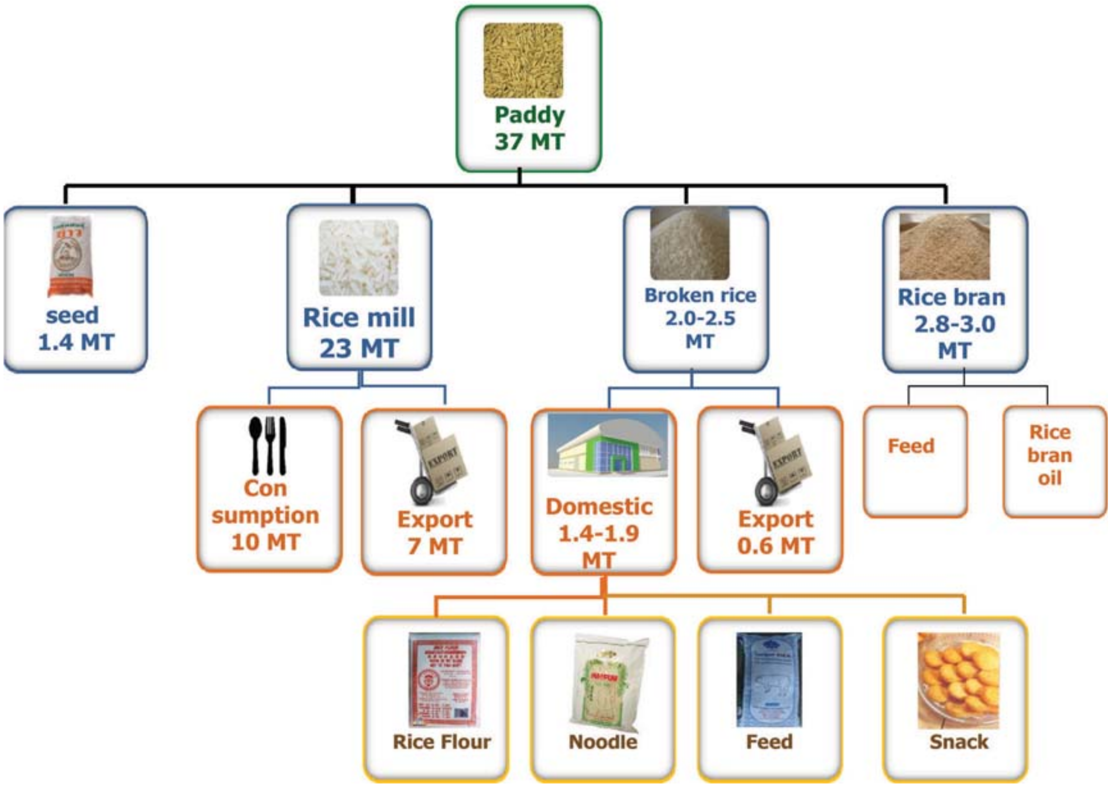

Fig. 1. Thailand's rice utilization in 2013
Source: Meerod et al., 2014

1.2 Export

Although Thailand had the lowest yield among the world's top 10 rice-producing countries, even lower than the world average, Thailand has ever been the largest rice-exporting country for almost 30 years because its production is much higher than a domestic demand, creating at least 6–10 million tonnes of rice surpluses for export in each year.

In 2013, top 10 rice importing countries of Thailand were United States, followed by China, Benin, Cote d' lvoire, and South Africa (Table 6). Nigeria reduced importing rice form Thailand, but imported from diversified sources such as Brazil, United States, UAE and India. Benin increased rice importing form Thailand despite its relatively small population because of a lower import duty than trader imports rice as transit to landlocked neighboring countries (Cadoni and Angelucci, 2013).

Table 6. Shares in Value of Rice Exports of Thailand by Major Trading Partner, 2011-2013

	Country	2011 (mUSD)	2012 (mUSD)	2013 (mUSD)
1	United States	417.64	405.74	456.59
2	China	235.70	152.58	251.13
3	Benin	104.07	189.54	466.81
4	Cote d'lvoire	330.09	238.47	203.93
5	South Africa	332.47	226.14	231.62
6	Cameroon	98.80	140.54	135.67
7	Hong Kong	218.17	177.69	185.41
8	Malaysia	200.29	69.62	91.21
9	Nigeria	775.24	677.72	92.35
10	Mozambique	87.06	102.24	101.13
	Total	6,432.39	4,632.77	4,420.37

Source: Ministry of Commerce

In 2013, total rice exports of 4,420 million USD; Hom Mali rice had the highest share at 42 percent, followed by white rice (33 %), parboiled rice (22 %) and glutinous rice(3%) (Fig. 2). The share of Hom Mali rice had increased while share of white rice and parboiled rice had deceased because of higher cost of production form the paddy pledging policy (Poapongsakorn, 2013). The cost of Thailand rice production had the highest when compare to Vietnam and Myanmar (Table 7).

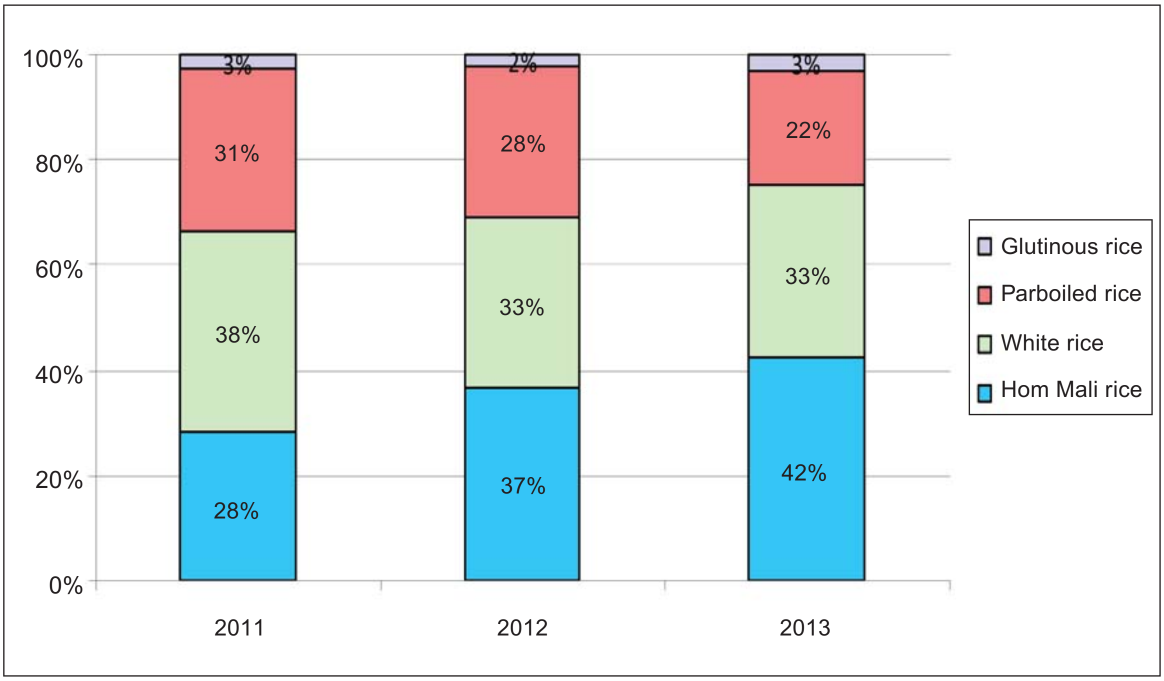

Fig. 2. Thailand rice export by major varieties in 2011-2013
Source: Ministry of Commerce

