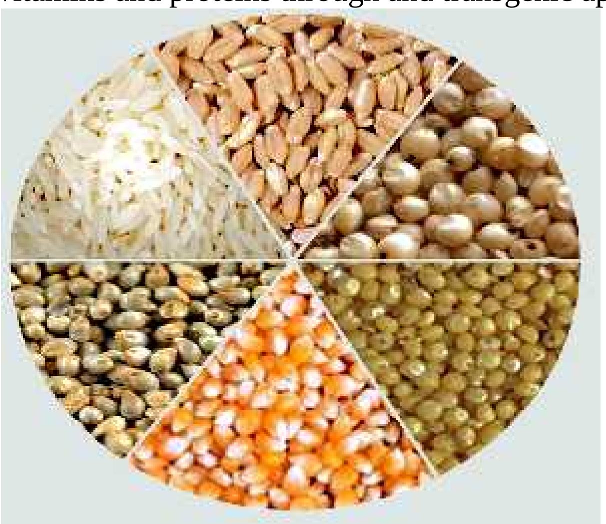
ICAR Agri-Consortia Research Platforms (Agri-CRP)

'Biofortification in selected crops for nutritional security'

Coordinator: Project Director, Directorate of Rice Research

Billions of people around the world and in India suffer from 'hidden hunger' or micronutrient malnutrition affecting the health of an individual directly and development of nations indirectly. Cereals as major sources of carbohydrates in food chain are inherently low in iron, zinc and protein contents with lesser bioavailability. Interventions like supplementation with pills and supported enhancement of intake of animal products are not sustainable in the long run. Improvement of standards of health by reducing child mortality and improving maternal health is one of the major Millennium Development Goals (Yuan et al 2011). The deficiency of iron, zinc, vitamin A and protein deficiency directly affect the health of an individual and indirectly economy of the nation by increasing the number of Disability-Adjusted Life Years (DALYs – a frame work, which quantifies the economic impact of disability and disease). The micronutrient malnutrition is distressing phenomena observed mostly in developing nations owing to their dependence on cereals as major staple food.

Biofortification refers to the genetic enhancement of key food crops with enhanced nutrients (Bouis, 2002). They can be effective in reducing the problem of malnutrition as part of a multi-pronged strategy that includes dietary diversification, supplementation, and commercial fortification, among others. By providing some of the recommended daily allowance for micronutrients, biofortified crops can be effective in reducing malnutrition due to micronutrient deficiencies. Biofortification can be done by adopting either conventional breeding approach or through the genetic engineering approach depending upon the trait of interest and variability for the trait available in nature. Several research attempts across the world led to the identification of key genes involved in micronutrient metabolism and their use in crop improvement programs. Under national and international projects, major crop species are being targeted for the enhancement of micronutrients; vitamins and proteins through and transgenic approaches.



Realizing the importance of crop biofortification in human health in the country, the Indian Council of Agricultural Research (ICAR) has sanctioned an Agri-Consortia Research Platform (Agri-CRP) for enhancing the nutritional status of major food crops of the country through biofortification approach. In the current proposal (revised) submitted under the CRP-Biofortification, five major cereal crops viz., rice, wheat, maize, sorghum and pearl millet, two small millets, (viz., finger millet and foxtail millet) and one tuber crop viz., potato have been selected for biofortification by Directorate of Rice Research (DRR); Directorate of Wheat Research (DWR); Directorate of Maize Research (DMR), Directorate of Sorghum Research (DSR), All India Coordinated Pearl Millet Improvement Project (AICPMIP), All India Coordinated Small Millet Improvement Project (AICSMIP), Central Potato Research Institute (CPRI), National Institute of Nutrition (NIN), National Institute of Animal Nutrition and Physiology (NIANP) and other associated centers. Though the selected cereals and potato form a major source of carbohydrates; the presence of nutrients after processing is far below the recommended level. With the availability of the genotypes and genes as proof of concept for biofortification and considering the significant progress witnessed in several crops with respect to biofortification, the current project is being proposed under the CRP-Biofortification to develop cereals and potato biofortified with β-carotene, iron, protein, zinc, enhance their bioavailability and reduce the anti-nutrients through conventional, marker-assisted breeding, genetic engineering approaches, assess the biosafety status of the biofortified crops and their socio-economic impact.

