Rice Flagship project 5:

New rice varieties

Rationale and scope

The contribution of new crop varieties to improving food security and reducing poverty is one of the best documented outcomes of international agricultural research, especially for crops such as rice and wheat (Evenson and Gollin 2003, Fan et al 2005, Raitzer and Kelley 2008, Renkow and Byerlee 2010). Genetic crop improvement is one of the pillars of the CGIAR and it features prominently in the SRF. In the rice sector, genetic crop improvement remains essential. Yields still need to increase to keep up with the increasing global demand for rice, and increasing genetic gain is one of the two main ways to increase yields (the other being improved agronomy/crop husbandry to close yield gaps, see FP3 [Sustainable rice faming systems]). Current annual rates of genetic gain of 0.8–1.0% need to increase to 1.5–2.0% to meet increased food demand in the future. Genetic gain includes raising intrinsic yield potential as well as increasing tolerance for, and resistance to, yield-limiting factors such as biotic and abiotic stresses. Stresses like drought, flooding, salinity, and adverse temperatures are already severe in many rice-growing environments, and will generally become more severe in the future because of climate change, which will also induce the emergence and spread of new pests and diseases. To respond to these challenges, a constant stream of new rice varieties with enhanced yield potential, yield stability, and multiple resistances to various stresses must be available to farmers.

Empirical research and socioeconomic analysis consistently shows feminization of rice farming in Asia, Africa, and South America because of rising off-farm wages and increased climatic stresses such as drought, flooding, and salinity. These two factors have led to a growing rate of male outmigration in small-scale farming households. As a result, farming responsibilities, particularly in unfavorable environments, are increasingly being taken care of by women farmers. Ironically, women farmers also suffer the most from food insecurity (Neha and Quisumbing 2013). Hence, specific needs and preferences of women farmers for particular rice varieties should be an important driver for the development of new varieties. Evidence also shows that women and children are more likely to be malnourished due to lack of access to nutritional food (Bhagowalia et al 2012). Since rice is widely consumed in the majority of low income-earning households in Asia, Africa, and South America, increasing the nutritional quality of rice will have a direct impact on women's and children's nutritional security. Finally, the purchase of rice by consumer households is dominated by women. Hence, their preferences are driving markets in relation to various quality aspects such as taste, cooking time, aroma, fluffiness, and stickiness.

Rice production has an environmental footprint, with the use of increasingly scarce water resources and the emission of GHGs being the most prominent factors. Breeding can play a mitigating role by developing varieties that perform well under management practices that reduce the use of scarce resources (e.g., water-saving) and the production of GHGs (methane-reducing technologies) or by developing varieties that intrinsically use fewer resources (such as water and nutrients) and inputs (pesticides).

The above needs for genetic improvement play out against the backdrop of rapid structural transformations in the rice sector such as increasing feminization that change the way rice is grown and that put new emphasis on quality and other market requirements (Mohanty 2014). Increasing labor scarcity is leading to the rapid adoption of mechanized direct seeding, which puts new requirements on rice varieties such as early uniform emergence, early vigor, weed competitiveness, and lodging resistance. Demand for rice with special properties such as aroma and better nutrition is steadily growing. To meet these demands, grain quality characteristics need to be mainstreamed in all regular breeding programs to offer a variety of new products to rice consumers. Farm diversification requires rice varieties with shorter duration to expand the window of opportunity for growing additional crops each year to increase nutritional security and income, particularly for women farmers.

Objectives and targets

Flagship Project (FP) 5 will speed up genetic gain for the development of improved and climate-resilient rice varieties to increase men and women farmers' income, reduce

FP5 research outcome	Sub-IDO	IDO	SLO or cross-cutting issue
Rice diversity in rice gene banks used globally for identification of traits and discovery of new genes	Increased conservation and use of genetic resources	Increased productivity	Reduced poverty Improved food and nutrition security for health
Novel tools for precision biotech breeding based on genetic diversity shared open access and globally	Increased conservation and use of genetic resources	Increased productivity	Reduced poverty Improved food and nutrition security for health
New rice varieties resulting in 1.3 % genetic gain in intensive systems	Enhanced genetic gain	Increased productivity	Reduced poverty Improved food and nutrition security for health
Rice varieties with 20, 15, 10% reduction in yield loss caused by factors induced by climate change, in mega deltas, rainfed lowlands, and uplands, respectively	Enhanced capacity to deal with climatic risks and extremes	Mitigation and adaptation achieved [to climate change]	Climate change
High quality and high nutritious rice varieties that are preferred by men and women farmers and consumers	Increased access to diverse nutrient-rich food	Improved diets for poor and vulnerable people	Improved food and nutrition security for health
Prototype C4 rice lines with increased yield potential available	Increased conservation and use of genetic resources	Increased productivity	Reduced poverty Improved food and nutrition security for health
Increased capacity on modern rice breeding technologies in partner research organizations	Increased capacity for innovation in partner research organizations	National partners and beneficiaries enabled	Capacity development