Table 7. Cost of rice production by country

Country	Cost per hectare (USD)
Thailand	2,008
Vietnam	1,217
Myanmar	943

Source : Isavilanon, 2013

2. Progress in hybrid rice development in Thailand

2.1 History of hybrid rice development

In Thailand, hybrid rice had been developed by Rice Department since 1979, starting with three-line hybrid system. Currently, research and development on hybrid rice has been conducted for both the three-line and the two-line systems. For the three-line hybrid system, Rice Department started it by introducing high yielding hybrid rice varieties from China for yield evaluation, and adaptation on Thai environments. The results showed that yields of hybrid rice from China were not higher than that of Thai inbred elite lines, and these lines were not adapted well in Thai environments (Somrith, 2007).

Later, the Rice Department introduced cytoplasmic male sterility rice lines and their maintainer lines from IRRI (International Rice Research Institute). The results showed that these lines were not adapted well in Thai environments. Thus, Rice Department developed several new cytoplasmic male sterility rice lines, and identified restorer lines from Thai elite lines. In addition, Rice Department evaluated yield of high yielding hybrid rice lines from IRRI. The results showed that yields of hybrid rice from IRRI were not much higher than that of Thai inbred elite lines, and eating quality of the grains from these lines was not as good as that of Thai rice (Somrith, 2007; Nugprachaya et al., 2009).

In 1994, the Rice Department evaluated yield of hybrid rice varieties developed from the new male sterility rice lines and the Thai restorer lines. The results showed that some hybrid rice lines showed 50-70 % higher yield than Thai elite lines such as Chainat 1, and Supanburi 1 (Somrith, 2007).

In 2001, a private company, CP, started hybrid research by introducing 8 hybrid varieties from China for yield evaluation in Thailand. The results showed that 3 hybrids yielded higher that that of Thai elite lines, indicating the potential use of hybrid in Thailand. After eight years on hybrid research, CP released CP304, a high yield of 1, 200 kg per rai with its first planting in farmer fields in 2010. (http://www.bangkokpost.com/business/economics/38572/cp-plans-launch-of-new-hybrid-rice-seed).

In 2011, the Rice Department released its first hybrid rice variety, RDH1, giving 51 and 23 % higher yield (1006 kg per rai) than Pathumthani 1 (666 kg per rai) and Suphanburi 1 (817 kg per rai), respectively. (http://www.brrd.in.th/rkb/varieties/index.php-file=content.php&id=131.htm).

In 2012, the Rice Department, in collaboration with public and private sectors, evaluated yield of hybrids developed by public and private sectors to identify hybrids with 15-20% higher yield than that of the Thai elite lines.

In 2013, the Rice Department released RDH3 giving high yield of 1, 415 kg per rai (http://skt-rsc.ricethailand.go.th/index.php/2013-06-04-07-20-25/61-4).

2.2 Status and trends of hybrid rice development

2.2.1 Progress in hybrid rice research

In addition to the Rice department, several universities and research institutes have been involved in hybrid rice research such as National Center for Genetic Engineering and Biotechnology, Kasetsart University, Rajamangala University of Technology Lanna lumpang, and Maejo University. They have been working on both the three-line and the two line-systems. Their works include development of hybrid rice parental lines, development of high yielding hybrids, genes and proteins involved in male sterility, and maker assisted selection.

The National Center for Genetic Engineering and Biotechnology (BIOTEC) has been working for several years on the two-line hybrid system, including genes controlling temperature sensitive male sterility (*tms*). Starting in 2005, BIOTEC obtained seven temperature sensitive male sterility rice lines (TGMS) from IRRI. In collaboration with Rice department, they evaluated sterility and fertility conditions, and adaptability to Thai environments of the obtained male sterile lines. The result indicated that some of these lines adapted well in all tested areas including central, lower-North and Northern areas of Thailand. Most of these lines were sterile during March to August, and they had reasonable seed setting rate during October to January (Booncharoen, et al 2007).

BIOTEC also studied genetic structure of Thai rice germplasm and rice germplasm from IRRI. The results from this study indicated that Thai and IRRI germplasm are in separated groups, suggesting that not only for trait improvements, IRRI germplasm can also be used to broaden the genetic base of Thai rice (Chakhonkaen et al, 2012). The information obtained from this study would be useful for selecting parent materials used for hybrid rice production.

In collaboration with 3 rice research centers, the 4 promising obtained TGMS lines for hybrid production were used as female parents to cross with 25 Thai lines to generate F1 hybrids. Forty-three and forty F1 hybrids were planted in 2012 and 2013, respectively for inter-station yield trials at 3 rice research centers. The hybrids were evaluated along with 4 standard varieties using randomized complete block design (RCBD) with three replications. In each year, there were two experiments, about 20 hybrids in each experiment. Yield and yield component were recorded. In 2012, there were 6 hybrids having grain yield 20-32% higher than the mean of the 4 best standard varieties. In 2013, there were 21 hybrids having grain yield 22-61% higher grain yield than the mean of the 4 best standard varieties. A total of 16 out of 31 hybrids tested in both years showed 20-44% higher yield than the average yield of the 4 best standard varieties. The high yielding hybrids trended to have higher seed number, seed setting rate, and earlier flowering than those of the standard varieties (Sangarwut, et al 2012; Sangarwut, et al 2014, abstract submission for RICE CONGRESS 2014). Several selected hybrids will be planted again for yield evaluation in 4 rice research centers and later in farmer fields.

