GLDC | # CGIAR Research Program

Grain Legumes and Dryland Cereals Agri-food Systems

Demand-Driven Innovation for the Drylands

Full proposal

CONTRIBUTIONS

List of contributors to the development of the GLDC proposal

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CGIAR Research Program (CRP) - Phase II

Contents

GRAIN LEGUMES AND DRYLAND CEREALS (GLDC)

Executive summary

The Grain Legumes and Dryland Cereals Agri-food Systems CGIAR Research Program will increase the productivity, profitability, resilience and marketability of critical and nutritious grain legume (chickpea, cowpea, pigeonpea, groundnut, lentil, soybean) and cereal (sorghum, pearl millet, finger millet) crops grown within the semi-arid and sub-humid dryland agroecologies of sub-Saharan Africa and South Asia. These agroecologies are where poverty, malnutrition, climate change and soil degradation are among the most acute globally. By 2022-2030, as a consequence of this research, 8.9-21.7 million farm households will have adopted improved varieties, helping 4.4-11.8 million people to exit poverty and 12.7-24.8 million people meet daily nutritional requirements, with 50% of beneficiaries being women. The logic is that improved innovation capacities within agri-food systems of key cereal and legume crops will enable coherent and integrated research and development, production, market and policy reforms that deliver resilience, inclusion, poverty reduction, nutritional security, environmental sustainability and economic growth.

Sorghum, millets and the grain legumes are grown, eaten and traded together within the same agri-food systems. The CRP will coordinate research interventions that recognize and build on the synergies in these cereal-legume-tree-livestock systems. Prioritization for this research was based on metrics of poverty prevalence, agroecological alignment, value of crop production, foresight projections of significant demand and/or deficit in supply, *ex-ante* return on research investment, consideration of quality, market and environmental traits and alignment with stakeholder priorities. Consequently, first-order priorities for research consist of an incomplete matrix of the 9 crops grown in 13 countries of sub-Saharan Africa (Burkina Faso, Ethiopia, Malawi, Mali, Mozambique, Niger, Nigeria, Sudan, Tanzania, Uganda, Zambia) and South Asia (India, Myanmar).

The CRP is logically structured on five Flagship Programs. Informed by purposeful monitoring and evaluation, research planning is driven by the analyzed needs of these agri-food systems (FP1: Priority Setting and Impact Acceleration). Through strategic partnerships, sector intelligence will identify and leverage value chain interventions that support dryland cereals and grain legume markets (FP2: Transforming Agri-food Systems). These analyses and innovation system engagements can inform and direct the cultivar requirements from crop improvement programs, seed and input supply systems (FP4: Variety and Hybrid Development) and the farming systems practices (FP3: Integrated Farm and Household Management) that lead to resilience and sustainable intensification outcomes. Modern breeding approaches will both underpin and increase the efficiency and effectiveness of crop improvement innovations that meet market demands (FP5: Pre-breeding and Trait Discovery).

This Program is a Research for Development investment of US$413 million over five years (2018-2022).

1.1 Rationale and scope

Overview

Improved capacity and inclusivity of women, men and youth to innovate in the production, trading, value-addition and consumption of nutritious grain legumes and dryland cereals will be the outcome from the **Grain Legumes and Dryland Cereals Agri-food Systems CGIAR Research Program (GLDC)**. This program supports prioritized integrated research for development (R4D) on six legume (chickpea, cowpea, pigeonpea, groundnut, lentil, soybean) and three cereal (sorghum, pearl millet, finger millet) crops grown in the semi-arid and sub-humid dryland agroecologies of sub-Saharan Africa (SSA) and South Asia (SA) (Figure 1a). It marries and develops the traditional strengths of crop improvement science, farming systems research and social science in the CGIAR and National Innovation Systems, with R4D that fosters wider market and policy opportunities within the targeted agri-food systems.

It is in these dryland agroecologies where societal grand challenges, specifically targeted in the CGIAR Strategy and Results Framework[1] (SRF), are most acutely evident — malnutrition[2], climate change[3], soil degradation[4], competition for land[5], post-harvest losses[6], ageing and changing workforce[7]. Most of the world's extreme poor live here and it is on these 90 million hectares of mixed farming systems of the semi-arid and sub-humid drylands where over 300 million poor and malnourished both reside and depend on GLDC crops[8].

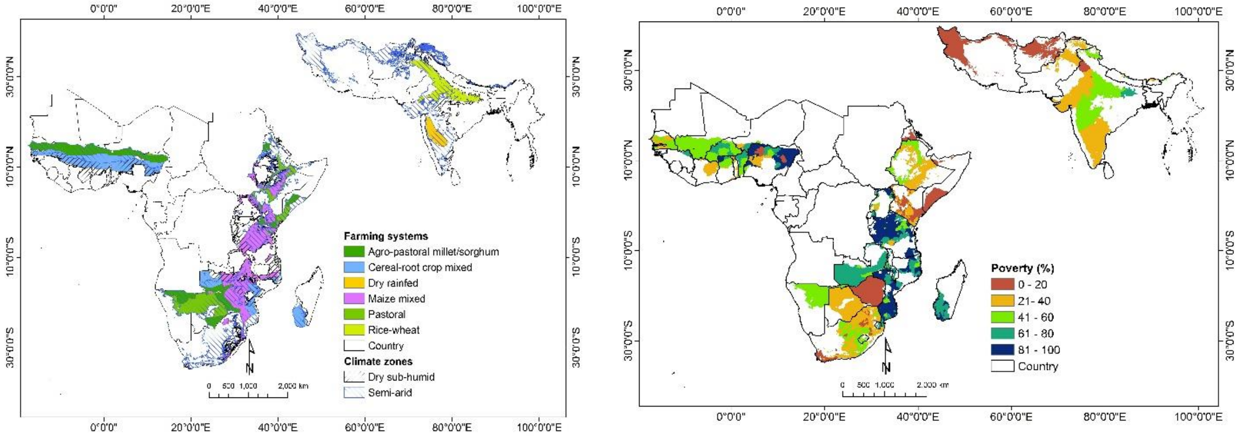


Figure 1a: The semi-arid and sub-humid agroecologies and dryland farming systems of SSA and SA; and 1b: Prevalence of poverty in these agroecologies.

Successful transformation of smallholder agriculture requires not just adapted crop varieties and agronomic management but also the right enabling environment in which these technologies are embedded[9]. Specifically, the right mix of input and output markets, formal and informal institutions and agricultural and trade policies are required to create the incentives for adoption of agricultural innovations such as new and improved varieties, hybrids, management practices and, most importantly, scaling-up models to achieve sought-after impacts. Attracting youth into agriculture through agribusiness entrepreneurship and digital agriculture offers real opportunities for the transformation being sought.

GLDC builds on three Phase I CRPs – Dryland Cereals (CRP-DC)[10], Grain Legumes (CRP-GL)[11] and Dryland Systems (CRP-DS)[12]. In focal regions in SSA, SA, Middle East and North Africa (MENA), Latin America and the Caribbean, between 2012-2016, these programs supported the release of over 370 new varieties of 12 crops and fostered sustainable dryland farming practices; a notable example being the increasing adoption of integrated watershed management programs in India. In phase II, GLDC narrows its focus to SSA and SA, sharpens its research priorities into fewer crops and breeding traits, and targets its system interventions to address poverty and malnutrition in the dryland agroecologies where there is most need[A].

Current and projected challenges

Despite the global rate of extreme poverty decreasing from 28% to 11% between 1999 and 2013, poverty levels remain high in SSA and SA[13]. In fact, the actual number of poor in SSA has increased due to population growth. Poverty rates in the semi-arid and sub-humid drylands, the target GLDC agroecologies, are far higher than the continental rates, ranging from 49% in semi-arid SA to 83% in dry sub-humid Eastern Africa[14] (Figure 1b).

Between 2000 and 2015, food security improved on a global scale, but not as fast as poverty alleviation — the global prevalence of undernourishment decreased from 15% to 11% of the world's population[15]. Trends in child malnutrition decreased globally over this same period. However, by 2016, SSA and SA still had the highest prevalence of child stunting: 34% and 36% respectively. Both regions accounted for 77% of the total number of stunted children recorded globally, amounting to about 199 million stunted children. The high prevalence of stunting in these regions indicates inadequate diets, food availability and access.

Looking to the future in 2030, the target date for the Sustainable Development Goals (SDGs), foresight analysis projects that the global population at risk of hunger will decline from 800 million people worldwide to 600 million, but with climate change slowing progress (Figure 2). By 2030, the number of people at risk of

[A] The rationale and recommendations for narrowing the Phase II CRP can be found in an Expert Panel Report to the CGIAR Systems Management Board. http://www.cgiar.org/wp-content/uploads/2017/04/SC4-05B_%20Expert-Panel-Report-on-GLDC-28April2017.pdf hunger would reach 17% for SSA and 8% for SA; these rates would further reduce by 2050. However, both regions are projected to account for the highest number of people at risk of hunger in 2030 and 2050.

Child wasting is projected to decrease substantially across the world, but the majority of stunted children would still be found in SSA and SA[16]. In this context, GLDC crops are high in protein and micronutrients and should be a key contributor to addressing malnutrition. However, foresight projection[17] suggests an increasing deficit between long-term aggregate supply and demand for GLDC crops (Figures 3a and b), especially with grain legumes.

GLDC crops are highly nutritious[18] and fulfill some of the highest nutrition needs in developing countries, and particularly the needs of women and children. The most common micronutrient deficiencies are iron, Vitamin A, iodine and zinc[19]. Micronutrient deficiencies have a grave impact worldwide and cause untold suffering, especially on at least half the small children aged between 6 months and five years. Overall more than two billion people are affected[20]. Most GLDC crops are high in iron; pearl millet is extremely high in iron, zinc and folate with bioavailability studies by Harvest Plus in Africa and India showing that it can reduce anemia[21]. Finger millet has three times the amount of calcium (364mg/100g) as the equivalent weight of milk[22]. Legumes are particularly high in calcium and protein which are particularly important for growth and development.

To ensure food and nutritional security in GLDC target agroecologies, given the dependence of poor households on agriculture for livelihoods and food security, the supply side constraints in the production of GLDC crops need to be addressed through continued R4D and diffusion of technologies. Meeting this challenge is the driving motivation for investing in CRP-GLDC.