their vulnerability to climate change, and increase farmers' and other consumers' food and nutritional security. FP5 will focus on increased use of genetic variability (including genebank accessions), precision breeding, and innovative breeding tools to address yield stagnation, yield reduction by climate-related stress, yield reduction by biotic stress, and inclusion of nutritious and quality traits across all breeding activities. It will collaborate with the genetic gains platform in developing and using new prebreeding tools. Together with its partners and with FP1 (Accelerating impact and equity), FP5 will also strengthen dissemination and seed distribution networks of the improved varieties. Throughout, it will pay particular attention to needs and preferences of women farmers and of women rice purchasers in relation to rice varietal traits. Capacity development activities will support individual and institutional strengthening of FP5 partners on a range of topics, such as novel breeding tools, harnessing genetic diversity, modernization of breeding programs to accelerate genetic gain, and strengthening gender awareness.

FP5 will deliver the following research outcomes to selected sub-IDOs, IDOs, SLOs, and cross-cutting issues of the SRF (see also Tables A-D of the performance indicators matrix):

Impact pathway and theory of change

Fig. 5.1 presents the impact pathway and theory of change, with risks and associated enabling actions of FP5. The logic flow of the impact pathway is that farmers obtain higher income from growing novel varieties that have higher yield (under stress and climate change), yield stability, resource-use efficiency, and/or added value by having quality traits that are in high (new) market

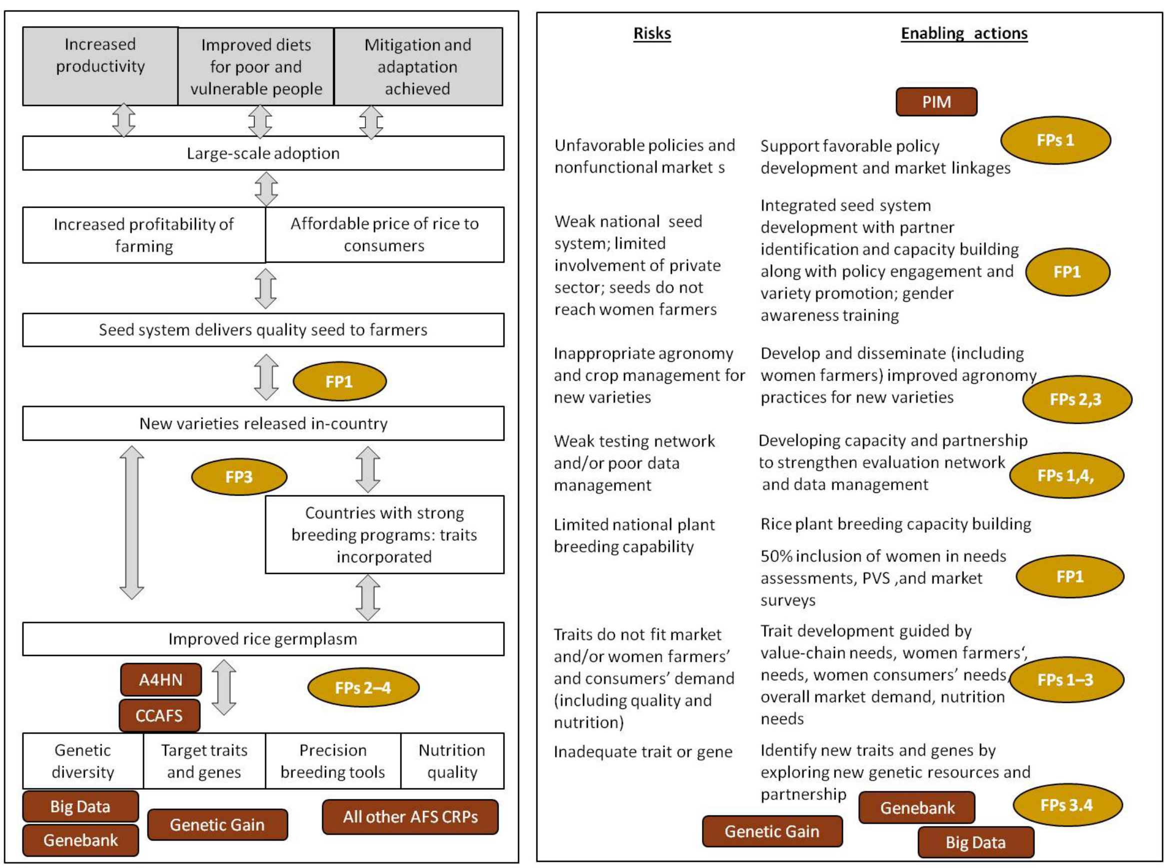

Fig. 5.1. Impact pathway (left) and theory of change (right) of FP5. Grey boxes are IDOs, ovals (with FP x) refer to links with other FPs, and the dark boxes refer to links with other CRPs (see Annex 14.2 for abbreviations).

demand. In order for this to happen at scale, desired traits need be identified, built into new varieties, and disseminated to and adopted by large numbers of farmers and value-chain actors (millers, processors, and traders). Support for large-scale delivery of new varieties through improved seed distribution systems is undertaken in FP1, through Cluster of Activity (CoA) 1.4 'Seed delivery systems', which is very closely linked with FP5. The specific targeting of women farmers will lead to increase in their income, which will have a multiplier effect on family food and nutrition security. With successful large-scale production and marketing of the new varieties, rice will remain affordable for net consumers (including small farmers), thus contributing to their food and nutrition security and reduction of their poverty status.