In collaboration with 3 rice research centers, the promising *tgms* genes have been transferred to several Thai elite lines by generation of recombinant inbred lines and by backcrossing. Currently, F8 and F9 recombinant TGMS lines are growing at Phathumthani Rice Research Centers and at BIOTEC for studying their fertile and sterile conditions (Sangarwut, et al 2014, abstract submission for RICE CONGRESS 2014). Furthermore, some of these recombinant male sterile lines have been used as female parents to develop two-line hybrids. Currently, the developed F1 hybrids are growing for preliminary yield evaluation and phenotypic observation at BIOTEC, Phathumthani Rice Research Center, Chainat Rice Research Center, and Pitsanulok Rice Research Center (unpublished data).

In addition to hybrid rice breeding, BIOTEC has been studying on genes and proteins involved in temperature sensitive male sterility (TGMS), including the development of molecular markers linked to male sterility genes. The male sterility lines obtained from IRRI were not only used for hybrid breeding, generation of the new male sterility lines, but also used for studying on genes involving male sterility. Previously, groups in BIOTEC and Kasetsart University indentified SSR markers linked to *tms2* (Lopez et al, 2003). Later, BIOTEC indentified a 70 kb deletion in the *tms2* mutant rice lines, and identify closely linked markers used for selecting this gene in breeding population (Pitnjam et al, 2008). Recently, BIOTEC identified candidate genes for *tms2*, and confirmed function of the candidate genes using RNAi. The candidate gene is in ORMDL family protein, which highly conserved across kingdom, from human to plant. In yeast, this gene was reported to be involved in sphingolipid metabolism. The resulting RNAi transgenic plants with low expression of *ORMDL* gene were sterile, having abnormal pollen morphology and staining. In addition, both sphingolipid metabolism and expression of genes involved in sphingolipid synthesis were perturbed in the *tms2* mutant rice plants and in the RNAi transgenic lines (Chueasiri, et al, 2014).

BIOTEC also developed molecular markers linked to another two male sterility genes controlling TGMS in the IRRI germplasm (Booncharoen et al, 2007; Fuemoy et al, 2007; Sangsawang et al, 2012). In addition, BIOTEC have been study transcriptomic and proteomic to identify genes and proteins involved in mechanisms controlling TGMS (Pitnjam et al, 2013; Chakhonkaen et al, 2013). The information obtained will be useful for hybrid rice breeding and normal rice breeding programs.

Kasetsart University is one of the important institutes for hybrid rice development. Several works from this university were involved in hybrid rice development for both three and two line systems, such as classification of *indica* and *japonica* rice germplasm using molecular markers, and making database of these rice germplasm including information on desirable genes for agronomic important traits. This information is very useful for rice breeding programs, including the two-line and the three-line hybrid development (Funding: CPMO, NSTDA). In addition, This university also conducted several works related to three-line breeding such as development of A lines, R lines, evaluation of heterosis of F1 hybrids over their parents, and study commercial seeds production for maternal and hybrid seeds (Funding: ARD).

Rajamangala University of Technology Lanna lumpang was also involved in development of two line system. The works from this university included the development of two TGMS lines, selecting high yielding male lines with disease and insect resistances. In addition, they generated F1 hybrids from these selected parents, and the results from the yield evaluation trials indicated that 8 hybrids yield higher than 1 000 kg/rai with moderate eating quality suitable for consumption and flour industry (Funding: CPMO, NSTDA).

Maejo University introduced a TGMS line (T29S) from Vietnam to develop new TGMS lines in several Thai genetic backgrounds such as KDLM105, PTT1, Chainat 1, RD11, and RD21, using molecular markers. These TGMS lines will be used as female parents for two line hybrid development (Funding: CPMO, NSTDA).

2.2.2. Status of HR production

Impact of HR adoption

Hybrid rice had been planted in farmer fields since 2010. Total seed production by Crop Integration Business (CP) and Rice Department were about 100 tonnes in 2013. Planted area of HR during 2013 was estimated at about 1 600 hectares of the rice area, largely concentrate in Nakhon Pathom. The average yield of HR on sample farms in Bang Len's Demo Farm of Nakhon Pathom province, was 7.58-9.42 tonnes per hectare (Table 8).

Table 8. HR Yield of Nakhon Pathom in 2010

Farms	Area of Planting (ha)	Yield (tonnes per hectare)
A	4.80	9.42
B	4.00	9.30
C	0.96	8.54
D	1.92	8.28
E	1.60	8.26
F	3.76	8.24
G	3.20	8.22
H	1.60	8.21
I	2.24	8.06
J	1.44	7.99
K	1.92	7.63
L	5.28	7.58

Source: CP, 2010

Based on research survey in 3 provinces, average yield of HR was 7.0-7.5 tonnes per hectare while that of inbred was 5.6 tonnes per hectare (Table 9). Farmer used HR had gained profit more than that of inbred about 400 USD per hectare. However, this survey was not a good representative of the whole country because of a limited sample size and selected farmers with best practices.

Table 9. Yield, Cost and Profit of Hybrid Rice and Inbred

	Hybrid Rice			Inbred
	Province A	Province B	Province C	
Yield (ton/hectare)	7.0	7.5	7.5	5.6
Cost (USD /hectare)	786	783	891	1,220
Profit (USD/hectare	1,393	1,398	1,269	850

Source: Meerod et al., 2014

3. Constraints and gaps in HR development

3.1 Technology constraints

The major constraints for HR development in Thailand are limitation of male sterile germplasm, and breeder teams (Somrith, 2007). For the three-line system, another problem is low seed setting rate of female parents. For the two-line system, another problem is effect of environment on sterility/fertility of female parents, leading to impurity of hybrid seed produced. Both three-line and two-line hybrids still are unable to exceed 20% higher yield than that of the best inbred variety.

3.2 Social and economic constraints

Hybrid rice seeds cost higher than that of inbred, as much as four to six-fold. The retail price of F_1 seed that the company offered during the 2010-2013 was aboutUS$4-5 per kg. However, the total cost of HR was not different from that of inbred because farmer used HR seeds of about 62.5 kg/hectare while they need to used inbred seeds of about 125.0-187.5 kg./hectare, which is a normal rate of seed used in present. Although, the research showed that farmers planting hybrid rice had gained profit about 400 USD per hectare higher than that of farmers planting inbred lines. This is not attractive to them because yield of hybrids is not much higher than that of inbred elite lines. To make hybrids more favorable to farmers, their yield has to be higher than 8.0 tonnes per hectare. In addition, changing mindsets of farmers for practicing and management of their fields is challenging. Furthermore, public's acceptance of hybrid technology is still low and misunderstanding.

3.3 Capability constraints

- Few research and breeder teams on hybrid rice (Somrith, 2007);
- Limitations of research stations and field testing;
- Limitations of funding for research and investment; and
- Low collaborations within and between countries;

3.4 Policy constraints

Thailand has set HR policy in Rice Research Strategy in 2012-2016. However, it does not have specific plans or resource allocation to research and development technology. Although, Thailand has conducted research for three decades, Thailand had only three hybrid varieties which had been approved by the Rice Department.