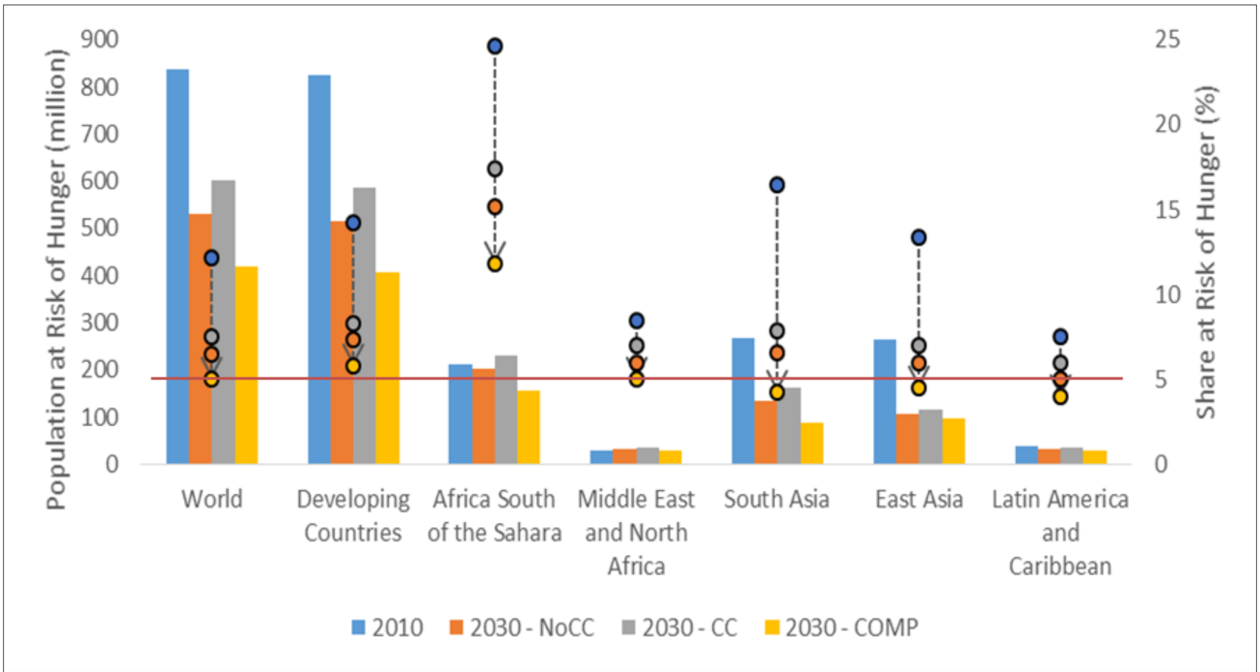


Figure 2: Hunger in 2030 by climate and investment scenario[23]. Bars show numbers on the left axis, dots showing shares on the right axis. 2030-NoCC assumes a constant 2005 climate; 2030-CC reflects climate change using RCP 8.5 and the Hadley Climate Model; 2030-COMP assumes climate change plus increased investment in developing countries.

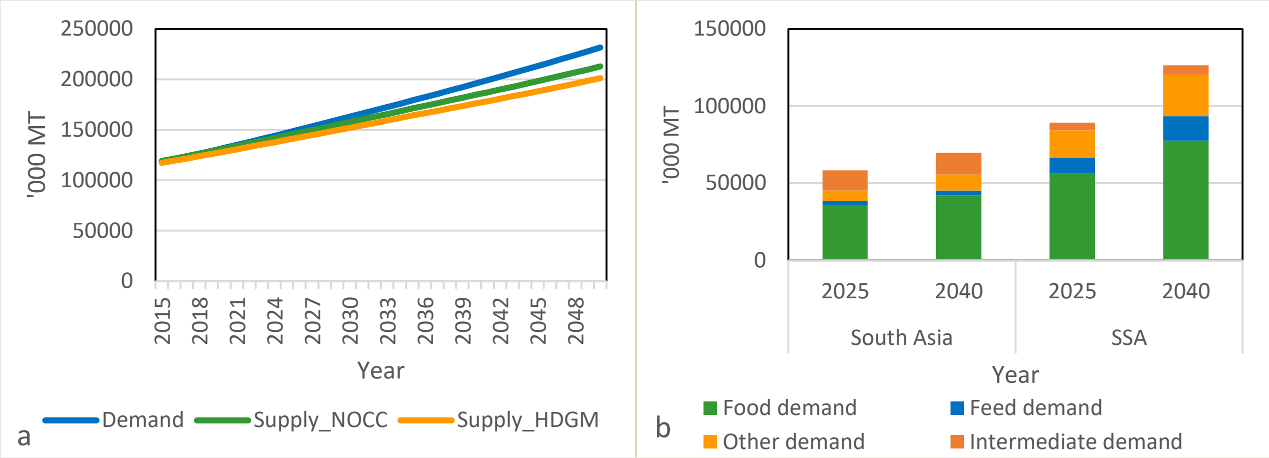


Figure 3a: Supply and demand projection of aggregate GLDC crops in Low Income, Food Deficit Countries with and without climate change; 3b: Projected disaggregated sources of demand of GLDC crops by region in 2025 and 2040 ('000 MT). Source: IMPACT version 3.3, IFPRI, based on SSP2 with 'No Climate Change' (NoCC) and Climate Change (CC) using RCP 8.5 and the Hadley Climate Model..

Cereal-legume synergies

Against the background of current and projected challenges, GLDC will contribute to transforming agri-food systems in target agroecologies and, in doing so, will significantly contribute to meeting the SRF objectives of reduced poverty and improved food security, nutritional security for health and improved natural resource systems and ecosystems services. The CRP's value proposition is based on a rationale of logical synergies between sorghum, millets and the grain legumes grown in common agroecologies[24]. These cereal and legume crops share multiple values in agri-food systems as resilient crops that provide nutritious food for local consumption and as traded commodities[25], or as feed and fodder for livestock[26] and in their particular importance for women farmers and end-consumers[27]. In contrast to the major cereal commodities, these crops suffer the constraints of underdeveloped agri-food systems due to inadequate support and investment by the public and private sectors[28]. Yet they are of critical importance for transforming smallholder farming to become more resilient, productive and sustainable.

In the mixed and agro-pastoral dryland agroecologies of SSA and SA, sorghum, millets and grain legumes are grown in mixed crop-livestock farming systems, in rotation or as intercrops[29]. These systems offer multiple cereal-legume synergies for research intervention, such as improved on-farm sequencing of rotations and intercrops[30]; better management[31] of soil, water, fertility, diseases, pests and weeds; integrating crops with livestock[32]; risk-mitigation through enterprise diversification[33]; and household management of labor, diet and income[34]. Achieving these synergies will require agronomic and farming system research and closely coordinated efforts in breeding with traits that offer complementarity in season length, plant nutrient composition, growth habit and carry-over attributes[35]. GLDC also purports real synergies in post-farm gate research to find and develop the priorities, opportunities and niches for these cereal and legume crops in emergent agricultural value chains.

The place-based farming, household and market synergies of sorghum, millets and grain legumes are one argument for a coordinated R4D program. As importantly, the research facilities that support these crops within the CGIAR and National Agricultural Research and Extension Systems (NARES) partners are also place-based, located throughout the semi-arid and sub-humid drylands. Given the relatively small research infrastructure investment for GLDC crops, shared facilities must offer efficiencies in use and inspiration[B].

Past research and lessons learned

To guide GLDC development, past research investment in GLDC crops was critically assessed based on published material and available evidence, including from Phase I CRPs[36]. A framework of markets,

[B] The multiple synergies between cereals and legumes was the compelling argument of Prof MS Swaminathan when ICRISAT was established in India in 1972 - see http://www.icrisat.org/icrisat45years/

institutions and policies was used to analyze case studies of high and low adoption and draw strategic lessons to guide GLDC design and implementation.

Current adoption rates of improved varieties provide the benchmark. On average, improved varieties cover about one-third of the area planted to GLDC crops in SSA and about two-thirds in India. This level of adoption has taken 30-40 years of Research and Development (R&D). Rates of adoption show large differences between regions – the average area planted to improved varieties of the nine crops in West and Central Africa (WCA) (27%) is considerably lower than in Eastern and Southern Africa (ESA) (40%). Of the area planted to improved varieties, 26% is occupied by varieties released since 2000. This suggests that, in some locations, seed systems have performed well and that models of seed delivery exist that can be replicable elsewhere. Adoption of improved varieties is accelerating for some crops such as hybrid millet in India and WCA, and for cowpea, groundnut, chickpea and pigeonpea and soybean in WCA and ESA. Rapid adoption for these crops in target countries suggests that significant spillover benefits exist for non-target countries. Since 2000, a total of 541 improved varieties have been released for the 9 crops, a median of 26 per crop, or 2 varieties per year across 5 countries in WCA, and 6 countries in ESA and India, indicating a strong pipeline for plant breeding programs. However, for sorghum and groundnuts in India, the high number of releases is not reflected in higher adoption. The reasons for this require careful scrutiny and corrective action by current breeding programs.

A conclusion is that crop improvement R&D for the semi-arid tropics can give high returns[37]. An analysis for 10 ICRISAT interventions gave an average Internal Rate of Return (IRR) of 42% and a return of US$43 for each dollar invested. Impact assessments of microdosing in SSA and hybrid pearl millet in SA showed significant increases in yield, improving household food security[38]. These figures indicate that adoption and impacts can be expected from continued investment through GLDC, although its research needs to identify and address the reasons for differences, learn from these experiences and test their replicability.

The performance of agronomic research has been mixed. While the full package of Conservation Agriculture or integrated soil fertility management options are not so widely adopted[39], the fertilizer component has been successful, with most farmers in SSA who adopt microdosing, using fertilizer for the first time. Given widespread low soil fertility, the impact of microdosing on yields is visible and immediate which explains why microdosing is popular, with adoption rates of 30% in Zimbabwe and 18% in Niger[40]. Since improved varieties are fertilizer-responsive, crop management in GLDC needs to focus on increasing the adoption of fertilizer and optimizing the fertilizer-use efficiency among smallholders with limited cash resources. Integrated watershed management has increased household income by 32%[41].

The commissioned report argues that the Markets-Institutions-Policy rubric is useful because the enabling environment can make or break a new technology. Success stories like pearl millet in India and cowpea in Nigeria show pre-conditions played an important role in achieving high adoption. However, while they are necessary for high adoption, they are not sufficient. Case studies of low adoption like improved pigeonpea in Malawi and conservation agriculture in Zimbabwe reinforce the importance of having the right product along with targeted uptake efforts. In addition, many lessons have already been incorporated in crop improvement programs, resulting in adjustments to breeding objectives. These include:

- ***Increasing adaptability by exploiting traits from local varieties**:* In Mali and Burkina Faso, hybrid parents from Guinea-race sorghum hybrids were developed directly from local varieties in order to incorporate photoperiod sensitivity, but also grain quality and yield stability[42]. All new breeding populations for pearl millet in WCA were derived from local germplasm. Photoperiod sensitivity allows late planting in dry years, giving farmers greater flexibility in coping with drought.
- ***Participatory plant breeding that incorporates farmer preferences early in the breeding program**:* For instance, much of the development of breeding material in early generations for sorghum in Mali and Burkina Faso and millet in WCA is done in collaboration with farmers, to ensure that improved varieties fit within the farming systems and the conditions on farmers' fields, specifically high and low phosphorus (P) [43].
- ***Dual-purpose crops that integrate crops and livestock**:* The cowpea program in Nigeria recognized the importance of cowpea fodder and developed varieties that produced both high grain and fodder yield[44]. ICRISAT has incorporated stover quality into its breeding program for sorghum, pearl millet and groundnut in India.