As Fig. 5.1 shows, assumptions and risks that can prevent achieving full impact range from inability to identify and produce the desired trait response to nonadoption by farmers and weak or remote seed release systems that prevent delivery of sufficient quality seed to end users.

To minimize the risk of not successfully identifying desired traits or of developing varieties that are not attractive to farmers, FP5 will use outcomes of FP2 (Upgrading rice value chains) in understanding value-chain demand (e.g., millers, processors, and traders) and market preferences of consumers, especially those of women. Such traits typically relate to shape and size of grains, head rice recovery, taste, aroma, texture, etc. Also together with FPs1 and 2, needs, preferences, and opportunities for specific varietal traits will be identified among men and women farmers in the target rice-growing environments. Such traits are typically related to yield potential; maturity and duration; tolerance for stresses such as drought, submergence, salinity, and problem soils; resistance to pests and diseases; and quality characteristics related to home consumption and markets. Especially important are traits related to climate change. Predictions of future climates are needed in order to develop climate-smart varieties (i.e., varieties adapted to climate-induced changes in weather, pests, diseases, and other environmental factors) specifically suited for RICE target environments. FP5 collaborates with FP4 (Global Rice Array) and CCAFS to obtain maps of climate-change induced weather patterns and stresses, especially for mega-deltas and coastal regions predicted to be affected by sea level rise (increasing incidences of flooding and salinity intrusion). Similarly, accurate regional and location-specific predictions will be sought of increases in day and night temperature, shifts in cropping seasons and rainfall patterns, and occurrences of droughts. Consequences of climate change on geographic shifts in populations of insect pests and emergence of new insect-borne diseases and their interaction with abiotic stresses need to be better understood as the changes become more apparent.

After desired traits have been incorporated into novel germplasm, participatory approaches such as varietal selection and taste panels among farmers, including women, will reduce the risk that the varieties do not match demand and are not adopted. FP5 works with local partners in developing and releasing location-specific cultivars. It will invest in institutional capacity development to modernize local or national breeding programs to accelerate breeding cycles and the development and delivery of new varieties. Breeding networks involved in evaluating new material will be strengthened and monitored to ensure the collection of relevant high-quality data that are properly managed and analyzed.

To reduce the risk of failure to deliver seeds of new varieties to target farmers, FP5 will support FP1 in the development of partnerships to strengthen weak seed distribution systems and to develop them where they are nonexistent, e.g., through development of community seed banks. FP5 will also partner with an array of public, private, and civil society (NGO) partners depending on location-specific circumstances. Capacity development will play a large role. FP5 will work with FP1 nationally and regionally to influence changes in local policies and regulations to accelerate varietal release processes, and to align partners along the seed chain to ensure production and timely delivery of high-quality seeds. Improving varietal release guidelines, seed certification policies, and seed system infrastructure, together with enabling environments for private-sector involvement, will accelerate delivery and shorten the time for outreach and varietal turnover.

To reduce the risk that women farmers and consumers insufficiently benefit from the new varieties, they are explicitly targeted in the identification of desired traits, in participatory variety selection processes, in preference and taste panels, and in outreach activities such as seed distribution, demonstrations, and training. Together with FP1, FP5 also invests in raising gender awareness among its research and development partners.

Science quality

FP5 will accelerate genetic gain by capitalizing on breeding material, knowledge, and tools developed during GRiSP. The global phenotyping network and associated phenotyping methodologies developed by FP4 will be intensively used for early evaluation of the breeding material in FP5. Rapid uptake of genotype-phenotype relationship information and prebreeding material produced in FP4 will be assisted by streamlining the use of conventional tools (such as marker-assisted gene introgression-pyramiding and rapid generation advancement) and by adapting and adopting some emerging concepts and technologies. These will include genomic selection and gene editing, and by hosting blue-sky research such as systems biology and C_4 rice. The ability to undertake large-scale phenotyping in multiple environments using the facilities developed in FP4 will be another asset for accelerating genetic gain.

The streamlining of conventional marker-assisted selection (MAS) will be achieved through the ongoing establishment of breeding-dedicated genotyping platforms of homogeneous and compatible characteristics across the three CGIAR centers. To take full advantage of the 3,000 sequenced genomes of rice, a few additional accessions will be sequenced to fill some gaps in the representation of rice genetic diversity.