4. Opportunities for hybrid rice development

Thailand has large diversity of genetic resources that is beneficial for hybrid rice development with a good quality and high yield. In addition, future effective collaboration between good partners (outside and inside the country) to share resources and knowledge will strengthen hybrid rice development. In addition, potentially clear direction of government on hybrid research will help to overcome several limitations.

In terms of technology, new technologies available such as genomics and marker-assisted selection can be used to explore on a large scale identifying genes responsible for ever more yield and to reduce time for HR development.

5. Key strategies and policy options to promote HR development inThailand to 2020 and 2030

- Increased capability of hybrid rice production

  - Develop male-sterile lines which suitable for Thailand;
  - Produce hybrid seeds with reduced cost;
  - Utilize new molecular technologies to speed up hybrid rice breeding; and
  - Develop product.

- Technology transfer:

  - To set demonstration farm for farmer learning; and
  - Multi-location testing with farmer participation

- Public and Private Partnership:

  - Private sector can obtain breeding material from the public sector, especially;
  - from Rice Department, whose rice germplasm bank conserves about 20,000;
  - accessions of seed collected from around the country;
  - Public and private sector work together for regular varietal testing and evaluation; and
  - Public-private linkage is in an area of human capital development.

- Policy:

The Thai government should support of R&D investment in both public and private sectors by facilitating private companies to rapid expansion of HR production and to set their research station in Thailand.

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Research and Development of Hybrid Rice in Vietnam: Constraints and Perspectives

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1. Introduction

1.1 Land and population of Vietnam

Of the total area of 33 million ha, about 55 percent (18 million ha) is now under "production use" of which 40 percent is under agriculture and the remainder is under forest. In per capita terms, Vietnam's cultivated land resource base is among the lowest in the world. The cultivated area per capita averages over 0.1 ha.

The population of Vietnam is about 90 million with 54 ethnic groups. The annual population growth rate is around 1.7- 2%. The rural population is about 70 percent of the total.

1.2 Role of agriculture in Vietnam's economy

Vietnam is predominantly an agricultural economy, based on paddy rice production. Among the other edible crops, maize, sweet potato, cassava, vegetables are most important. Rubber, coffee, tea, coconut, sugarcane are the most important industrial plants.

Vietnam is an agriculture-based country with more than 73 percent of its population depending on agriculture. Agriculture provides a livelihood for some 23.4 million labourers, or 62 percent of the labor force.

Rice is the most important crop with a cultivated area of 7.2-7.6 million ha. Almost all rice varieties are inbred ones, with hybrid varieties accounting for around 700,000 ha. Rice variety improvement is on the top of priority for rice research during the last two decades.

1.3 Achievements in rice production in Vietnam

From 1986 to 2005, the average yield of rice increased from 2.81 to 4.93 tonnes/ha (1.7 times). The total rice production increased from 16 to 36 million tonnes. Rice export increased from 0.06 to 5.2 million tonnes. In 2013, the average yield is 5.6 tonnes/ha to produce 43 million tones and export 8 million tones.

1.4 Achievements in agriculture

- High and sustainable agricultural growth at 4.3-4.5 percent over a long period (1990-2004);

- An increased market orientation. Recognition of the farm household as the basic unit of agricultural production and marketing decision making and rationalization of the owned enterprise system to use efficiency under market competition;

- Improved income and living standards. Farmers' income increased with remarkable successes in poverty reduction. People under poverty line decreased from 29 percent in 1990 to 10 percent in 2009;

- Improve rural infrastructure such as roads, irrigation system. electricity, heath care and education facilities; and

- Achievements in the protection and recovery of forest, with an increased recovery rate of forest from 28 percent in 1995 to 37 percent in 2003.

1.5 The reasons for achievement in rice production

- Land policies:

  - The land law was transferred from long-term lands use rights of the Government to social economic institutions, households and individuals: 20 years for annual crops and aquaculture, 50 years for perennial crops, and 50-70 years for forestry land;
  - Five rights are exchange, transfer, lease, inheritance and mortgage; and
  - Ceilings for agriculture at 2-3 ha, for forestry at 10 ha in the river delta and 30 ha for mountainous areas and uplands.

- Investment, especially in irrigation system.

- Application of advanced technologies.

- New rice improved varieties and advanced technology:

  - 149 varieties from 1986 to 2005;
  - 45.1% VN rice varieties were applied in the production;
  - New advanced technologies widely applied: INM, IPM, ICM, "3 reductions, 3 gains"; and
  - Hybrid rice: cultivation area covering 600,000-700,000 ha.

2. Progress in hybrid rice development in Vietnam

2.1 History of hybrid rice development

The history of hybrid rice development in Vietnam is presented in the following Table:

Year	Highlights
1980-1983	Rice breeders started to introduce and evaluate A and B line from IRRI at CLRRI and VASI.
1992	Vietnam introduced F1 seeds from China for testing and demonstration in the farmers' fields.
1992-1995	Rice breeders introduced A Lines, B Lines from IRRI, China for hybrid rice breeding in Vietnam. Hybrid Rice Research Center belonging to VASI was established by MARD. MARD gave subsidized fund for hybrid rice seed production and hybrid rice commercial production. FAO supported Vietnam TCP Project providing training rice breeding in China, provided International consultant on seed production and hybrid rice breeding and provided some equipment for hybrid rice research.
1996-2000	Second TCP project supported by FAO for seed production and training at IRRI and in China. ADB/IRRI hybrid rice project supported for parental lines purification and hybrid rice breeding Hybrid rice breeding and seed parent purification funded by MARD. MARD gave subsidized fund for hybrid rice seed production.

2001-2015	Hybrid rice research project funding by MARD (US$ 80 000-100 000 pêr year). Local hybrids (3 lines and 2-line hybrids) have been developed and released for F1 seed production 2 000- 3 000 ha had been used for hybrid rice seed production per year, with a yield of 2.0-2.5 tonnes/ha

2.2. Status and trend of hybrid rice development

2.2.1 Progress of hybrid rice research

Exploitation of imported CMS lines and development of new CMS lines for breeding suitable 3-line hybrid

More than 70 CMS lines were introduced for evaluation in Vietnam. Only a few CMS lines were selected for use in breeding domestic hybrid rice. The CMS lines BoA and II32A were used for producing F1 seeds of some hybrids originally developed from China. Only IR58025 A could be used for breeding three hybrids and they were released for commercial rice production.