- ***Earliness as a strategy for coping with drought and improving household food security.*** Improved varieties of pigeonpea in ESA were tailored to match the phenology of the crop with specific agroecosystems based on day-length and temperature[45]. This ensures maturity before the crop is exposed to drought and shortens the hungry period.
- ***Gender-responsive plant breeding**:* This has resulted in inclusion of women in participatory varietal selection (PVS) and gender-disaggregation of trait preferences. Gendered trait preferences reflect gender roles, with women and men giving higher priority to traits that are important for their specific roles in production, processing and marketing[46]. Since gender roles vary by crop and country, so do gendered trait preferences in each breeding program.

Beyond the varieties and hybrids resulting from CGIAR breeding programs, Centers must be assessed by adoption of modern breeding practices for achieving genetic gains. Commitment to achieving continual modernization of crop improvement programs, both within the CGIAR and NARES programs, needs to be at the forefront of GLDC R4D investment. The emphasis should be on empowering of national breeding programs and development of high-functioning, integrated testing networks alongside the NARES and other partners.

Prioritization

The framing brief for GLDC is to address the agri-food systems of critical grain legume and cereal crops grown within the semi-arid and sub-humid dryland agroecologies of sub-Saharan Africa and South Asia[14]. In accord with this recommendation, a stepped process of prioritization was undertaken to identify the targeted agroecologies, countries, crops and breeding targets that will be the research priorities for GLDC. This prioritization process drew on both available material and explicitly commissioned analyses.

a) Agroecologies

A full characterization of the climate and soils, predominant farming systems, population pressure and livestock numbers, and the environmental threats for semi-arid and sub-humid dryland agroecologies of SSA and SA is provided by Hyman et al. (2016) [47]. The regions, agroecologies, commodities and farming systems considered are presented in Figure 1 and Table 1.

Table 1. Crop area ('000 ha) of considered crops in the farming systems of sub-Saharan Africa and South Asia[8]. Shaded cells are GLDC agroecologies.

Farming Systems	Region	Chick pea	Cow pea	Ground nut	Lentil	Pearl millet	Small millet	Pigeon pea	Sorghum	Soy bean	Total
Cereal-root crop mixed	SSA	32	2,983	2,949	1	4,649	128	78	9,594	295	20,709
Maize mixed	SSA	107	387	977	7	655	432	431	1,976	309	5,281
Agro-pastoral millet/sorghum	SSA	1	3,489	1,751	0	7,551	0	8	5,596	108	18,504
Pastoral	SSA	21	2,070	725	7	4,798	9	0	2,955	14	10,599
Rice-wheat	SA	1,966	0	277	977	4,012	144	543	966	362	9,247
Rainfed mixed	SA	4,062	4	4,014	595	2,628	1,697	2,149	4,226	7,276	26,651
Dry Rainfed	SA	1,030	0	1,168	0	1,148	68	735	3,829	210	8,188
Total		**7,219**	**8,933**	**11,861**	**1,587**	**25,441**	**2,478**	**3,944**	**29,142**	**8,574**	**99,179**
Total GLDC ecologies		5,146	8,546	10,607	603	20,774	1,902	2,970	26,200	627	84,651

The semi-arid and sub-humid dryland agroecologies — agro-pastoral millet/sorghum, pastoral, rainfed mixed and dry rainfed farming systems, as per FAO characterization[48] — are where most of the relevant crops are grown and hence much of GLDC research will be implemented in these farming systems. However, these crops are not all grown exclusively in these systems. Grain legumes are extensively intercropped or rotated with maize in the humid tropics of Africa and in rotation with rice in South Asia — in the maize-mixed, rice-wheat and cereal-root crop mixed systems (Table 1).

In terms of the full portfolio of agri-food system CRPs, there is clearly a close connection of GLDC to the on-farm research being undertaken in CRPs RICE, WHEAT, MAIZE and ROOTS, TUBERS & BANANAS (Section 1.7). These CRPs have agreed to take responsibility for farming systems research on how legumes are managed in combination with their dominant crops. It is crucial, however, that breeding priorities for GLDC crops grown in these dominant systems are fed back into GLDC research priorities.

An outlier in Table 1 is the large area of soybean grown in rainfed mixed systems of SA. Here there are large research investments on soybean by the private sector, alongside global investments in GMO soybean by the USA, Argentina, Brazil and China. Despite the growing demand in SSA for new high-yielding soybean varieties — the region imports about 72% of its soybean requirements — there is limited investment in breeding by the private sector for conventional soybean improvement. Hence, the National Systems and local seed companies rely on CGIAR germplasm[49]. Consequently, for prioritization, soybean in SSA is considered, but not in SA.

b) Value of production

A congruence analysis[50] on the economic importance of 9 crops in 14 countries is provided in Table 4. The total value of production is slightly lower in SA than in SSA, and split evenly between ESA and WCA. Total value of production in the crop by country observations is *circa* US$44 billion per annum. Six crops account for 94% of the value of production in Table 2.

Table 2. Relative economic importance of select crops in 2014 aggregated across 14 countries – Burkina Faso, Ethiopia, India, Kenya, Malawi, Mali, Mozambique, Myanmar, Niger, Nigeria, Senegal, Sudan, Tanzania, Uganda

Rank	Crop	No. of countries grown	Value of production (US$ million)	Share of value of production (%)	Cumulative share
1	Groundnut	10	10,680	24.2	24.2
2	Sorghum	8	9,087	20.6	44.8
3	Chickpea	6	7,730	17.5	62.4
4	Pearl millet	8	7,165	16.2	78.6
5	Pigeonpea	7	3,612	8.2	86.8
6	Cowpea	8	2,992	6.8	93.6
7	Finger millet	4	1,339	3.0	96.6
8	Lentil	2	978	2.2	98.8
9	Soybean	6	511	1.2	100.0
TOTAL		59	44,094	100.0	

c) Foresight analysis

Foresight analysis of demand and supply of commodities indicates where high future demand and/or significant supply deficits are projected for each combination of crop and country. Such analyses consider historical trends in productivity, assumed continued returns from R&D investment, and the impacts of projected climate change along with changes in population and income. Accordingly, a foresight report on the full matrix of crop and countries in scope for GLDC was commissioned to guide prioritization[51].

Projections of aggregate demand for dryland cereal in SA will be higher than the future production for both 2025 and 2040 (Figure 4a). The demand-supply gap is widening between both periods. However, the demand in SSA will be equal to the production for both 2025 and 2040 periods, but this masks substantial differences in terms of deficit across countries in this vast continent. The demand will increase from 65 million tons in 2025 to 93 million tons in 2040. The demand for grain legumes grows much faster in SA than the production and it increases the demand-supply gap in the future with current level of productivity growth in grain legumes (Figure 2b). The increased production of aggregate grain legumes in SSA is mainly from the area expansion of legumes.

The foresight analysis indicates that demand for sorghum in SA (India) will increase by 2040, but the production in future will not be sufficient to meet this growing demand (see report[35] for details). In SSA, especially in WCA (Burkina Faso, Mali, Niger, Nigeria), the demand for sorghum will increase and the demand-supply gap will widen in the near future with the current level of productivity growth. For millets, demand will increase in India and SSA, with more than 50% of the world millet demand in 2040 being from

WCA (especially Burkina Faso, Mali, Niger, Nigeria, Senegal). Millet demand in India will increase in future at a slower rate. Demand for sorghum and millets is high in several ESA countries (Ethiopia, Sudan, Uganda, Tanzania) with some supply deficit is projected.

Among grain legume crops, more than 90% of world total demand for chickpea, pigeonpea and lentils would be from the SA region. The chickpea demand in SA (India, Myanmar) will increase in the future but the increase in production will not be sufficient to meet the growing demand in the region and so a demand-supply gap will widen assuming current productivity growth. Likewise, pigeonpea demand will increase, both in SA (India, Myanmar) and in ESA (Kenya, Malawi, Tanzania, Uganda), but the productivity growth will not be sufficient to meet growing demand. For lentils, the widest gap between production and supply of lentil is observed in India, where imports of this commodity will grow around 40% between 2025 and 2040. In ESA, lentils net trade will be negative in 2025 and 2040 which indicates its relevance, especially in Ethiopia.

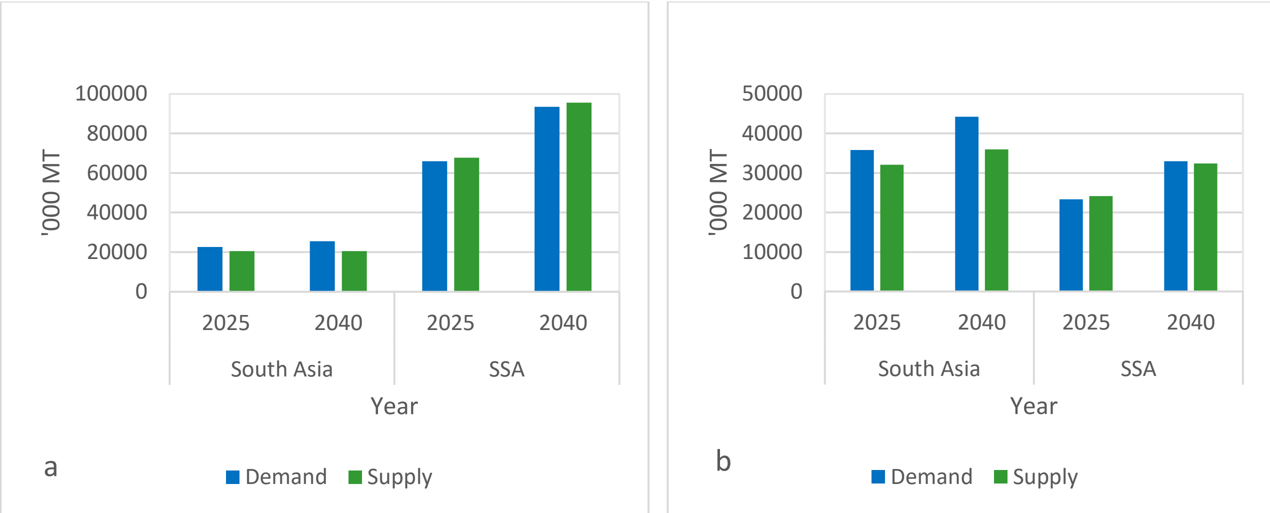


Figure 4: Projected supply and demand by region in 2025 and 2040 ('000 MT) of aggregate a) dryland cereals (sorghum and millet) and b) grain legumes (chickpea, cowpea, lentils, pigeonpea and soybean). Source: IMPACT version 3.3, IFPRI, based on SSP2 with no climate change[35].

For cowpea, SSA would account for about 94% of the world's demand by 2040, the bulk of which would be from WCA (Burkina Faso, Mali, Niger, Nigeria). Nigeria is the largest cowpea consumer and producer in the world, but the gap between production and demand could reach 20% of total demand by 2040. Groundnut demand for Africa is projected to increase with the major demand (more than 90% of Africa demand) from WCA (Burkina Faso, Ghana, Mali, Nigeria, Senegal) and the residual from ESA (Malawi, Sudan, Tanzania). In South Asia (India, Myanmar), groundnut is important but the growth in demand is stagnant. For soybean, SSA (Nigeria, Malawi, Zambia) has a demand-supply deficit that is growing over the years with very little private sector investment in smallholder production. Africa will be importing more than 90% of its soybean consumption requirements by 2040.

d) *Ex-ante* evaluation of research and technology options

To support an *ex-ante* evaluation of relevant GLDC technologies, a commissioned study[52] employed yield gap estimates, *ex-ante* impact analyses and return-on-investment projections, benchmarked against past results to rate priorities for crop improvement for the nine target crops. The projected economic benefits of the different lines of research are measured in terms of the net present value (NPV), IRR and benefit-cost ratios (BCR). To guide priority setting, the crop improvement options were ranked by agroecology based on the BCR as a measure of the net economic benefits per unit of investment.