To go beyond MAS for individual gene/QTL, a systems biology approach will be implemented for some traits heavily involved in resource-use efficiency (i.e., root development) or yield potential (i.e., panicle architecture) to identify relevant gene/allele networks that are targeted in the breeding programs. Allele mining, using the 3,000 genome data, will be systematically undertaken for major QTLs/genes identified in FP4, to detect/validate the most favorable haplotypes and/or the most compatible donors for the recipient breeding program. New breeding populations optimizing recombination rate and genetic resolution power (e.g., MAGIC) will be developed using the above-mentioned high performing and/or multipurpose donors.

Genomic selection, a promising and powerful methodology developed about 15 years ago to increase genetic gain in breeding, is aggressively implemented in private plant breeding companies. In FP5, the genomic selection concept will be applied to rice breeding. The development of a rice-specific breeding program simulator will help optimize the application of genomic selection and new breeding schemes to attain the highest genetic gain per unit resource and time.

FP5 will continue GRiSP's efforts in mastering gene editing tools based on Cas9/CRISPR technology and will use them for validation of candidate gene function. FP5 will also explore their use for targeted upgrading of popular varieties and as a complementary tool in breeding programs. FP5 will also use genotyping platforms and analytical pipelines that are being developed in the CGIAR centers and cross-CRP partnerships such as the Genetic Gains platform and the Genomic and Open-source Breeding Informatics Initiative (GOBII) to accelerate genetic gain. Lastly, FP5 will continue the quest for a major breakthrough in genetic gain by working on the long-term scientific challenges of developing a rice plant with a C_4 photosynthetic engine and adapted anatomical attributes.

GRiSP FP3 performed well in terms of scientific publications, with 33 of the top 50 most-cited publications in GRiSP since 2011 being on molecular breeding, genomics, genetics, and physiology. The RICE FP5 will continue to emphasize high-quality journal papers, and, as per Independent Evaluation Agreement (IEA) recommendation, FP5 senior scientists will mentor junior colleagues, especially those at the lower end of the H-index scale and in Africa. To enhance the number of quality publications in peer-review journals and to reduce publications with no or very low impact factor, FP5 management will monitor publication output and encourage stronger research collaboration among RICE core partners and with partners in ARIs for improving the overall quality of scientific output through jointly authored, high-quality publications. FP5 includes partnerships with prominent scientists in ARIs throughout the world to further augment the upstream research capacity of FP5 CGIAR centers and to access state-of-the-art technologies and bioinformatics support for handling and interpreting the massive amounts of data generated.

Lessons learnt and unintended consequences

FP5 builds on GRiSP FP1 (Harnessing genetic diversity to chart new productivity, quality, and health horizons) and FP2 (Accelerating the development, delivery and adoption of improved rice varieties). A key lesson is that the identification of desired traits should not be limited to needs assessment among farmers but should include preference assessments of all value-chain actors (millers, processors, and traders) and consumers. Otherwise, adoption of new varieties may be hindered because millers or traders will not buy the surplus for marketing. Another key lesson is that the structural transformations taking place in the rice sector are driving segmentation of rice markets, and that breeding programs need to be able to respond by rapidly developing targeted breeding pipelines.

A further lesson from GRiSP is the important role of women farmers, processors, sellers, and consumers, especially in less favorable areas. Through linkages with FPs 1 and 2, special attention will be paid to women's preferences and needs through targeted inclusion of women (50%) in needs and opportunity assessments, participatory varietal selection, sensory preference panels, and market research. In CoAs 5.3–5.5, special attention will be paid to ensuring that women farmers receive new varieties that match their needs through, among others, collaboration with women's farming groups and specialized NGOs, and, in linkage with FP1, through raising awareness among other actors in seed delivery systems.

Trade-offs may exist among the traits of new varieties. For example, tolerance for abiotic stresses such as drought or submergence may come at the expense of yield potential under nonstress conditions (leading to a trade-off in yield level and yield stability). Similarly, positive or negative interaction may exist between seedling stage tolerance for salinity and submergence. These trade-offs will be minimized, or as much as possible removed altogether, during the breeding process, but if they persist, farmers will be made aware of them and guided in the proper use of the new varieties.

Another potential unintended consequence is that improved varieties may preferentially reach the better-off farmers as happened in the early years of the Green Revolution. Together with FP1, FP5 will strengthen seed delivery systems to benefit poorer farmers, especially women farmers who live in marginal areas with most risk of climatic stresses. Partners in seed distribution networks will be sensitized to gender inequalities and village and community seed systems will be strengthened by training women on the effective and efficient management and multiplication of seeds. Impact assessments conducted in FP1 will show how new varieties are contributing to improve farmers' income and well-being and to women's empowerment (i.e., women's control over the increased income). Gender-differentiated adoption studies will identify adoption rates and diffusion paths under different dissemination models in different environments.