The results of developing new maintainer lines for developing new CMS lines were as follows:

- Seventeen good maintainer lines with short duration, short stature and good adaptation to Vietnam conditions, tolerance to diseases and having good combining ability were identified and selected from testcross nursery for developing new CMS lines. The complete male sterile plants were selected for back crossing to their corresponding CMS lines. The backcrossing populations were in different states. Among the 12 crosses selected, three complete sterile CMS lines were developed and named as OM1-2A, AMS 71A and AMS 72A. These new CMS lines have been used for test cross in the hybrid rice breeding programme. The remaining back crossing generations from BC4 F1 to BC7 F1 have shown 60-96.5 percent of population to have complete pollen male sterility. The percentage of complete pollen sterile plants increased gradually in later back crossing generations.

- In order to diversify and improve maintainer lines for using in three-line hybrid rice breeding, seven available maintainer lines were crossed in pair with the objective of developing new maintainer lines having short duration, good phenotype, good tiller number, high stigma exertion and improvement of quality of CMS lines. The plants of F1, F2 and F3 generations of six crosses involved eight maintainer lines as their parents were selected following the bulk method. In F4 generation, 20-25 individual plants were selected for back crossing in pairs with corresponding individual plants of each CMS lines. Six promising new CMS lines from this programme have been developed and used for breeding three-line hybrids in Vietnam (Hoan, 2013).

Results of developing new tropical TGMS lines in Vietnam

To create new tropical TGMS lines adapted to the tropical condition, the adapted cultivars were crossed to available TGMS lines. New TGMS lines have been selected in segregating generations. The new TGMS lines had stable pollen sterility under critical temperature of 23-24 ^{o}C, uniform in phenotype combined with good combining ability and good flower characteristics. Thus, they were selected and used for crossing new hybrid rice combinations. The new TGMS lines created by different research institutions are presented in Table 1 (Hoan 2003, Luong 2005).

Table 1. Available TGMS lines developed and used in Vietnam during 2001-2005

Lines	Source	Institution	Critical fully sterile T^0	Critical fertile T^0	Usage
T1s-96, 103s	T1SxPeiai64	HAU	25.5	22-23^{0}C	Commercial use
P5s	T1SxPeiai64	HAU	25^{0}C and day length 12h16'	≤ 24^{0}C	Commercial use
P47S	Selected from Peiai64S	HAU	25^{0}C	≤ 24^{0}C	For breeding
AMS27S (7)	TGMSx nbred	VASI	25^{0}C	23.5^{0}C	For breeding
AMS 28S	TGMSx nbred	VASI	25^0	23.5^{0}C	For breeding
AMS 29S	Selected from segregated material	VASI	24.5^{0}C	23^{0}C	Promising variety
AMS 30S	Selected from segregated material	VASI	24.5^{0}C	23^{0}C	Commercial use
AMS26S (CL64S)	Selected from Peiai 64S	VASI	24.5^{0}C	23^{0}C	For breeding
AMS31S	CL64S x VN292-2	VASI	25.5^{0}C	≤ 23^{0}C	Promising variety
AMS33S	CL64S x BM9820-11	VASI	25.5^{0}C	≤ 23^{0}C	For breeding
TGMS1	Crossing	FCRI	25^{0}C	≤ 24^{0}C	For breeding LDH5, LHD6
TGMS20	Pollen culture TGMS6/Xi23	FCRI	25^{0}C	≤ 24^{0}C	For breeding, Promising LDH4
D101S	VN1 xDT12	AGI	>24^{0}C	≤ 24^{0}C	For breeding
D102S	VN1 xDT12	AGI	>24^{0}C	≤ 24^{0}C	For breeding
D103S	VN1 xDT12	AGI	>24^{0}C	≤ 24^{0}C	For breeding
TGMS18-2	H84 x CR203	AGI	>24^{0}C	<24^{0}C	For breeding
TG1	103S/ Peiai64S	Vanlam			For breeding
TG22	TGMS2/R15	Vanlam			For breeding

Among the new developed TGMS lines, T1S -96, 103s, AM30s and P5s were used as female for released two-line hybrids: VL20, TH3-3, TH3-4, HC1,TH5-1, HYT103, HYT102, and VL24. Other TGMS lines, viz., P5S, AMS29S, AMS30S TGMS1, TGMS20 were used as female of promising two-line hybrids, viz., HYT106, HYT107, LHD5, and LHD6. (Hoan 2006, Nhan 2005).

Developing new TGMS lines based on genotype of parental lines (maintainer line and restorer lines of adapted three-line hybrids)

In order to overcome the instability of several CMS line such as II-32A, IR58025A and Jin 23A, there were limited number of restorers, improvement of characters of some female parents (CMS) and limitation of three-line hybrids.

Available maintainer lines are II-32B, IR58025B, Jin23B, BoB, Zhenshan97B and restorers viz. Fuhui838, 827R, Gui99. These parental lines are characterized by short duration, short plant height, good combining ability and adapted to Vietnam conditions. These parental lines have been used to cross with four TGMS lines viz. Peiai64S, 7S, CN26S and TG125S and successively backcrossed to recurrent male parent to BC2F11, BC3F1 generation before selecting pure TGMS lines. The work had been done from spring of 2002.

The result of test crosses confirmed that new TGMS lines based on maintainer lines of three-line hybrids system have been developed. These results have opened opportunity to replace the two-line hybrids for three-line hybrids to overcome several limitation viz. instability of pollen sterility of II-32A, medium exertion of IR58025A in Vietnam. In addition, new TGMS lines based on the B lines require no restorer genes in their male parents therefore it has more chances to breed highly heterocyst two-line hybrids compared to existing three-line hybrids.

Table 2. Characteristics of newly developed TGMS lines derived from existing CMS lines

TGMS	AMS 35S-45	AMS 35S-46	AMS 36S	AMS 34S-10	AMS 34S-11	AMS 37S-76	AMS 30S(đ/c)
Stigma color	White	White	Black	Black	Black	Black	white
Grain shape	L	L	B	B	Bả	L	L
Panicle length	22.3±8	21.3±7	22.0±6	18.7 ±8	18.7 ±7	21.3 ±7	-
Panicle. No./ hill	5.0	8.4	6.6	10.4	10.4	6.6	5.4
Spikelet/panicle	272.7	177.3	204.7	183.0	173.7	234.3	158.0
Spikelet under covered (%)	7.1	3.9	2.8	7.1	10.2	5.0	-5.0
Off type (%)	0	0	0.1	0	0.1	0	0
Stigma exert. (%)	60	60	72 - 75	70 - 72	70 - 72	70 – 72	70
Sterile pollen (%)	100	100	95 - 100	100	100	100	100
Critical To pollen Sterile	23.5	23.5	24.0	24.0	24.0	24.0	23.5

Results of development parental lines having WC gene

The conventional high-yielding varieties, adapted to Vietnamese conditions, are Xi23, Q5, Chiem77, R242, BM9855, etc. These varieties were used as male to cross with donor having WC gene viz. Peiai 64S, N22, Palawan, Dular, Calotoc, Lambayeque1, Moroberecan. Single crosses were done and selection for parental lines followed two directions:

- Select fertile plant in segregating generation to male parent having WC gene

- Selected sterile plants in segregating generations of single crosses or in back crossing generations. A total of 8 uniformed TGMS lines having 100 percent of pollen sterility were selected. These selected TGMS lines having good stigma exertion, short duration, phenotype acceptability are good. Those selected TGMS lines have been crossed to Indica/Japonica check. The high seed setting of the F1 crosses confirmed that TGMS lines named D52S, D60S, D64S, D67S,D116S have Wc gene of male lines containing WC.