The *ex-ante* economic impact assessment shows considerable potential for impact of investments in GLDC research. A number of research and technology options across agroecologies and crops have great potential to generate positive economic impacts, indicating the high profitability of investments in GLDC research to address a whole range of production and related constraints. The highest ranked research and technology options are:

i. Short-duration, drought-tolerant varieties of groundnut, cowpea, soybean, pearl millet, sorghum, finger millet, pigeonpea and lentil coupled with soil and water conservation practices;
ii. Low P-tolerant varieties of groundnut and cowpea coupled with soil fertility management practices;
iii. Insect-resistant varieties of cowpea (aphids, thrips, pod sucking bugs, maruca) and pigeonpea (pod borers, pod fly, pod bugs) coupled with integrated pest management practices;
iv. Herbicide-tolerant varieties of chickpea and lentil;
v. Disease-resistant varieties (Fusarium wilt, leaf spot/root rot) of chickpea, lentil and pigeonpea; and
vi. Disease-resistant varieties (rosette, rust, and blight) of groundnut, soybean, lentil and chickpea.

e) Additional quality, market and environmental traits

The commissioned foresight and *ex-ante* impact analyses did not include the critical contribution that GLDC crops make in terms of their importance to human nutrition or as a source of forage and fodder for livestock in the target agroecologies. For quality attributes of commodities, such as biofortified cereals, aflatoxin-free groundnut varieties, or varieties with desired market attributes, further efforts are needed to refine the models to fully account for economic gains due to shifts in the demand function and the resulting price changes. This will be a priority investment in the early stages of GLDC implementation. In the meantime, a more qualified assessment of attributes for each crop is suggested in Table 3, in light of a commissioned analysis of GLDC crops and such attributes[53].

Nutrient-rich dryland cereals and the grain legumes are increasingly recognized for their contributions to both food and nutritional security[54]. Research coverage of GLDC agri-food systems must deliver both resilience in food and nutritional security and opportunities for market-oriented development for smallholder farmers. Breeding for nutritional quality, mainstreaming biofortification for nutrients such as iron and zinc, addressing aflatoxin health concerns and responding to market-demand for commodity traits must be priorities for GLDC.

Table 3: Heat map of quality, market and environmental traits; *darker the shading, higher the contribution.*

Crop	Nutrition & health	Market demand	Livestock	Environment
Sorghum	High Fe, Zn, folate	Hybrids; alcohol	Stover yield, digestibility	Ground cover, C sequestration
Pearl millet	High Fe, Zn, folate	Hybrids	Stover yield, digestibility	Ground cover, C sequestration
Finger millet	High Fe, Zn, Ca	Hybrids	Stover yield, digestibility	Ground cover, C sequestration
Chickpea	Cooking time, high protein, Fe, Zn	Machine-harvestable		N fixation, C sequestration
Pigeonpea	Cooking time, high protein, Fe, Zn	Hybrids, Seed color/size, milling parameters, fuelwood		N fixation, C sequestration
Groundnut	High oleic oil, aflatoxin-free	Aflatoxin-free	Haulm yield, digestibility	N fixation, C sequestration
Lentil	Taste, cooking time, protein, Ca, Fe, Zn	Machine-harvestable	Stover yield, digestibility	N fixation, C sequestration
Cowpea	Taste, cooking time, protein, Ca	Color, seed size	Stover yield, digestibility	N fixation, C sequestration
Soybean	High protein and oil content	Seed size, mechanized harvesting	Grain protein, stover yield, digestibility	N fixation – promiscuous nodulation, C sequestration

Livestock (large and small ruminants, poultry, pigs) remain the livelihood backbone and main source of insurance for risky smallholder agriculture[55]. Over 200 million cattle are kept in GLDC target agroecologies[56] which are, and will remain, the main producers of ruminant products. The current and future accelerating demand growth for red meat in SSA is evident now, although with warnings that the capacity of these value chains for ruminant livestock to respond is likely constrained by feed and forage resources[57]. While farmers will not forsake their staple food production of millets, sorghum and legumes, the croplands of SSA and SA must produce the stover residues and feed for market-oriented livestock enterprises. GLDC's crop breeding for mixed crop-livestock farming systems in the target agroecologies must develop varieties and hybrids with dual-purpose use as food, feed and fodder.

f) Alignment with regional, country, industry and CGIAR priorities

In 2016, a 10-year research strategy for pulse crops was developed[58]. This strategy called for research investment in the development of improved varieties and improved management and in fostering food system shifts that increase demand for and add value to pulse crops. It demanded the building of multi-disciplinary pulse research capacity and spatially-explicit data and models for guiding interventions and quantifying the impact of pulses on human well-being and agricultural sustainability. GLDC endorses and adopts these imperatives for the grain legumes for which it will undertake research.

GLDC will fulfill the CGIAR mandate of bringing benefits to end users through partnerships with Apex and Sub-Regional Organizations (SROs) and NARES by undertaking R4D and scaling-up initiatives in the target regions. In this regard, GLDC priorities have been cross-checked with SRO strategies and priorities[59]. Alignment with SRO and National Strategies is critical as GLDC's regional coverage is limited. SROs will be instrumental in scaling out benefits from CRP interventions within similar agroecological zones to neighboring countries. GLDC will work within these existing structures to accelerate benefits. Furthermore, the implementation phase of GLDC will encompass purposeful refinement of research priorities and approaches on a country basis to align with and reinforce national priorities and to complement national efforts. In this regard, ICRISAT has existing Country Strategies that serve such alignment.

The CGIAR has research facilities, operational breeding and agronomy programs and research staff resident across the full target ecologies and countries relevant to GLDC. The three CGIAR Centers with breeding mandates (ICRISAT, IITA, ICARDA) currently operate 22 crop improvement programs for the nine GLDC crops within the target agroecologies. CGIAR facilities and breeding programs represent local comparative advantage, although not all will be accorded the same priority in terms of GLDC investment.

1°, 2° order and spillover priorities

GLDC takes R4D responsibility for nine crops grown within the target agroecologies. Weight of such responsibility is ordered into first-degree (1°), second-degree (2°), and spillover priorities that will largely drive access to CRP resources and fund-raising efforts. In GLDC, 1° order priorities are supported by all funding windows and have precedence in proactive pursuit of grant applications. Thereafter, 2° order priorities, while important contributors to GLDC objectives and beneficial of CRP cross-cutting investments, need to be largely supported by bilateral grants mapped to GLDC. It is also recognized that dryland cereals and grain legumes are grown worldwide and spill-in/out opportunities exist which should not be ignored. Spillovers will result from collaborations within the CGIAR CRP portfolio and with global partners. Already referenced are the maize and rice-based systems that produce GLDC crops. Further spillovers are anticipated for GLDC crops, especially those grown in MENA countries[60], a number of which were part of Phase I CRPs and where the CGIAR continues to contribute. ICARDA will particularly seek to ensure GLDC research outputs are leveraged within the MENA region.

Prioritization for GLDC provided metrics on poverty prevalence, agroecological statistics, value of crop production, foresight projections of significant demand and/or deficit in supply, *ex-ante* return on research investment, consideration of quality, market and environmental traits and alignment with stakeholder priorities. For investments in crop improvement, an incomplete matrix of 'region x ecology x country x crop x breeding trait' resulted in nominated 1° order priorities for 9 crops grown in 13 countries (Table 4). Research on sorghum and groundnut is 1° order in all regions, in seven and six countries respectively. Pearl millet research will be targeted to WCA and India (five countries), cowpea to WCA and ESA (four countries), and chickpea and pigeonpea both to three countries in ESA and SA. Soybean and finger millet research investment will concentrate on two countries, while lentil research is only targeted for India. These priorities will feed directly into the crop improvement imperatives for GLDC.

The research agenda of GLDC is broader than the priorities listed in Table 4. Some quality, market and environmental traits will also be 1° order, but for the same crops and countries in Table 4. Likewise, 1° order interventions in agronomy, integrated pest management (IPM), soil conservation or fertility management, and value chain innovations need to be aligned with the crops and countries nominated in Table 4 – the *ex-*

ante analyses returned high BCR in a number of these cases[61]. However, beyond Table 4, GLDC includes mapped bilateral projects that are closely aligned to the GLDC agenda and target agroecologies, but in different countries (e.g. Ghana, Kenya, Zimbabwe) or for alternative traits and practices. These 2° order priorities contribute to the GLDC impact targets and will benefit from and contribute to the GLDC R4D portfolio. Ongoing prioritization and feedbacks may shift priorities during the life of the program.

Table 4: Incomplete matrix of 'region x country x crop x breeding trait' 1° order priorities and the range in their prospective return on investment; regional breakdown can be found in *ex-ante* economic report[41].

Crops	Countries	Breeding priorities	NPV US$ million	IRR %	BCR
West Africa					
Sorghum	Nigeria, Mali, Burkina Faso	Early maturing varieties and hybrids with tolerance to drought; resistance to *Striga*; tolerance of stem borer/ midge	289-1555	76-130	5-23
Groundnut	Nigeria, Mali	Drought-tolerant, short-duration, rosette and early- and late-leaf spot-resistant varieties	52-173	40-49	6-21
Soybean	Nigeria	Drought-tolerant, disease-resistant varieties	43-58	53-58	14-16
Cowpea	Nigeria, Mali, Burkina Faso	Insect-resistant lines, drought-tolerant, low P-tolerant *Striga*-resistant and disease-resistant varieties	123-356	44-57	6-16
Pearl millet	Nigeria, Niger, Mali, Burkina Faso	Early-maturing, drought-tolerant, dual-purpose hybrid parents/cultivars with high and stable yields with disease resistance (downy mildew and blast)	253-450	50-64	6-14
East & Southern Africa					
Sorghum	Ethiopia, Sudan, Uganda	Early maturing varieties/hybrids, tolerant to drought; resistant to *Striga*; tolerant of stem borer/midge	158-468	83-129	8-28
Pigeonpea	Malawi	Cleisto varieties, resistant to Fusarium wilt and *Cercospora* leaf spot, photo-insensitive, drought-tolerant, and intercropping-compatible varieties	4-33	32-62	6-15
Groundnut	Malawi, Tanzania	Drought-tolerant/resistant variety and short-duration varieties	20-49	32-63	5-14
Chickpea	Ethiopia	Varieties resistant to *Ascochyta* blight and Fusarium root rot and drought/heat-tolerant varieties	13-17	40-50	6-12
Soybean	Zambia	Drought-tolerant and disease-resistant varieties	10-15	36	8-9
Cowpea	Mozambique	Drought-tolerant varieties and insect-resistant lines	12-14	28-31	6-8
Finger millet	Ethiopia	Terminal drought-tolerant, blast, downy mildew and *Striga* resistant varieties	8	26	5
South Asia					
Chickpea	India, Myanmar	Varieties resistant to Fusarium root rot and Botrytis grey mold, herbicide/drought/heat tolerant varieties	273-499	82-104	9-17
Pigeonpea	India	Varieties resistant to Fusarium wilt and *Cercospora* leaf spot, and tolerant of pod borers, pod fly and pod bugs	65-258	58-91	5-16
Lentil	India	Varieties tolerant of drought and herbicide and resistant to wilt, root rot and *Stemphylium* blight	16-80	37-62	5-15
Pearl millet	India	Early-maturing, drought-tolerant and disease resistant (downy mildew and blast) hybrids	180-310	54-57	7-10
Groundnut	India, Myanmar	Varieties resistant to foliar fungal disease, bud necrosis and soil-borne diseases	66-105	39-56	8-10
Finger millet	India	Terminal drought tolerant and blast resistant varieties	16-21	28-40	4-6
Sorghum	India	Varieties and hybrids that are early-maturing and tolerant of drought and stem borer/ midge	74	65	5