The introduction of high-yielding varieties may induce farmers to overuse inputs such as fertilizers or pesticides, as recorded on occasion with hybrid rice. Such unintended consequences of new varieties that are introduced in farming systems will be monitored through FP5 together with FP3 and addressed through training and capacity development on proper management of the new varieties.

Clusters of activity (CoA)

CoAs 5.1 and 5.2 engage in so-called prebreeding activities, the outputs of which feed into CoAs 5.3 and 5.4 that will develop novel varieties for intensive and irrigated, and unfavorable rainfed ecosystems, respectively. CoA5.5 will develop grain quality traits and novel food products that also feed back into the development of new varieties in CoAs 5.3 and 5.4. CoA5.6 focuses exclusively on the development of C_4 rice, with links to CoAs 5.1 and 5.2, and potential spin-off to CoA5.3 in the breaking of existing yield barriers.

Breeding efforts will focus on accelerating genetic gain by improving key steps in the breeding process such as increasing the accuracy of selection using molecular markers in routine selection, reducing the generation interval from cross to cross, increasing population size using mechanization and automation, and taking advantage of multienvironment trials (METs) for wide testing. Breeding lines developed in CoAs 5.3 and 5.4 will be evaluated by METs for adaptation, yield in the target environment, tolerance for climatic stresses, resistance to pests and diseases, and grain quality. The evaluation of breeding lines will have strong linkages with national variety testing programs of different countries.

Participatory varietal selection (PVS) and sensory evaluation (with FP 2) will be carried out prior to releasing varieties meeting the national quality requirement as well as rice farmers' demands. In PVS as well as in sensory evaluation, participants will include at least 50% women to ensure the breeding program captures traits preferred by women. Promising breeding lines will be made available to other institutions through INGER.

5.1 Harnessing rice diversity

Intensive use will be made of the 3,000 sequenced genomes of rice for allele mining and identification of multipurpose donors while maintaining the long-term aim of sequencing new sets of accessions from different subgroups of *O. sativa*, *O. glaberrima*, and wild relatives. The methodology used for diversity analysis using sequence data will be also updated. The 3,000 genome resource will also be used for QTL and gene discovery for traits needed by breeders. Donors identified in initial screening in the Global Rice Array developed in FP4 will be validated through targeted phenotyping in hot-spot sites or in controlled conditions. A plant-systems biology approach will be used to identify key genes and gene networks for adaptation and resource-use efficiency such as root development, and yield potential-related traits such as panicle architecture. The gene discovery approach will include multiscale physiological description and modeling of developmental processes, forward and reverse genetics, functional analyses, modeling of regulatory gene networks, and integrative functional modeling. Knowledge of the genotype-phenotype relationships and of the best donors for target traits will be incorporated into breeding programs through MAS within dedicated breeding populations that have a high level of recombination and genetic resolution power (MAGIC). The exploration and use of rice diversity will be underpinned by effective conservation and management of rice accessions maintained in genebanks. Conservation research to improve the understanding of seed physiology and longevity will be critical to ensure the sustained use of this invaluable resource.

5.2 Precision breeding

A breeding scheme for yield potential and tolerance for major abiotic stresses (such as drought, submergence, salinity, and extreme temperatures) will be progressively adapted to allow the application of genomic selection concepts. The first steps will include proof of concept for efficiency of genomic selection in population breeding, and the use of large diversity panels to predict the breeding value in the progeny of bi-parental crosses. A breeding program simulator will be developed that helps optimize the breeding scheme for faster and cheaper genetic gain than at present.

Tools for precision genome editing such as site-directed nucleases will be used to induce small mutations in loci of interest, to replace alleles, and to insert genetic material at specific sites. This will enable the rapid validation of candidate genes and the efficient introduction and/or fixing of known traits or new alleles into elite material without linkage drag. Diagnostic markers will be used to develop markers for QTLs and genes for different traits. SNP assays will be designed and used to introduce genes and haplotypes for traits required in specific ecosystems and regions. QTLs identified in GRiSP, RICE FP4, and this CoA will be fine-mapped; candidate genes will be identified and functionally validated to develop gene-based markers. Marker-assisted breeding in CoAs 5.3 and 5.4 will then use these markers to pyramid sets of alleles desired for a particular ecosystem into popular varieties and elite lines to develop new varieties. CoA5.2 will also use genotyping platforms and analytical pipelines that will be developed in the Genetic Gains Platform and GOBII.

5.3 Intensive systems

CoA5.3 aims to produce new high-yielding and stable varieties for the intensive rice environments; such varieties will respond to the challenge of climate change, have resistance to pests and diseases, and have desirable quality characteristics responding to the needs of farmers, value-chain actors, and consumers. Building on progress made in GRiSP, breeding efforts will focus on accelerating genetic gain by improving key steps in the breeding process such as increasing the accuracy of selection using molecular markers in routine selection, reducing the generation interval between crosses, increasing population size using mechanization and automation, and taking advantage of multienvironment trials for comprehensive testing. Using the information from CoA5.1 and precise breeding techniques from CoA5.2, this CoA will use new germplasm resources: genes for more grains per panicle, higher panicle branching, more tillers, higher percent grain setting, taller plants, and sturdier stem than in existing varieties. Based on improved understanding of underlying genetic and physiological mechanisms, and using novel modeling approaches, appropriate combinations of traits will be determined to achieve increased genetic gain.