Proof-of-concept available for biofortification (through transgenics and conventional breeding)

Crop	***Transgenics/Transgenes being introgressed into popular varieties***	***Conventional breeding***
Rice	Golden Rice (β-carotene rice)	High zinc rice, High protein rice
	High iron Rice	
Wheat		High protein, iron, zinc
		Low phytate
		High phytase
Maize		High protein

Progress in bio-fortification in crops

Rice	
Transgenic approach	✓ Golden Rice– Pro-Vitamin A breeding lines are developed ✓ High iron lines are developed ✓ Marker-assisted product diversification is in progress
Conventional approach	✓ Lines with high zinc and protein available
Wheat	
Conventional and marker-assisted Breeding	✓ Identification of germplasm with high iron and zinc, low phytate and high phytase, high protein completed ✓ Breeding lines with high zinc and low gluten

	through molecular breeding available
Maize	
Conventional and marker-assisted Breeding	✓ Lines with low phytate content available ✓ QPM lines with high ß carotene levels available ✓ Breeding lines crtRB1 for enhanced ß carotene available
Pearl Millet	
Conventional Breeding	✓ Germplasm with high iron and zinc content available
Small Millets	
Conventional Breeding	✓ Germplasm with high iron and zinc content available

Economic and other relevant aspects of the proposal:
Biofortification through breeding is cost effective and sustainable. In principle, once such micronutrient-rich crops are developed and successfully disseminated, they automatically form part of the food chain. Hence, one-time investment on this strategy can produce a constant stream of future benefits to consumers of these crops. According to calculations by Stein et al 2005, the current burden of iron deficiency (ID) in India amounts to 4m healthy life years lost each year. The analysis also showed that iron biofortification is not only effective in reducing the burden of ID, but also cost-effective compared to other health interventions. In an optimistic scenario this burden would be reduced by more than 75% by biofortification intervention and less than $1 is sufficient to save one healthy life. Extending this analysis – for pragmatic and advocacy reason – to a cost-benefit analysis, the results are impressive. In the pessimistic scenario, we derived an internal rate of return of 74%, while in the optimistic scenario this figure even reached 152%. It may also have important spin off effects for environmentally beneficial increase in farm productivity (Graham et al 2001). Other studies also indicated that minerals are essential in helping the plants to better resist the diseases and other environmental stresses. Generally, micronutrient rich seeds are associated with greater seedling vigour, which in turn is associated with higher plant yield. All this could contribute to reduce the need for fertilizers, fungicides and irrigation (Ficco et al 2009). Other encouraging results are that iron and zinc are significantly and positively correlated and they are independent of both grain yield and grain size suggesting that there is good scope for improving Fe and Zn contents and no trade-off existed between yielding ability and micronutrient contents.

The project will lead to development of high productive varieties and parental lines with higher micronutrient contents in the grains. On the longer run, the cultivation and consumption of the micronutrient rich grains would help in alleviating the micronutrient deficiency in the target population leading to improved health. Hence, the economic implications will be huge from this project. A significant difference can be made to the nutritional security of the target populations that can be measured through the impact analysis. Further, biofortification also enhances the feed value of the crop. Millets are grown by resource poor farmers in remote areas and hills under rainfed situations which are hot spots of hidden hunger in the country. Nutritional enriched millets will be highly useful to combat the hidden hunger/ malnutrition and bring nutritional security in remote areas of the country.

Objectives of the proposal:

1. Development of crop genotypes with high β-carotene, iron, protein through genetic engineering and marker assisted introgression of transgenes and their bioavailability and biosafety studies
2. Development of crop genotypes for high zinc, iron, protein through conventional breeding and identification of genomic regions associated with enhanced micronutrients and proteins through mapping and association mapping
3. Development of transgenic lines possessing high micronutrients (Fe, Zn and ß carotene), proteins and reduced phytates and their diversification into high yielding/popular varieties and development of lines possessing genomic regions and transgenes associated with high micronutrient and protein content in the genetic background of high yielding/popular varieties
4. Gene discovery, allele mining and functional genomics for discovery of candidate genes associated with enhanced micronutrient and protein content and reduced phytate content through Next Generation Technologies
5. Development of value added products for ready to cook and multigrain mixtures suitable for mid-day meal schemes
6. Socio-Impact studies for assessment of consumer knowledge, preference and preparedness for biofortified products and sensitization and popularization of biofortified products.

List of approved centres for each of the crops is given below along with the trait and approach earmarked for each Institute

Crop wise list of Institutes (35)

	Crop		**Institutes**
1	Rice**(7)**	β-carotene, iron, zinc, protein, folic acid, low phytate	DRR, IARI, CRRI, IGKV, UAS-B, TNAU Univ of Kolkata
2	Wheat**(8)**	Iron, zinc, protein, low phytate, phytase, low gluten	DWR, IARI, PAU, CCSHAU, UAS-D, NRCPB, AIIMS, NII
3	Maize**(6)**	Protein, iron, zinc, B-carotene, phytate,	DMR, IARI, TNAU, CCSHAU, PDP, VPKAS
4	Sorghum**(3)**	Iron, zinc	DSR, AICSIP-R, AICSIP-A
5	Pearl Millet**(6)**	Iron, zinc	AICPMIP, JAU, CCSHAU, SKRAU (SKNAU), MPKV, IARI
6	Small Millets**(2)**	Iron, zinc	AICRP (SM), MDRF
7	Potato**(1)**	β-carotene, iron and zinc	CPRI
	BIOAVAILABILITY and BIOSAFETY **(1)**		NIN/other agencies
	Evaluation of VAC for animal feeding**(1)**		NIANP