1.2 Goals, objectives and targets

CRP Goal

The overall goal of the Grain Legumes and Dryland Cereals CRP is to concurrently achieve the outcomes of:

- Expanded, resilient and inclusive production, value addition, trading and consumption of nutritious grain legumes and dryland cereals in target countries; and
- Improved capacity and inclusivity of agri-food system stakeholders to collaboratively develop innovations that respond to the needs of women, men and youth in GLDC-based livelihoods and value chains.

These two end-of-program outcomes will contribute positively to the higher-order SRF outcomes of reduced poverty and improved food security, nutritional security for health, and improved natural resource systems and ecosystems services.

Targets

The SRF was designed to illustrate impact of agricultural R4D by 2030; it evaluates system-wide anticipated achievements towards the SDGs. GLDC leverages and encourages enabling environments to take advantage of policy, technology and partnerships to accelerate adoption of profitable technologies by farmers.

GLDC targets are calculated[62] based on cost per beneficiary and weighted contributions across the five GLDC flagships for each SLO target (Table 5). SLO1 was calculated at the expected rates GLDC can improve incomes above the US$1.90/day threshold. A means to improve rural livelihoods is by improving production and for each 1% increase in yields there is a corresponding 0.8% reduction in poverty[63]. In the case of households adopting improved varieties, the cost is ~US$15 per household from the investment made in GLDC. In the case of improved varieties, the estimated ROI by 2022 is 10:1. This is based on annual increases in productivity and discount factors for each target country and crop. This intervention will translate into an increase in value of production of US$1.3 billion by 2022 over a baseline productivity growth estimated at 0.75%.

Many cropping systems for the drylands are grown in marginal lands that will be disproportionately impacted by climate change. Grain legumes, as companion crops to cereals, can increase soil health through nitrogen fixation – a distinguishing feature of GLDC within the CGIAR portfolio. GLDC will work with N2Africa and other large initiatives to further enhance nitrogen fixation contribution to farming systems. Fixing nitrogen and sequestering carbon in the drylands directly contributes to SLO3.

Table 5: Calculated GLDC targets as contributions to the SRF.

	Aspirational CGIAR and Partners' development targets		GLDC targets to contribute to SLO		
	Target 2022	**Target 2030**		**2022**	**2030**
SLO 1	**Reduce Poverty**			**GLDC Targets**	
1.1	100 million farm households have adopted improved varieties, breeds or trees, and/or improved management practices	350 million farm households have adopted improved varieties, breeds or trees, and/or improved management practices	Number of farm households that have adopted improved GLDC varieties (million)	8.9	21.7
1.2	30 million people, 50% women, exiting poverty	100 million people, 50% women, exiting poverty	Number of people assisted to exit poverty, 50% women (million)	4.4	11.8
SLO 2	**Improved Food and Nutrition Security for Health**				
2.1	Improve the rate of yield increase for major food staples from current <1% to 1.2 -1.5%/year	Improve the rate of yield increase for major food staples from current <2% to 2.5%/year	Rate of yield increase for GLDC crops (%)	1.2	2.0

2.2	30 million more people, of which 50% are women meeting minimum dietary energy requirements	150 million more people, of which 50% are women meeting minimum dietary energy requirements	Number of people assisted to meet daily energy dietary requirements, 50% of whom are women (million)	12.7	24.8
2.3	150 million more people, of which 50% are women, without deficiencies of one or more of the following essential micronutrients: iron, zinc, iodine, vitamin A, folate and Vitamin B12	500 million more people, of which 50% are women, without deficiencies of one or more of the following essential micronutrients: iron, zinc, iodine, vitamin A, folate and Vitamin B12	No. of people assisted to meet daily protein dietary requirements, 50% of whom are women (million)	29.8	50.3
2.4	10% reduction in women of reproductive age who are consuming less than the adequate number of food groups	33% reduction in women of reproductive age who are consuming less than the adequate number of food groups	Number of women of reproductive age assisted to meet daily protein dietary requirements (million)	7.5	12.6
SLO 3	**Improved Natural Resources Systems and Ecosystems services**				
3.1	5% increase in water and nutrient (inorganic, biological) use efficiency in agroecosystems, through recycling and reuse	20% increase in water and nutrient (inorganic, biological) use efficiency in agroecosystems, through recycling and reuse	Cumulative carbon input to soils (from 2017) from increased GLDC productivity (million tons)	4.9	13.1

1.3 Impact Pathway and Theory of Change

The future demand for dryland cereals and grain legumes suggests tangible production, market and diversified diet opportunities for women, men and young farmers, value chain actors and consumers (Figure 3). Barriers to capturing these opportunities encompass non-adoption of improved germplasm, poor agricultural practices, restrictive diet options for consumers, underdeveloped value chains, market failures, regulatory constraints and contradicting agricultural and trade policies. Although these barriers vary in terms of intensity and scale, they restrict dryland cereals and grain legumes in fulfilling their full ecological and economic potential across the semi-arid and sub-humid dryland agroecologies. Capturing the opportunities or tackling barriers in isolation of each other, however, greatly underestimates their interconnectedness and the 'wicked' nature[64, 65, 66] of the societal grand challenges prominent in the drylands of SSA and SA.

The theoretical underpinning for GLDC is institutional theory[67], conceptualized in the form of sociotechnical 'regimes' – i.e. agri-food system regimes that have resulted from the co-evolution of institutions and technologies over time. Consequently, the GLDC Theory of Change (ToC) argues that household-level outcomes of food security, resilience and poverty reduction depend on the ability of smallholder farmers and other actors to tackle system-level change in agri-food system regimes[68, 69] (Figure 5). The institutional setting (social values, rules, norms, traditions and practices) within such regimes and prevailing organizations and processes (technologies, markets, policy-making and governance) often act as a "hidden hand"[70] that locks farming and market systems into practices impeding the creation, development and use of improved crop improvement and agronomic technologies. For GLDC to contribute to smallholders overcoming challenges and capturing opportunities, crop improvement and farming systems research are necessary but insufficient investments. Socio-economic science, contemporary development practice and scaling partners must be well integrated within GLDC to support different types of agency of actors[71, 72] to unlock opportunities in the context of their differing innovation capacities and agri-food system regimes.