In temperate regions where yields of japonica varieties are generally high, existing cultivars need improvement for resistance to insects and diseases, tolerance for extreme temperatures, and better grain quality traits. Precision breeding techniques will allow overcoming barriers and sterility problems in crosses between indica and japonica varieties. New traits such as high biomass production, nonstructural carbohydrate accumulation and translocation, lodging resistance, tolerance for cold and heat, low solar radiation, and anaerobic germination will be combined.

Mechanized dry direct-seeded rice is an emerging technology replacing manual transplanted rice in areas affected by labor shortages. Suitable varieties will be developed with such traits as early and uniform emergence, early vigor, weed suppression, roots with increased nutrient uptake, lodging resistance, and water-use efficiency. Root plasticity traits that allow rice to have better access to nutrients, flexibility for establishment whether transplanted or dry direct seeded, and better adaptation to cycles of aerobic-anaerobic soil conditions, will provide flexibility to farmers to adapt crop establishment methods according to weather conditions and seasonal labor availability.

5.4 Unfavorable ecosystems

Drought, submergence, salt, extreme high and low temperature, low soil fertility, iron toxicity, low solar radiation, and high disease pressure, individually or in different combinations are among the most serious factors that reduce rice yields in unfavorable rice-growing environments. Droughts are increasing in severity and often alternate with periods of uncontrolled flooding. Many mega-deltas are increasingly affected by floods and salinity intrusion, while incidences of pests and diseases like blast, bacterial blight, and brown planthoppers remain rampant. CoA5.4 will develop novel varieties that combine tolerance for multiple abiotic and biotic stresses using recent (GRiSP) and new discoveries of donors/genes for anaerobic germination, stagnant flooding, salinity, and drought, together with genes for resistance to prevalent pests and diseases. Many of the traditional varieties grown in unfavorable ecosystems possess excellent grain and cooking quality traits. FP5.4 will collaborate with FP5.5 to capture such quality traits and embed them in the new varieties.

Potential donors with traits of interest (identified in FP4 and validated in CoA5.1) and the main relevant QTLs/genes will set the base for the introgression of key traits. Breeding lines will be developed using new breeding technologies (CoA5.2) to gain efficiency and hasten line development. MAS with donors/QTLs/genes that have tolerance for drought, submergence, salinity, high and low temperature, and iron toxicity, coupled with genes for improved nutrient-use efficiency and resistance to relevant biotic stresses will help develop rice varieties with higher and more stable yield in unfavorable rice-growing conditions. Inclusion of MAS in the breeding scheme will result in faster genetic gains by accelerating the breeding cycle through (1) rapid generation advancement, (2) gene introgression, and (3) population breeding. Genomic selection combined with breeding simulations will enable the development of appropriate ideotypes for drought-prone rainfed lowlands and uplands that in turn will contribute to increased rice production in the less favorable ecosystems.

5.5 Grain quality and nutrition

RICE will continue the development of rice with high content of micronutrients, especially zinc, as undertaken in GRiSP and in collaboration with A4NH through HarvestPlus. The development of high-zinc rice is a joint investment with A4NH whereas RICE mainstreams traits for high nutrient content in rice grains throughout its breeding programs.

In market-driven product development (see FP2), associating multiple parameters of grain quality (as proxy traits) can enable breeders to tailor new varieties according to consumer demand. Sensory evaluation has seen limited routine use in rice improvement programs because it is low in throughput, yet it is an integral component of food product development as it captures attributes that routine quality evaluation assays leave out, and it measures consumer preferences. CoA5.5 will use sensory evaluation platforms and novel holistic tools for grain quality traits to capture men and women consumers' preferences for premium quality (organoleptic properties) of cooked rice. Phenotypic assessments of grain quality preferences through metabolic signatures for aroma and taste, and identification of diagnostic markers (using the 3,000 sequenced genomes of rice) for medium-quality and premium-quality rice will be undertaken with emphasis on consumer preferences. Value-added rice products will be generated from specialty rice varieties developed in the categories of (1) healthy and nutritious rice in terms of high levels of micronutrients, high fiber, slow digestibility, and low glycemic index; (2) best cooking quality; and (3) best keeping quality after processing. These will be used to derive processed rice products suitable for the agroindustry in FP2.