Table 3. The main characteristics of TGMS lines expecting to have WC gene selected from single crosses involving female parents having WC gene

No.	TGMS line developed	Original cross	Duration from seeding to flower Ing (days)	Critical T^0 to induce male sterile (0.C)	Sterile pollen (%)	Stigma exertion (%)	Pheno. Accept able score	Pani-cle no./ hill
1	DS116	CL64S/IR23030//IR23 030	64	24	98-100	75	1	15
2	D67S	CL64S//GR272/Xi12)	62	24-25	98-100	70	3	14
3	D64S	7S//7S/W3)	62	24-25	98-100	70	1	14
4	D52	CL64S/Q5	65	24	100	70	3	12
5	D59	7S/Lemon	64	24	100	75	3	11
6	D60	CL64S/Chiem77	65	24	100	75	3	10
7	161	Peiai64S/IR62030// IR62030	62	25	98-100	70	3	14
8	D66S	-	64		98-100	70	3	15
9	D68S	CL64S//C70/CR203	64	25	98-100	70	3	15
Check	CL64S	From China	63	24	91,5	75	3	10

Along with observation and study in field, leaves of the male lines were collected to analyse and by using PCR reaction with molecular marker RM225, RM253, linked with WC gene which was determined in the previous study.

Combination two analyses result with two markers RM225 and RM253, we obtained 16 perspective male lines which absolutely contain WC gene: D16-3, D27, D18-3, D22, D27-5, D14, D25-2, D1-5, D17, D16-1, D16-6, D26, D19, D52, D46 and D67.

Table 4. Growth duration, phenotypic acceptability and seed setting in testcrosses with check variety for WC gene in new restorer lines

New Developed male parents	Original crosses	Growth duration (seeding to heading)	Phenotype acceptance (score)	Seed setting when crossed with IR36(%)	Seed setting when crossed with Taiholen127 (%)
D16R	Peiai64S/ BM9855	107	3-5	>80	>80
D17R	Peiai 64S/ Xi23	107	3	>90	>80
D18R	Peiai64S/ BM9855	109	3	>90	>80
D19R	Peiai64S/ Chi[a]m77	110	3	>90	>75
D34 R	Peiai 64S/ R564	115	3	>85	>80
D46R	Peiai 64S/ C70	110	3	>80	>80
D47R	Peiai 64S/ C70	110	3	>80	>80

These male parents have been used to developed Indica/Japonica hybrid in Vietnam.

Table 5. Yields obtained for promising super hybrid rice (*Indica/Japonica*), on the Spring 2014 at Daklak, Taynguyen

Hybrids	Growth Duration (day)	Plant height (cm)	Panicle//m^2	Filled grain/ Panicle	Sterile grain rate (%)	P1000 (gr)	Theory yield (tonnes/ ha)	*Actual Yield (tonnes /ha)
SL9	105	108	541	120	30.3	21.0	13.63	11.97
SL6	101	107	492	117	30.4	22.5	12.95	11.34
SL15	108	108	453	97	18.9	30.2	13.27	11.27
SL13	105	90	487	128	15.6	22.7	14.15	12.30
SL11	100	98	493	126	33.6	22.1	13.73	11.90
SL10	104	107	448	106	24.0	29.8	14.15	11.77
SL8	101	98	597	108	12.6	21.7	13.99	11.50
SL1	103	102	479	106	11.7	24.3	12.34	11.01
SL5	102	97	486	112	15.4	26.0	14.15	12.84
SL2	103	106	483	105	31.5	25.6	12.98	11.17
SL7	102	98	521	116	16.3	22.9	13.84	12.24
SL14	104	109	502	106	19.2	26.4	14.05	12.40
SL3	104	106	482	105	28.4	28.2	14.27	11.14
SL4	103	105	497	96	19.1	27.6	13.17	10.80
SL12(HYT108)	102	95	498	104	150	26.8	13.88	11.8

*LSD .05 = .315; CV: 1.6 %

Studies on disease resistance

Twenty seven parental lines of two- and three-line hybrids were screened to 10 races of xanthomonas oryzae pv. Oryzae (isolated from IRRI). Reaction of parental lines to the diseases was reported (Buu and Lang 2003). The data showed that II-32B is resistant to 10 races. Peiai 64 and Son thanh are resistant to 9 races. There are 4 parents viz. IR 78595A, IR 75601A, II-32A and IR 68885B resistant to 8 races. The parents resisting to 7 races are BoA, IR 73328A and Buc Khoi 838. It is important to note that only 12 among 27 parental lines showed resistance to Race 3. Study also showed that Race 2 and Race 3 are the most relevant in the hot spot of bacterial leaf blight diseases in the northern provinces of Vietnam.

The standard lines with known resistant genes from IRRI were screened for 11 races of the bacterial. The data showed that 4 lines viz. IRBB4 (Xa4), IRBB5 (xa5), IRBB7 (Xa7) and IRBB21 (Xa21) are good resistant to 6–9 races of bacterial causing BLB diseases .However, genes viz. xa5, Xa7 and Xa21 are very important to be incorporated into parental lines of rice hybrids in Vietnam.

To determine the existence of molecular markers linked to bacteria leaf blight resistance genes, extracting and analyzing PCR products of parental lines F1 and F2 confirmed that:

- Two molecular markers (STS_MP1, MP2) are linked to the bacterial leaf blight resistance gene Xa4.

- One molecular marker (RG556) is linked to the bacterial leaf blight resistance gene xa5.

- One molecular marker (P3) is linked to the bacterial leaf blight resistance gene Xa7.

- Two molecular markers (PTA818, PTA248) are linked to the bacterial leaf blight resistance gene Xa21 (Hoan et al., 2013).

Results of developing new hybrid rice combinations for commercial hybrid rice production

Twelve stable male sterile CMS lines, 10 TGMS lines, and male parents (inbred lines and varieties) were used in test cross for developing two-line and three-line hybrids for Vietnam. Good identified combinations were evaluated in observation yield trials and primary yield trials and about 15-18 promising hybrids were selected per year and were tested in the National Hybrid Rice Yield Trials (NHYT). These trials were conducted on different ecological conditions (6-9 locations).