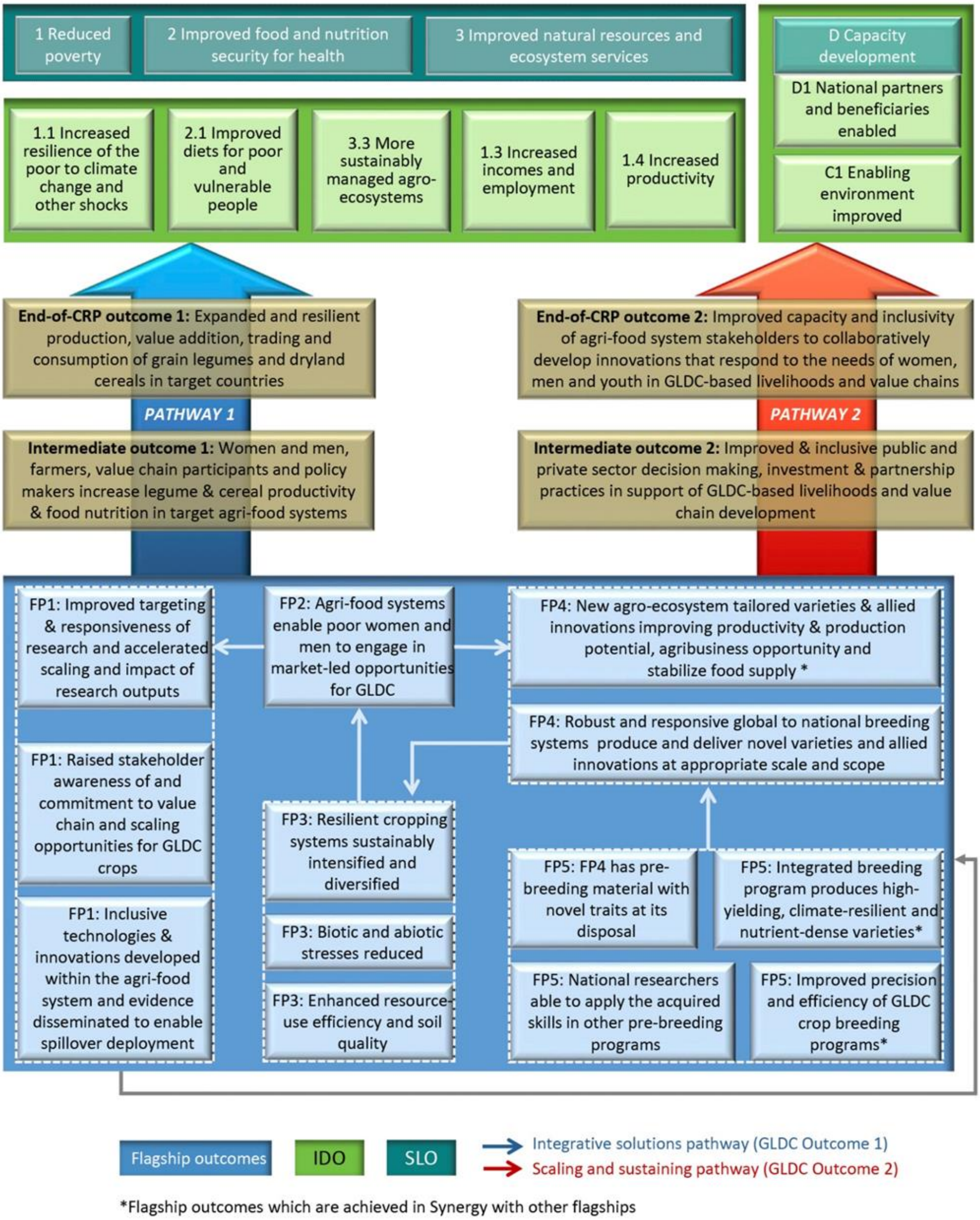


Figure 5: GLDC Impact Pathway

Table 6: Assumptions underpinning the impact pathway	
Assumptions underpinning impact pathway logic	
SLOs	Improved GLDC production and farming systems practices in target countries will reduce poverty and enhance food and nutrition security for women and men.
IDOs	Strengthened governance, stakeholder collaboration and improved public and private investment decisions strengthen the adaptive capacity of agri-food systems to respond to the evolving needs of women and men GLDC farmers (e.g. market access, productivity and income).
CRP Outcomes	• Technological, institutional and policy solutions that respond to emerging challenges and farmers' needs can be identified, prioritized and developed through inter- and transdisciplinary research. • Researchers will work closely with development partners and stakeholders to maintain ownership, access research sites and data, and to forge agreements. • Modeling the leverage points and sequences of interventions (FP1) will encourage the farmers, NARES, entrepreneurs, NGOs and public agencies to experiment with novel technologies and social practices (FP2,3,4). • Improved effectiveness of value chains through technical, institutional and policy innovation creates incentives for farmer technology adoption and improves market access. • The combined insights of multi-actor experiments will create replicable GLDC-models and tangible scaling strategies. • Informed by the outcomes of the strategic experiments, the coupling of technological, institutional and policy solutions will enable adoption of improved GLDC farming system practices (FP2, 3). • Capacity gaps within the GLDC agri-food system that inhibit responses to farmer and market demand and adoption of technological and institutional innovations can be identified and resolved. • Improved GLDC production and farming systems practices in target countries (FP3) will improve agricultural sustainability and enhance food and nutrition security for women and men and market actors through value addition. • Findings from research, coupled with engagement mechanisms, can help decision-making of key stakeholders and agri-food systems governance arrangements can be developed that align stakeholder investment towards food and nutritional security, poverty reduction and resilience.
	Public and private stakeholders will continue to invest in the maintenance and development of the agri-food system in the long term. Collaboration with local, regional and global umbrella organizations — e.g. RUFORUM, AWARD, YPARD — will be crucial for program success, both in terms of prioritizing and scaling of outcomes

GLDC will contribute to the SRF through two distinct impact pathways. In the first pathway (Figure 5, 'integrative solutions', left-hand side of the impact pathway diagram), research will lead to household level outcomes by developing integrated technological, institutional and policy solutions with key partners. Inter- and transdisciplinary research will connect component solutions; notably improved varieties and hybrids (FP4, FP5), seed delivery systems (FP4), inclusive agribusiness models (FP2), modern agronomic practices (FP3), and policy platforms (FP1). Research evidence will help unlock opportunities through consideration of crop, livestock, tree, household, farm, value chain and institutional contributions and their interdependency (Figure 5). The GLDC consortium will work towards increased protein availability from legumes and reduced risk of hunger season through diversifying crop and duration of varieties. Further, improved feed and fodder for livestock-based protein will be an immediate benefit. Specific emphasis will be given to shifting consumption of pulses from an export to a value addition opportunity for local consumption through mechanization of processing to reduce drudgery and increase consumption through convenience and increased unit price for processed, cleaned and graded products. Here, FP1 will identify the right leverage points (desired breeding traits, market preferences and resolvable value chain bottlenecks) developed in FP2-5 (Figure 5). The underlying rationale is that, if trait discovery and variety development (FP4, FP5) respond to current and future needs of farmers and consumers (FP1, FP3), and if business and value chain innovation (FP2) create market incentives, farmers will adopt GLDC technologies. Feedback loops between the different FPs accelerate solution development, and participation of targeted stakeholders guarantees solutions based on end-user demands. Across FP1, FP2 and FP4, experiments achieve robust 'proof of concept' strategies.

Along the second impact pathway (Figure 5, 'scaling and sustaining', right-hand side of the impact pathway diagram), GLDC will use insights from strategic niche management theories[73,74] to implement five mechanisms for working with 'change agents' to address agri-food system-barriers and secure sustainable outcomes. Firstly, GLDC informs the work of policy-makers, development NGOs and private sector actors by documenting realized and high-probability impacts from intervention scenarios. Secondly, linkages, partnerships, platforms and relationships across stakeholder groupings will contribute to improved governance arrangements and system capacities. This includes collaboration with multi-lateral organizations, such as the African Union and the Committee of World Food Security (CFS), lobbying and advocacy and engaging in institutional reforms. Thirdly, capacity development leads to outcomes that can be repeated and strengthened, contributing to more responsive agri-food systems. Fourthly, researchers develop general principles on how to strengthen the capacity of agri-food systems, e.g. through the development of inclusive investment mechanisms which can be applied to other contexts. Finally, agri-food system change happens through replication of successful initiatives developed under the different FPs (e.g. through market signal crowding in further business and farmer investments). Transformation will take place through incubated initiatives that gradually start changing institutions and discovering new markets.

Consideration of gender and youth as catalysts of change throughout all FP activities contributes to impact acceleration, on one hand due to the prominent role of women in GLDC cultivation and otherwise through engagement of future pioneers paving the way toward more sustainable GLDC farming and agri-food systems.

1.3 Gender

Structuring of the Phase II GLDC is a valuable opportunity for re-thinking its Gender Strategy to strengthen focus on 'Gender integration and social inclusion in the drylands'. GLDC is committed to creating a platform of continued learning and improvement in gender research, analysis, intervention and reporting. In GLDC, the investment in gender research has primacy over the more service roles of gender training and reporting, hence the inclusion of a specific CoA1.3 in FP1.

The GLDC priority commodities are cereals and legume crops that are generally identified as 'women crops'[75], however, men and women of different ages are involved in farming of these crops, adopting innovations, and marketing their surpluses. Dryland farming is a livelihood practice that is in a social context, whose variables change depending on the complex relations of farming communities[76]. Gender analysis offers an opportunity to understand how GLDC will operate in these social systems to contribute to inclusive growth and empowerment.

Recently, women in the drylands are increasingly taking responsibility to head households when men migrate to urban areas in search of employment[77]. Differential access to resources leads to gender gaps in production, crop yields and incomes. The main source of labor in dryland farming has been women labor, with the requirement for long hours of field work each day (drudgery) as women have triple roles of production, reproduction and community service. Women provide a significant amount of unpaid labor in the seed management, field production, processing and distribution of dryland cereals and grain legumes. With responsibility for these labor-intensive tasks, women experience chronic 'time-poverty'[78].

The nutrition of women and children under five is currently a global challenge with high cases of anemia, malnutrition, vitamin and mineral deficiencies being reported[79]. The Phase I CRP breeding programs have released dryland cereal and grain legume varieties that are nutrient-dense, with the natural contribution to protein diets combined with the high accumulation of iron, zinc and calcium. This is a paradox since most women who are growing these crops exhibit problems of anemia while their children under the age of five are stunted or malnourished[80]. Complex interaction between use of nutritious foods for income generation, as market-oriented value chains are developed for the women empowerment, potentially causes shifts in household power relations and un-intended negative impacts on household nutrition security[81].

There are unique cultures in GLDC target regions whose norms and practices still limit the participation of women in public domains because of religious or social norms[82,83], thus hampering if/how women can interact with agents of change. Yet there are major benefits in involving women in variety-development processes, as this opens possibilities of targeting specific crop traits e.g. the snapping trait in millet stems that has the potential to save women labor during harvesting; specific morphological traits of pearl millet that indicate drought tolerance that have led to the development of modern varieties that are high yielding in good years with very stable yields under drought conditions. Advances in technology currently support plant breeding methodologies to respond to the needs of women through precision and efficiency of transferring specific genes, as well as the precision and scale with which adoption of specific varieties and traits can be observed. This offers a great opportunity for gender analysis to contribute to plant breeding that responds to the needs of women.

Gender research is designed to support GLDC in ensuring inclusion and equity among female and male beneficiaries and stakeholders, and adapting capacities and strengthening institutions to ensure (i) a convincing evidence-base on strategic gender topics, (ii) mainstreaming gender analysis across GLDC research areas, (iii) enhancing gainful participation of women and youth in GLDC value chains, and (iv) developing interventions that are responsive to gender and social inclusion interests.

The gender research agenda will be unique for each GLDC FP and aligned to the key issues on the impact pathway. The issues are assumed to be distinct enough to allow for implementation of different activities in each FP. GLDC will focus on five strategic areas: i) traits, preferences and breeding product profiling (FP5 and 4); ii) inclusive seed delivery systems (FP4), iii) gender gaps in cereals and legume production systems (labor, decision-making, knowledge access, yield, participation) and nutrition (FP3), iv) gendered value chain development, learning and impacts (market linkages, livelihood options (FP2), and v) social norms and behavior change for men and women to support women empowerment and impacts on delivery of GLDC research outputs (FP1). Capacity building on gender analysis will be integrated at graduate/postgraduate level as well as implementing partners.

The program implementers in GLDC, at management or activity level, will use the strategy as a guide for integration of gender responsive approaches, from planning, to staffing, to budgeting, to operationalization of field activities, as well as integrating with the MEIAL framework. The needs, preferences, constraints and opportunities of various social classes (men, women, youth) will be the focus of the strategy at each stage. Other stakeholders in the GLDC agri-food system include policy makers, service and agro-input providers, private sector, seed merchants/companies, traders, NGOs and financiers who will benefit from the strategy as a reference document for developing intervention programs.

Establishment of long-term databases with sex-disaggregated variables will be linked with the baseline datasets, to establish a learning platform for continued improvement of processes and practices. Standardized sex-disaggregation, in all levels of demographic data collection and analysis, will be coupled with emphasis on the need for recruitment of female enumerators for survey data-collection with female respondents. Sex-disaggregation, as a standard survey practice and subsequent analysis, will be included in the key Performance Indicators.

The gender research team in GLDC will benefit from gender expertise carried over from Phase 1 CRP-DC, CRP-GL and CRP-DS, including a gender working group, as well as three postdocs in the programs facilitated through the CGIAR Gender Network. Learning from the CRP-MAIZE program's 'Gender competencies training', CRP-DS' 'Gender Guidelines for Biophysical Researchers' and online gender capacity building tools, GLDC will develop a gender competency framework that will require each project team to undergo basic training to facilitate acquisition of minimum competencies, appropriate knowledge, attitudes and skills as they develop proposals and identify/implement key gender research questions. This is expected to harmonize, strengthen and improve the overall understanding of concepts and processes of gender analysis and integration of gender questions in FPs. The GLDC gender research team will continue to engage with the Gender Platform in addition to identifying opportunities for cross-CRP collaboration in research and capacity strengthening. Learning from the CRP-RTB program, GLDC will initiate a GLDC-University Partnership (Penn State University among others) for Gender Research Development and postdoc fellowship program in which graduate students will be hosted in GLDC through the USAID Linkage Grants program to complement gender capacities, answer specific gender research questions and develop capacities for the future.