5.6 C_4 rice

CoA5.6 focuses on C_4 rice activities, part of a global C_4 rice consortium of GRiSP that attempts to introduce the C_4 photosynthetic pathway into rice, with the aim of achieving 25–50% increase in rice yield while greatly reducing water and nitrogen inputs, increasing profitability and reducing environmental footprint. The technology is widely applicable to other C_3 crops such as wheat and soybean and thus has benefits across a wide range of CRPs. C_4 photosynthesis research involves the construction of transgenic lines with multiple transporter genes via gene stacking, and crossing those transgenes with lines containing the C_4 biochemical pathway produced in GRISP to develop transgenic lines with increased C_4 photosynthetic flux. Genes will also be transferred into rice to alter leaf anatomy and provide the necessary structure to support C_4 photosynthesis (e.g., vein density and bundle sheath cells). An important component of CoA5.6 is the training of a new generation of young scientists at the cutting edge of molecular and genetic science.

Partnerships

FP5 will engage in strong partnerships throughout the variety development pipeline. At discovery research level, FP5 will involve partnership research at ARIs across the globe on genomics, system biology, gene and gene network identification, and their use in precision breeding. Specifically with ARIs in China and India, FP5 will develop strong research partnerships on C_4 rice, germplasm sequencing, gene identification, population development, and trait development. At proof-of-concept level, FP5 will partner with ARIs on genomic selection, marker-assisted breeding, trait development, design QTL pyramiding, and association mapping. For scaling-out, FP5 will partner with NARES on evaluation of lines, PVS, sensory evaluation, and varietal release. The CGIAR institutes associated with FP5 are aware of strong NARES in many rice-growing countries. With those NARES, FP5 will partner more on trait development, marker development for traits, precision breeding tools, standardization, and refinement and use of genomic selection strategies in rice.

A strong comparative advantage of this FP is the 40–50 years of experience in rice breeding of the CGIAR centers AfricaRice, CIAT, and IRRI, including their worldwide partnership networks that cover all the major rice-growing environments, their global breeding efforts, and their ability to integrate knowledge produced by the international community working on rice as a model plant. The CGIAR centers of FP5 are unique in their ability to facilitate the exchange of germplasm across national borders, assuring phytosanitary health and meeting regulatory norms in an increasingly restrictive global situation. They lead global and regional varietal evaluation networks, such as MET in Asia with more than 50 partners, the Africa-wide Rice Breeding Task Force with 29 national partners, and CIAT/FLAR with partners from 17 countries in Latin America. These networks provide a unique global partnership for developing and sharing new rice germplasm that responds to both global and local challenges. Equally relevant is the expertise of Cirad, JIRCA, and IRD with system biology, genomic selection approaches, gene identification, and integration of modeling with breeding programs.

Through IRRI, AfricaRice, and CIAT, GRiSP has pioneered the transformation of rice breeding programs by the conversion of breeding activities into market- and product-oriented trait and variety development pipelines, acceleration of selection using rapid generation advancement, and development and use of HTP, genotyping, and information management platforms. FP5 continues and expands this program, and will transfer its model to NARES partners.

Climate change

The main grand challenge that FP5 addresses is climate change. New rice varieties will be developed and delivered with tolerance for stresses induced or exacerbated by changing

Some major partners and their roles are:		
Discovery	Proof of concept	Scaling out
BGI-Shenzhen, ACIAR, CSIRO, US$A, Cornell University, Duke University, Max Planck, University of Cambridge, University of Oxford, University of Sheffield, University of Nottingham, University of Toronto, Washington State University, University of Dusseldorf, Shanghai Institute of Biological Sciences, Australian National University, Academia Sinica (Taiwan), Simon Fraser University, National Institute of Agrobiological Sciences (NIAS, Japan), INRA (France), University of Milano, University of Aberdeen, Yale University, University of Tokyo, Embrapa, National Agriculture and Food Research Organization (NARO, Japan), Department of Biotechnology (India), and Chinese Academy of Agricultural Sciences	Indian Council of Agricultural Research, Bangladesh Rice Research Institute, FLAR partners in Latin America, Africa-wide Rice Breeding Task Force (29 NARES in Africa), CRA (Italy), Embrapa, HRDC in Asia and Latin America, UPLB, PhilRice, MARD (Vietnam), MARDI (Malaysia), RDA (Republic of Korea). Central Rice Research Institute (India), Indian Institute of Rice Research, Chinese Academy of Agricultural Sciences	DARE, NSP, and agricultural universities from India; Nepal Agricultural Research Council; Cambodian Agricultural Research and Development Institute; CARP (Sri Lanka); DOA (Thailand); PARC (Pakistan); PhilRice and PCAARRD (Philippines); MAF (Laos); MOAI (Myanmar); GSDM (Madagascar); Consejo Mexicano del Arroz (México); Genarroz (Dominican Republic); ANAR (Nicaragua); Senumisa (Costa Rica); Fedagpa, Secosa, and Conagro (Panamá); Iancarina, DANAC, Aproscello, Asoportuguesa, INIA, and Fundarroz (Venezuela); GRDB (Guyana); Aceituno, CORPOICA, SEMSA, and Fedearroz (Colombia); INIAP (Ecuador); CIAT/FENCA and CAISY (Bolivia); INIA-ACA (Uruguay); INIA (Chile); IRGA (Brazil; INTA, Copra, and Adecoagro (Argentina); DICTA APHRA ANAMH (Honduras); ICTA (Guatemala); El Potrero Farm (Peru); FEPRODES and UNIS (Senegal); Syngenta Seed, Notore Seed, Value Seed, and Lumiere Seed (Nigeria); Neema Agricole Du Faso (Burkina Faso); and FASSOKABA (Mali)