The high-yielding hybrids with wide adaptability, good quality and tolerance to diseases and insects were selected and released for commercial rice production. The released hybrids were HYT83, HYT92 and HYT100 (three-line hybrids) (Fig. 1) and VL20, TH3-3, TH3-4, HC1, HYT102, HYT103 and HYT108 (two-line hybrids) (Hoan, 2011).

Fig. 1. The hybrids HYT83 (left) and HYT100 (right) developed in Vietnam were released for commercialization

A quality aspect study on milling, percentage, heading percentage, length of grain, L/W ratio, amylose content, etc. showed that these characters of hybrid rice are similar to inbred check. However, amylose content of hybrid rice is at a lower range of 18-20 percent. For eating quality, hybrid HYT100 and HYT92 were evaluated as with very good quality with aromatic smell. HYT83 and TH3-3 were evaluated as with good eating quality (Hoan, 2003 and Tram, 2005).

The advantages of two-line hybrids developed in Vietnam are that they are of short duration and suitable for late spring and early and very early summer rice crop in Vietnam, while most of the existing three-line hybrids are not adapted to early summer rice crop in Vietnam. In addition, the hybrid seed production of two-line hybrids is easy to produce to obtain 2.5-3.0 tonnes/ha, while only. 1.5-2.0 tonnes/ha from three-line hybrids (HYT83, HYT100, HYT92). The available rice hybrids used in commercial hybrid rice production are presented in Table 6 below.

Table 6. Major rice hybrids released for commercial rice production in Vietnam

Name of hybrid	Season	Source	Yield (tonnes/ ha)	Status	Year released
Boyou 903 (three lines)	Summer	China	6–8	Present	1996
Bo you 253 (three lines)	Summer	China	6–8	Present	2004
Shan you 63 (three lines)	Spring	China	7–9	Less	1992
Er you 838 (three lines)	Spring	China	7–8.5	Present	2000
Er you 63 (three lines)	Spring	China	7– 8 .5	Present	2000
D.you 527 (three lines)	Spring	China	7–9	Present	2001
CNR36 (three lines)	Spring	China	7-9	present	2006
Van quang 14 (two lines)	Summer	China	6-8	present	2006
VL 20 (two lines	Summer & Spring	Vietnam	6-8	Present	2002
HC1 (two lines)		Vietnam	6-8	Present	2005
VL24 (two lines)	Summer	Vietnam	6-7	present	2006
TH3-3 (two lines	Summer & Spring	Vietnam	6–8	Present	2003
TH3-4 (two lines)		Vietnam	6-8	present	2005
HYT102 (two lines)	Summer & spring	Vietnam	7-9	Present	2007
HYT103 (two lines)	Summer & spring	Vietnam	7-9	present	2007
TH5-1 (two lines)	Spring	Vietnam	7-8	present	2006
HYT83 (three lines)	Summer, Spring	Vietnam	7–9	Present	2003
HYT92 (three lines)	Summer, spring	Vietnam	6.5-8	present	2005
HYT100 (three lines)	Spring	Vietnam	7 -9	present	2005
B-Te1 (three lines)	Summer	India	6-9	present	2007
Thuc Hung 6 (three lines)	Spring & summer	China	7-9	present	2007

2.2.2. Status of hybrid rice seed production in Vietnam

In-country training programmes

In order to spread F1 seed production technology in Vietnam, in-country training programmes were organized to train seed growers on seed technology by different organizations: local extension departments, Hybrid Rice Research and Development Center and support training from ADB/IRRI project.

In view of the comprehensive training in seed production, the area of hybrid rice seed production increased from 267 ha in 1996 to 620 ha in 2001. Yield and production of hybrid seed also increased from 1.75 tonnes/ha to 2.3 tonnes/ ha and from 467.5 tonnes to 1,426 tonnes in the same period, respectively. In 2001 about 1,400 ha was used for hybrid seed production. Some area, more than 2 tonnes/ha seed yield could be obtained but due to unfavorable climate conditions during 2001, average yield was reduced to 1.7 tonnes/ ha. During the period 2002 to 2011, Vietnam produced annually in an area of 1 500 - 2,200 ha an average yield of 2 000 kg -2 500 kg/ha.

Decrease in FI seed production

The trend of F1 seed production in Vietnam decreased in recent years. The reasons for this decrease include:

- Support subsidized fund from government declined (250 USD/ha) by about 10 percent of seed production cost per ha, while cost of fertilizers, chemicals and labour increased.

- Crops were damaged due to changing of climate, viz., too hot or too cold, which led to no benefits for seed growers.

- The system of cooperatives involved in F1 seed production led to difficulties in selling and distributing F1 seeds in commercial markets.

New approach for hybrid seed production in Vietnam

Private or joint stock foreign seed companies purchased breeder right, exclusive right to produce F1and sell the hybrid rice seeds. These hybrids viz. VL20, TH3-3, TH3-4 and HYT103, have been purchased by four seed companies. The Ministry of Agriculture and Rural Development has set policy to support every seed company to carry out seed production in area of more than 100 ha. The support included a subsidized fund of US$250/ha and support funding for developing irrigation systems, dryers, training, etc.

Table 7. Results of cooperation between hybrid rice breeding and seed production (2000-2010)

Hybrids	Type of hybrid	Level of release	Organizations conducting F1 seed production
VL20	2-line hybrid	Registration	Hai Phong Seed Company
TH3-3	2-line hybrid	Registration	Cuong Tan Seed Company
TH3-4	2-line hybrid	registration	National Seed Company
HYT 100	3-line hybrid, quality	Registration	Hai Phong Seed Company
HYT 102	2-line hybrid	Registration	Hai Duong Seed Company
HYT103	2-line hybrid	Registration	Dai Duong Seed Company
SL 8H	3-line hybrid, quality	Registration	Dai Thanh Seed Company
HYT1`08	2-line hybrid, high yield	Registration	Thai Binh Seed Company National Seed Company Eakkar Seed Center
CT16	3-line hybrid	Registration	Cuong Tan Seed Company
TH3-5	2-line hybrid	Registration	HAU
TH7-2	2-line hybrid	Registration	HAU
LHD 6	2-line hybrid	Registration	Hanam seed company

Table 8. Area of hybrid rice seed yield and F1 seed production in Vietnam during 2001 - 2012 (Source: MARD, 2012)