1.4 Youth

The Youth Strategy of GLDC, will be implemented in close coordination with the GLDC Gender Strategy. The population of young people, between 15 and 24 years, in GLDC target and spillover countries is 461 million; 330-million are in the primary target countries alone. With limited absorption capacity of urban economic sectors, especially in SSA, many of the youth need to find viable employment in the farm and non-farm rural economy[84]. With rising levels of relative land scarcity, not all rural young people entering the labor force will be able to operate their own farms. Focusing on the youth as the 'farmers and agri-entrepreneurs of tomorrow' is being challenged as insufficient[85] and there is a call to rethink the youth agenda in a broader sense of 'youth inclusive rural transformation'[86] .

Being young is not a uniformly experienced transitional phase in life between childhood and adulthood, but a highly gendered one, that intersects with other identities such as marital status, ethnic affiliation, class, education or employment status[87,88]. Young people's embeddedness in families, social networks and communities, as well as norms and expectations related to age and gender, influence the exercise of agency[89] as well as livelihood decisions and outcomes. Developing a better understanding of how local contextual factors and social difference interact to shape the diverse pathways by which young people engage with dryland agri-food systems and the potential is an important starting point for youth research in GLDC.

GLDC will focus on understanding the 'youth in the drylands' – who they are, who is staying in agriculture, who is leaving agriculture, who is coming back to agriculture once they have left and the pathways they follow in engaging with dryland agriculture. This is done with a view of targeting youth for engagement in cereals/legume value chains; understanding the 'opportunity structures' and the unique challenges they have, assessing/testing the sectors of the legumes and cereals value chains that have the highest potential for the youth to engage and benefit, and testing support systems that lead to the youth engaging and benefiting from legume/cereals value chains. The penetration of smart mobiles into the rural areas create an opportunity for digital agriculture, easy access of agricultural knowledge and information, and inputs and outputs information among the young farmers. This has the overall potential of increasing productivity and effectiveness.

Harnessing the large potential of youth requires a multidimensional approach that combines education, strengthening and modernizing agricultural infrastructure, access to land and policies that lift the dryland agricultural livelihoods as a whole and re-socialize understanding of 'youth-inclusive rural transformation' in the drylands.

1.5 Program structure and Flagship projects

The overarching logic for GLDC is that improved capacity of the agri-food systems of key cereal and legume crops will enable production, market and policy innovation to deliver resilience, poverty reduction, nutritional security and economic growth without detrimental environmental effects. The Flagship structure and narratives flow from this overarching logic (Figure 6). Consequently, this reframing of the CRP logically orders the Flagships in line with the entry point being identified priorities, leading to agri-food and farming system opportunities, that must inform varietal promotion and seed distribution, and finally through to prioritized traits that meet market and consumer signals. This is also fully in line with current efforts to modernize breeding programs, starting with an inclusive definition of target traits, followed by aligned efforts across the FPs.

The overall GLDC goal is to achieve concurrently outcomes aligned with an integrative solutions pathway (expanded and more effective agri-food systems based on grain legumes and dryland cereals) and a scaling and sustaining pathway (improved capacity of agri-food system stakeholders to collaboratively develop innovations that improve the livelihoods of smallholder women and men farmers and consumer beneficiaries). Each of the five FPs of GLDC are developed to deliver into these two impact pathways.

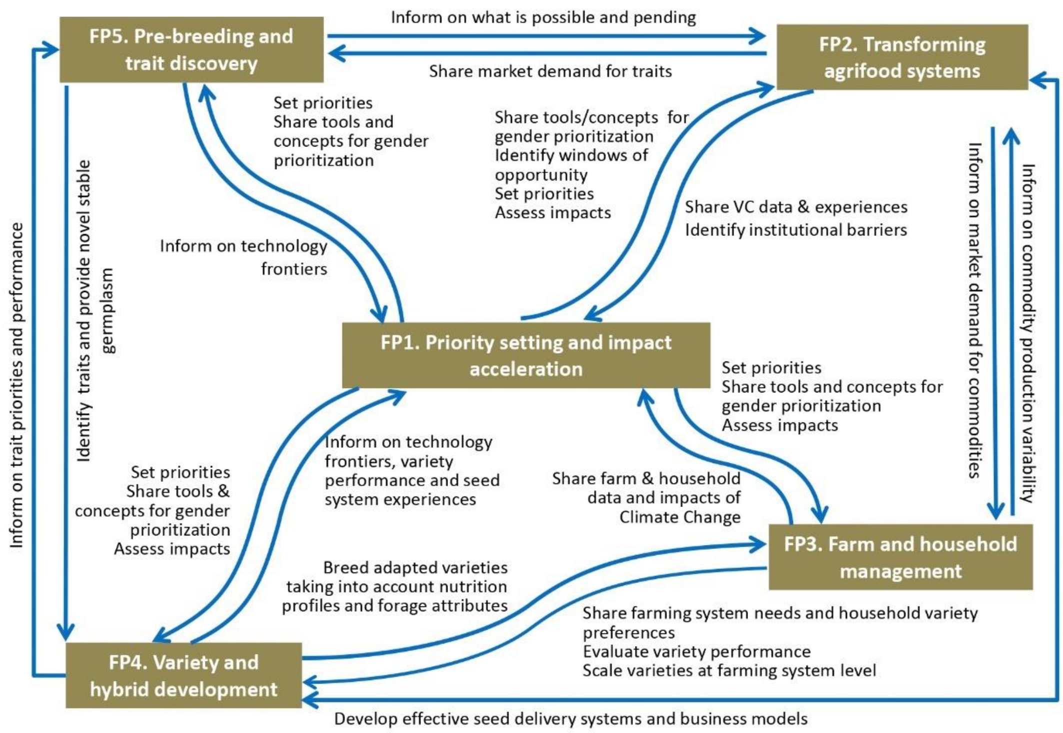


Figure 6: Connections between GLDC FPs.

FP1: Priority Setting and Impact Acceleration

Goal: Ensure that GLDC research is demand-driven, outcome-focused, inclusive and scalable with high potential for large impact contributing to the SRF and SLOs. FP1 has four CoAs:

1. Foresight, climate change analysis and priority setting
2. Value chains, markets and drivers of adoption
3. Enhancing gender integration and social inclusion in the drylands
4. Enabling environments and scaling to accelerate impact

FP2: Transforming Agri-food Systems

Goal: Strengthen agri-food system mechanisms to respond and adapt to context-specific and evolving needs of women, men and young farmers, value chain and governance actors. FP2 has three CoAs:

1. Incubating and unlocking opportunities at scale
2. Tools, models and processes to support at-scale innovation
3. Systems analysis and learning for at-scale innovation

FP3: Integrated Farm and Household Management

Goal: Improve the profitability, productivity and sustainability of smallholder farming systems using on-farm and in-household innovation to ensure household nutritional security and enhanced income generation through integrated crop, tree and livestock production systems. FP3 has three CoAs:

1. Cropping systems management
2. Innovations for managing abiotic and biotic stresses
3. Testing, adapting and validating options

FP4: Variety and Hybrid Development

Goal: High-yielding, nutrient-dense and market-preferred GLDC varieties and hybrids are locally available and utilized by women, men and young farmers and value chain actors. FP4 has four CoAs:

1. Environmental characterization and phenotyping
2. Breeding pipelines
3. Product testing and release
4. Science of scaling up seed technologies

FP5: Pre-breeding and Trait Discovery

Goal: Widen the genetic base of GLDC crops and provide an extensive tool kit of modern genomics, genetic enhancement, breeding tools and high precision phenotyping for efficient breeding. FP5 has three CoAs:

1. Pre-breeding
2. Trait discovery
3. Enabling technologies

1.6 Cross-CRP collaboration and site integration

GLDC will work together with the other Agri-food Systems CRPs and Global Integrating CRPs. Such cross-CRP collaboration is essential to realize farmer and agri-food system benefits from crop intensification and diversification, especially through companion cropping systems or to leverage opportunities for income and diet diversification through feed and fodder. Each CRP has agreed to these synergies to integrate their research as manifest in shared projects and through the communities of practice. The Country Coordination process proposed for the CRPs is fully endorsed and ICRISAT/GLDC will lead such coordination in India. More specifically:

LIVESTOCK: Crop-livestock smallholder farms of the semi-arid and sub-humid drylands of SSA and SA are the target systems for GLDC and a priority focus for LIVESTOCK. Based on feed supply and demand scenarios assessed by LIVESTOCK, GLDC will develop varieties and hybrids with dual-purpose use in food and feed/fodder that will be tested in animal feed trials by LIVESTOCK. Consequent priorities include staygreen introgression and promotion of new dual-purpose sorghum varieties; phenotyping varieties for fodder/stover value of the residue; understanding the nutritional limitations of sorghum and pearl millet forages; and the nutritional characteristics of legume fodder. Jointly targeting farming system options for responding to the demand for livestock products in SSA and SA is clearly a shared priority for both CRPs.

PIM: Given that the overarching logic of GLDC is on improved capacity of agri-food systems, working in conjunction with PIM must happen in diagnosing constraints to the enabling environment (markets, institutions and policies), in prioritizing those that matter most to GLDC agri-food systems and constituencies, in developing common approaches and tools for intervention and in quantifying the impacts from purposeful interventions. GLDC and PIM will jointly develop foresight modelling tools to assess the impacts of demand-driven innovations related to GLDC-priority agri-food systems which includes research on climate change impacts and adaptation technologies and management technologies at different scales of regional, farm and household level. Further collaboration will be in jointly developing actionable policy recommendations on GLDC seed system reforms and innovate extension methods to increase the adoption of innovations around agri-food systems.

WLE: GLDC will work with WLE at the interface of farms and landscapes; the former focusing on farm-level interventions and the latter on landscape-level interventions. Collaboration will include research on technologies for improved water-use efficiency in GLDC farming systems; interactions of cropping systems and land and water management practices; enhancing the role of agricultural water management including soil moisture and irrigation; developing the means for sustainable intensification of legume and cereal crops and crop-livestock systems; and understanding of water flow management through modelling and monitoring.

A4NH: There are three areas of collaboration with A4NH. Firstly, an existing priority is biofortification which will build on the superior ability of some of the target crops of GLDC to accumulate high levels of iron and zinc. The competitive advantage is the track record of the relevant CGIAR Centers in the improvement of these crops through breeding and the track record of the HarvestPlus program. The collaboration will deliver biofortified pearl millet and sorghum with enhanced levels of iron and zinc in India and West and Central Africa. The second area is in food safety, specifically, aflatoxin mitigation. This effort evaluates the use of farm-level mitigation technologies and practices that reduce aflatoxin in the produce and exposure of consumers. The third area of likely connection is through the GLDC FP2 research on functional agri-food systems, where food processing and other value chain interventions will be tested.

CCAFS: A central tenet shared by CCAFS and GLDC is the imperative for smallholders to better manage risks, particularly risks exacerbated by climate variability and change. In common with GLDC, CCAFS has much of its research targeted to the dryland agroecologies of SSA and SA. Most GLDC crops tolerate adverse climatic conditions, high temperatures and drought. GLDC will deliver to CCAFS varieties/hybrids (FP4) and climate-smart practices (FP3) to CCAFS climate-smart villages (CSVs). While GLDC will undertake research to support decision-making under uncertainty on farms (FP3) and in value chains (FP2), it will largely defer to and follow the lead of CCAFS in developing and delivering climate-risk management tools and information for the drylands.