and increasingly variable climates: variable water availability (drought and flooding), extreme temperatures, salinization, and the emergence and spread of new pests and diseases. The use of such varieties will increase and stabilize yields, reduce yield failures and yield reductions, and increase the resilience and adaptive capacity of farmers to climatic (and climate-induced) shocks. Also, the development and delivery of short-duration varieties will facilitate the diversification of farming systems, thus further increasing farmers' resilience and livelihood opportunities. The development of water-efficient varieties will contribute to the conservation of water as a natural resource.

Gender

FP5 aims to improve women farmers' livelihoods and family food security through the development and targeted delivery of stress-tolerant, short duration, and high-yielding rice varieties adapted to climate-change. Short-duration varieties will allow women to intensify the cropping pattern (and improve their nutritional security) by cultivating other crops such as legumes. High-yielding varieties will improve women-led households' food security and help them earn extra income. The development of varieties with improved productivity in unfavorable environments, either as a result of better stress tolerance or higher water-use and nutrient-use efficiency, will deliver further benefit to women farmers who are less likely to have access to resources like water, fertilizers, and phytosanitary products. Since rice is widely consumed in the majority of low-income earning households, increasing the nutritional quality of rice will have a direct impact on women's and children's nutritional security.

Together with FP2, attention will be given to the development of new rice varieties that specifically take women farmers' and women consumers' preferences into account, using two complementary activities. First, ex-ante preference analysis techniques such as investment games will be used to identify the needs of women farmers and consumers. Second, ex-post preference analysis such as PVS and sensory evaluation will be conducted to identify the most preferred varieties in terms of cooking time and specific organoleptic characteristics. A target of 30-50% women will be included in these assessments. Together with FP1, new varieties will be disseminated using women-centric delivery approaches, including women's organizations and self-help groups, pioneered under GRiSP (Women at the heart of technology delivery). FP1 will train women in seed management and multiplication to enhance their sustained access to seed of improved varieties.

Capacity development

In FP5, specific actions are undertaken related to the following four steps of the CGIAR Capacity Development Framework: Develop future research leaders, Research, Institutional strengthening, and Gender-sensitive approaches. Partners' breeding capacity will be strengthened through training of young breeders (the future research leaders—including at least 50% women) on advanced breeding tools and techniques, including molecular approaches and plant biology. This will be achieved through annual training programs at each of the CRP institutes or in their respective countries, on-the-job training in project activities, and through open online courses on rice genetics and breeding. FP5 and FP1 will also provide training on seed systems, directly or through training of trainers, to a larger array of stakeholders, including at least 50% women participants. Institutional capacity of NARES partners will be developed in transforming rice breeding programs to accelerate genetic gain, using experiences in this area under GRiSP. Women farmers and (aspiring) young entrepreneurs are especially targeted for capacity development in seed delivery, for example, through training on community seed banks, seed health, and marketing. Women farmers will also be trained on variety evaluation through participation in participatory varietal selection.

Intellectual asset and open access management

FP5 follows RICE policies and strategies on intellectual asset management, open access, and data management, in line with the CGIAR Principles on the Management of Intellectual Assets and their Implementation Guidelines, and with the CGIAR Open Access and Data Management Policy and its Implementation Guidelines. FP5 intellectual assets (research data, outputs) span the whole discovery research–delivery chain, from prebreeding products such as better characterized and exploited rice gene pools, new donors, genes of agronomic importance, advanced breeding tools and methodologies; to new genetic material with traits for stress tolerance, lines with high yield potential for intensive systems, and water- and resource-efficient varieties suitable for mechanized direct-seeded systems. Data will be widely and publicly accessible through pertinent and dedicated websites such as the International Rice Information System, (providing access to structured information on rice germplasm pedigrees, field evaluations, structural and functional genomic data—including links to external plant databases—and environmental (GIS) data) and the Rice SNP-Seed Database (providing genotype, phenotype, and variety information based on the 3,000 Rice Genomes Project). Through the International Rice Informatics Consortium (IRIC), FP5 will develop public/private-sector partner agreements for the use of discovered genes/materials to ultimately reach as many farmers and national breeding programs as possible. Access to data and germplasm will be guided by customized Material Transfer Agreements and specific collaborative and use agreements.

FP management

FP5 is led by Dr. Arvind Kumar, senior rice breeder IRRI. Each CoA is co-led by a team of senior scientists (focal persons) consisting of one or more representatives from each center.