Activity Milestones

Activity	2014-2014	2015-2016	2016-2017
Evaluation of available genotypes with enhanced nutrients for their bioavailability	√	√	
Development of varieties/breeding lines using base genotypes with target traits through diversification and combination strategies	√	√	√
Gene discovery and allele mining for candidate genes associated with high mineral and protein	√	√	√
Testing for bioavailability and biosafety of developed lines	√	√	√
Development of food products with multigrains/ready to cook	√	√	√
Fortification of processes for potato based foods with iron and zinc	√	√	√
In vitro and In vivo screening of biofortified crops for micronutrient bioavailability (Human)	√	√	√
Nutrient composition and nutrient bioavailability of value added cereals (VAC) (Animals)	√	√	√

Expected output of the proposal:

For the all the selected crops the following outputs are expected:

- ✓ Biofortified varieties for single nutrient or multiple nutrients for selected food crops
- ✓ Bioavailability studies for selected food crops
- ✓ Products from multigrain / ready to cook suitable for mid-day meal schemes
- ✓ Socio-Impact studies
- ✓ Information on micronutrient and protein content, phytate levels will be available with validation across laboratories and environment.
- ✓ Information on genetics; gene action; mapping information and candidate genes associated with micronutrient, protein content, phytate and gluten levels

Expected outcome of the proposal (crop-wise)

Rice	Biofortified varieties (3-5) for single nutrient or multiple nutrients Bioavailability of the biofortified varieties established
Wheat	Biofortified wheat varieties (3-5) with information on Bioavailability of the biofortified varieties established
Maize	Biofortified maize varieties (3-5) with information on Bioavailability of the biofortified varieties established
Sorghum/Pearl Millet/Small Millets	Biofortified sorghum/pearl millet/small millet varieties (3-5) with information on Bioavailability Products from multigrain / ready to cook suitable for mid-day meal schemes
Potato	Fortified potato varieties for Bioavailability studies

Deliverables of the proposal (crop-wise):

Rice	1. Biofortified rice breeding lines/varieties developed with transgenic approach for single or multiple nutrients 2. Biofortified rice breeding lines/varieties developed through conventional/marker assisted breeding and transgenic approach 3. Gene discovery 4. Information on Bioavailability and Biosafety
Wheat	1. Biofortified wheat breeding lines/varieties 2. Information on Bioavailability and Biosafety 3. Gene discovery 4. Breeding wheat lines with low gluten
Maize	1. Biofortified maize breeding lines/varieties 2. Information on Bioavailability and Biosafety 3. Gene discovery
Sorghum/Pearl Millet/Small Millets	1. Biofortified sorghum/pearl millet/small millet breeding lines/varieties 2. Information on Bioavailability and Biosafety 3. Gene discovery 4. Food products with multigrain/ready to cook suitable for mid day meal
Potato	1. Fortified potato products 2. Information on Bioavailability

Monitorable indicators of the proposal

1. Varieties/breeding lines with characterized for β-carotene, high zinc, high protein, high iron as per the crop
2. Biofortified varieties/breeding lines/ low gluten wheat lines through conventional breeding

3. Transgenic lines developed for β-carotene, high zinc, high protein, high iron, low phytate, folic acid as per the crop
4. Information on bioavailabilty studies
5. Identification and characterization of candidate genes and their allele mining
6. Breeding lines (three to five per trait per selected cereal) developed through conventional/molecular/transgenic approach

International linkages:

1. IRRI, Philippines
2. CIMMYT, Mexico
3. ICRISAT, India
4. CIAT, Colombia
5. HarvestPlus
6. Other advanced laboratories in USA, Europe and Australia for consultancy

Project management:

- A steering committee consisting of the following experts will review the programme periodically. The committee will be as follows:

  1. DDG (CS) – Chairman
  2. All crop Director/PDs/PCs (Rice, wheat, maize, pearl millet, small millets, sorghum, potato)
  3. Convener: PD, DRR

- The total budget allocated for the CRP on Biofortification is **Rs.130.00 crores**

- PDs/PCs of each crop will be coordinator for all research activities in respective crops. The crop sub-leaders will be:

Crop	Sub-leader
Rice	CN Neeraja
Wheat	Sewa Ram
Maize	Feroz Hussain
Sorghum	Hari Prasana
Pearl millet	BS Rajpurohit
Potato	BP Singh
Small millets	MVC Gowda

A Work Plan meeting involving all Partners/Coordinators/Sub-leaders on 16th December, 2014 at DRR, Hyderabad and a Financial Plan meeting involving all Coordinators and Sub-leaders on 10th January, 2015 at DRR, Hyderabad were conducted.


CRP - BIOFORTIFICATION