Year	Total		Dry season		Wet season	
	Area (Ha)	Yield (T/Ha)	Area (Ha)	Yield (T/Ha)	Area (Ha)	Yield (T/Ha)
2001	480,000	6.09	300,000	6.60	180,000	5.25
002	500,000	6.06	300,000	6.50	200,000	5.39
2003	600,000	5.91	350,000	6.45	250,000	5.15
2004	577,000	6.06	350,000	6.45	227,000	5.46
2005	553,000	6.05	353,000	6.50	200,000	5.25
2006	572,700	6.23	342,700	6.71	230,000	5.52
2007	620,000	6.10	390,000	6.39	230,000	5.60
2008	560,000	6.17	305,000	6.60	255,000	5.66
2009	709,820	6.21	404,160	6.73	305,660	5.53
2010	605,640	6.41	374,340	6.85	231,300	5.69
2011	595,000	6.40	395,190	7.00	199,810	5.60
2012	613,120	6.46	387,970	6.90	225,150	5.87

The yield of F1 seed production is lower in China leading to higher seed production cost. The area suitable for F1 seed production is located in the central and south Vietnam, far from intensive hybrid rice cultivation, viz. mountainous zone in the north, the Red River Delta and the North Central Vietnam.

Investments was provided by the Government to establish isolated locations for production of seeds of parental lines of hybrid rice (Fig. 2).

Fig 2. An isolated location to produce seeds of parental lines of hybrid rice

2.2.3 Commercial hybrid rice production.

Hybrid rice was planted to about 100 ha in Vietnam in 1991. The area covered by hybrid rice increased substantially to 200,000 ha in 1998, 480,000 ha in 2001 and 600,000 ha in 2003. Hybrid rice cultivation now is spreading to the south central coast, central highlands and Cuu Long Delta in addition to the 31 northern provinces. In general, the yield of hybrid rice are 6.5-8.0 tonnes/ha higher than inbred rice at 1-1.5 tonnes/ha.

3 Constraints and gaps in hybrid rice research and development

3.1 Social and economic constraints

When food security of the country had been controlled, Vietnam exported 7-8 million tonnes of milled rice to the world market with low price, which led to lower benefit for rice growers as well as lower demand for hybrid rice cultivation of rice growers.

The living standard of Vietnamese people sharply increased during the last 20 years, which led to high demand for higher quality rice in the domestic market. Thus, large areas of hybrid rice cultivation at the Red river delta returned to planting quality rice.

3.2 Capability constraints

The human resources required for hybrid rice research is higher in terms of quantity as well as quality than inbred rice research. However, very few rice scientists have been trained and worked full time for hybrid rice breeding and hybrid rice seed production.

The exploitation of biotechnology for hybrid rice research is still less and cooperation between hybrid rice breeder with biotechnologist, entomologist, pathologist are not good for hybrid rice breeding.

The facility for hybrid rice research in the public sector and infrastructure for hybrid rice seed production of the companies involved with F1 seed production in Vietnam are poorly established.

3.3 Policy constraints

Lack of insurance for F1 seed production, particularly since F1 seed production is high risk due to climatic change in recent years.

The policy of the Vietnam Government to give free for imported F1 seed from outside does not promote F1 seed production. Most small seed companies prefer to involve in distribution of F1 seed imported from outside.

There is no suitable condition for hybrid rice seed production in the north where hybrid rice is mostly cultivated to date, due to erratic climate and late harvesting time. Hence, there is a need to develop alternative seed production sites in the central and Cuulong River Delta provinces (Quangnam, Daklak, Longan, Haugiang, etc.)

4. Lessons learned

To achievel hybrid rice development, there is a need for policy support. The top leadership of the country has to confirm to invest in hybrid rice research and development of hybrid rice and develop a country strategy for research and development of hybrid rice.

The country has to invest in hybrid rice research involving rice breeders, entomologists, pathologists, biotechnologists and agronomists to cooperate in research and development of hybrid rice or apply hybrid rice technology.

Full-time scientists should work long term in hybrid rice research and development Scientists should be trained in hybrid rice technology. The required equipment for research should be provided

It is required to have a close cooperation between hybrid rice researchers and hybrid rice seed companies for the exploitation of new hybrid rice combination into commercial rice production.

It is needed to have partnership between the public and the private sector for hybrid rice seed production. .

It is required to develop a suitable management package for different types of hybrids to exploit fully the yield potential of hybrid rice.

For the success of hybrid rice development, the support from FAO and IRRI for funding and international technology consultants plays a very important role.

Opportunities for hybrid rice development

High-quality hybrid rice had been developed and exploited in large scale in different countries, viz., HYT100 of Vietnam, SL 8H of Agritech Philippines and Syn6 from China. Their yields reached 8-10 tonnes/ha and their quality are similar to quality of inbred rice group in Vietnam such as BT7, P6 and AC5.

China has successfully developed super high-yielding hybrid rice in commercial exploitation (12-14 tonnes/ha). In Vietnam, the yield of super high-yielding hybrids developed in the country gave 11-12 tonnes/ha in demonstration plots at suitable locations. These facts are opening greater potential to break the hybrid rice yield ceiling for the last 40 years.

It is expected that super high-yielding hybrid rice will play a crucial role to ensure food security for rice growing nations in Asia in the future as well as high quantity of rice which can be used for feeding livestock and other animals.

The high development of biotechnology tool in recent years can be exploited for hybrid rice development to develop rice hybrid with high yield, good quality, resistance to diseases and insect and good tolerance to high-stress conditions created by climate change.

The rapid development of the private sector in hybrid rice seed production and the partnership between the public and private sector are believed to be the main factors for sustainable hybrid rice development in Asia.

Key strategies and policy options to promote hybrid rice development in Vietnam to 2020 and beyond

- To exploit the advantage of agriculture research system through the cooperation of hybrid rice breeders with biotechnologists, entomologists, pathologists, agronomists, etc.

- To develop hybrid rice having high yield, good quality, resistance to major diseases and insects and tolerance to stress conditions such as drought, salinity and submergence created by climate changes

- To strengthen research and development of super high-yielding hybrid rice not only for food security but also for providing the material for processing food for livestock and other animals.

- To support cooperation between the public and the private sector to establish seed production bases at optimum locations in the north, central and the Ssuthern provinces of Vietnam.

- To support the development of irrigation systems, required machinery, etc. for F1 seed production.

- To support the training of seed growers as well as hybrid rice growers on advanced hybrid rice technologies.

- To strengthen extension systems to transfer hybrid rice technology.

- To set up new seed policy to give importing hybrid rice seed of new combination only for two years, after that the F1 seed have to be produced in country (Vietnam). It is required from all seed companies involved in domestic F1 seed production.

- To create a new policy to support seed companies to accumulate land at optimum locations for use for 50 years for F1 seed production similar to industry land.

- To apply insurance practices for F1 seed production for seed growers.

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