MAIZE: Maize constitutes a major cropping system where GLDC crops are grown as companion crops, especially legumes, in SSA and SA which provide possibilities for diversification and sustainable intensification of maize-based cropping systems. Mutual benefits of the two CRPs include insights on smallholder preferences and benefits to improve the match of technologies for various intercropping and rotation systems involving the target crops of each program. It is critical that the breeding priorities for GLDC crops are informed by MAIZE systems demands. Collaboration efforts will be supported by joint resource mobilization.

RICE: Rice fallows offer opportunities for the expansion of pulses in SA, especially early-maturing pulse varieties such as short-duration chickpea and lentil. At present, ongoing breeding and adaptation research exists for chickpea, lentil and groundnut in rice fallows (India, Myanmar). Opportunities for joint fundraising to focus and test rice-legume sustainable intensification in SA will be sought. It is critical that the breeding priorities for GLDC crops are informed by RICE systems demands.

RTB: Sorghum, millets and legumes occur in the cereal-root crop mixed systems in SSA and legumes have an increasing presence in rotations involving root crops in South Asia, specifically India. GLDC plans to work with RTB in co-developing and testing options for sustainable intensification, with an initial focus in India. It is critical that the breeding priorities for GLDC crops match RTB systems requirements.

WHEAT: Collaboration with the WHEAT program will be sought to out-scale sustainable intensification and diversification options with legumes for natural resource management, environmental benefits, risk management, improved nutrition and diet diversity. Legumes provide an option to intensifying the prevalent rice-wheat rotation in SA for increased incomes, improved resource use and better soil health. The three CRPs (RICE, WHEAT, GLDC) will build on current collaboration and jointly assess options for smallholders in the Indo Gangetic Plain.

1.7 Partnerships and comparative advantage

GLDC will be implemented through collaboration of four Tier 1 (ICRISAT, IITA, ICARDA, ICRAF) and three Tier 2 (ILRI, IWMI, Bioversity) CGIAR Centers and many strategic and operational partners, including Apex and Sub-Regional Organizations, the NARES in each target country, Non-Government Organizations (NGOs), Advanced Research Institutes (ARIs), Farmer Producer Organizations (FPOs) and private sector companies. A partial list of partners who endorsed the GLDC proposal and agreed to support implementation is provided in Table 7.

Critical to GLDC is the support provided by the Apex and Sub-Regional Organizations in SSA and SA, as they bring the support of their National members, many of whom are already close collaborators in GLDC-aligned R4D projects. Each of the relevant USAID Feed the Future Innovation Labs have agreed to seek mutual research partnerships. CSIRO from Australia and CIRAD and IRD from France have committed up-front co-funding to GLDC and to accepting leadership roles within FPs and CoAs. Membership of the GLDC governance committees will be drawn from representatives of these committed organizations. The comparative advantage of the CGIAR in leading GLDC, with ICRISAT as the Lead Center, was endorsed with strong rationale in two recent reviews relating to the GLDC proposal[90,91].

Critical to GLDC success in impacting on the enabling environments of agri-food systems will be in establishing and leveraging partnerships in the Development NGO and private agribusiness sectors. Scaling out of GLDC innovations depends on these relationships. Table 7 lists key scale-out partners, but many more such partners are already collaborating within mapped GLDC bilateral projects.

Table 7: Partners contacted and agreeing to support GLDC

Apex, Sub-Regional and National Organizations **Sub-Saharan Africa**	**Private Sector companies & consortia**	**USAID Feed the Future Innovation Labs**
FARA CORAF/WECARD CCARDESA ASARECA RUFORUM WACCI AWARD	DuPont Pioneer Advanta Seeds Syngenta Foundation (Seeds2B program) Seed Co, Zimbabwe Mars Chocolate Microsoft MANOBI-AFRICA, Senegal Hybrid Parent Research Consortium (HPRC) African Seed Trade Association (ASTA) India Pulses & Grains Association (IPGA) Farmer Producer Organizations (FPOs), India	Sorghum and Millet Peanut & Mycotoxin Legume Climate-Resilient Sorghum Climate Resilient Chickpea Climate-Resilient Cowpea
South Asia	**NGO & Large Programs**	**ARIs**
SAARC Agriculture Centre APAARI ICAR, India NIN	Alliance for a Green Revolution in Africa (AGRA) Catholic Relief Services (CRS) CARE Global Alliance for Improved Nutrition (GAIN) Farm Africa African Agricultural Technology Foundation (AATF) Self Employed Women's Association (SEWA), India Young Professionals for Agricultural Development (YPARD) N2Africa HarvestPlus	CSIRO Agriculture & Food, Australia CIRAD, France IRD, France FAO Research and Extension (AGDR) World Vegetable Center SLU, Sweden UWA, Australia

Innovation Fund: Agility and ability to respond to emerging opportunities will be key for GLDC to respond to scale-out opportunities. Consequently, GLDC will establish an Innovation Fund to provide a mechanism to seize emerging opportunities that will catalyze market development, especially in service of women farmers for whom GLDC crops are an important component of their farming system. GLDC will set aside an Innovation Fund of US$1million per annum (~12% of the W1/W2 research budget) that is used to incentivize innovation to address key market and institutional barriers that women and men farmers face. Interventions can range from innovative seed systems, value addition, market integration through to domain-specific decision-support tools and delivery mechanisms. Innovations should cross more than one Flagship domain but preference will be given to farmer- and market-facing innovations that incentivize local partners to making farming GLDC crops a viable enterprise. Principles underpinning expenditure of these funds include:

- Support for GLDC to systematically engage with private and public sector, civil society and smallholder farmer actors in targeted value chains that underpin GLDC crops for nutritional security.
- Fund collaborative design, implementation and outreach of GLDC projects that focus on understanding and overcoming constraints on the path to impact identified by various stakeholders, especially private sector and producer associations.
- Invest in unanticipated opportunities that can build a strong business case for sustainable and equitable benefits for smallholder producers of GLDC crops.
- Ability to utilize these funds to enable unanticipated opportunities for critical capacity building activities that address key institutional barriers along GLDC value chains.
- Leveraging co-investment from private, NGO or public sector partners for proposed initiatives is highly desirable.
- A robust, transparent process will be implemented to ensure fund expenditure adheres to formal governance process. Approval of expenditure from the Innovation Fund must be supported by the Independent Steering Committee.

An important identified risk in GLDC's Theory of Change is if stakeholders in targeted agri-food systems are unwilling to participate in prioritization and proposed intervention activities (Section 1.3). This risk will be mitigated by GLDC investing in engagement and consultation strategies, especially in the co-development of Country Strategies for GLDC targeted countries and through alignment with the CGIAR Country Consultation processes. Further mitigation can be sought through leveraging of existing private and public partnerships – two of many relevant examples are:

- *Bhoochetana*: Commissioned by the State Government of Karnataka, India, a consortium of eight CGIAR centers, other international institutions (World Vegetable Center), State Agricultural Universities, State Departments and private companies are working together to improve the livelihoods of millions of smallholder farmers in India.
- *MANOBI-AFRICA*: A private African company specialized in the use of IT platforms for inclusive value chain orchestration and smallholder business development services, partnering with ICRISAT to collaborate on Digital Agriculture solutions to help intensify smallholder agriculture and improve smallholder livelihoods in Sub-Saharan African and beyond.

Partnerships with the other Agri-Food System programs and the Global Integrating CRPs, as also with the Genebank, Excellence in Breeding (EiB)[92] and BigData[93] Platforms are detailed in Annex 3.7.

1.8 Evidence of demand and stakeholder commitment

The case for GLDC, based on poverty, malnutrition and prioritization metrics, was outlined in Section 1.1. Without significant additional investment into increasing the production of GLDC crops, a concerning deficit between their supply and demand is highly likely (Figures 3a and b). GLDC represents the CGIAR contribution to meeting the increasing consumer demand for these nutritious food crops. This same conclusion was reached in two recent reviews who strongly endorsed the rationale for CRP-GLDC joining the CGIAR Portfolio. If analytical studies, surveys and focal group discussions from Phase I CRPs are counted, along with recent consultations, over 7,000 stakeholders have provided support for a R4D investment in GLDC crops.

Representatives of this Phase II CRP have participated in the CGIAR country-level consultations during 2015 and 2016, and forged or strengthened commitment for implementation towards common goals with SRO and National priorities.

In preparation of this proposal, a diverse range of key partners were engaged and asked their interest in supporting GLDC. All partners listed in Table 7 have provided written endorsement for the GLDC proposal and confirmation of their willingness to contribute to GLDC R4D implementation from 2018. The forms of partnership in GLDC (see Annex 3.2 Partnership Strategy) were shared with all interested partners – *circa* 20% of W1/W2 funding is flagged for partner-led activities. CSIRO, CIRAD and IRD committed co-funding into GLDC, as represented in the FP budget tables. In fact, CSIRO leads FP2 and brings in new skills and experiences necessary for agri-food systems interventions. Likewise, CIRAD and IRD are committing to co-leading several CoAs and to leverage their strong networks in SSA. Several partners provided CVs of their staff (see Annex 3.8 - Staffing of Management Team and Flagship Projects) as members of FP teams, although such was not a demanded requirement.

The breadth and quality of GLDC partners well demonstrate the GLDC team's commitment to its R4D agenda.

1.9 Capacity development

Improved capacity and inclusivity of agri-food system stakeholders to collaboratively develop innovations that improve livelihoods is an explicit goal and outcome within the GLDC impact pathway (Section 1.3). Hence, capacity development is critical for the success of the CRP as it strongly contributes to achieving development outcomes based on the CRP's research outputs. The GLDC hypothesis is that real-life impact can be achieved only by developing the skills of various actors. As such, all GLDC FPs contribute in different ways to developing capacities of diverse stakeholders. Many activities simultaneously achieve the capacity development SLO as well as other SLOs.

The main focus of GLDC's capacity development will be on National Innovation Systems, specifically NARES, national and regional development agents and private sector entrepreneurs who wish to invest in GLDC agri-food systems. GLDC commits to contributing to developing these actors' capacity and each FP has articulated its contribution. CGIAR and NARES teams are already partners in many R4D projects, often on equal footing, but also with evident gaps in skills and facilities.

While all GLDC participants take responsibility for capacity development of partners, a GLDC Taskforce, consisting of experienced facilitators of transdisciplinary research processes, will support the GLDC team in being more efficient in their efforts. The Taskforce will therefore focus on the development of the CRP teams' capacity to conduct capacity building. Concrete activities in this sense will be coordinated during the implementation of the program. They are likely to include stakeholder analyses, capacity development needs assessments of partners, specific skill trainings for NARES scientists (e.g. leadership or science writing trainings), financial support for partner inclusion into FP activities, fund raising for capacity development activities, trainings for partners in capacity development approaches and techniques and support in embedding cutting-edge expertise into the curricula of National tertiary education programs. GLDC will leverage the principles, established modes and networks for capacity development that prevailed in its predecessor programs, CRPs GL, DC and DS. The CGIAR Country Coordination and ICRISAT's Country Strategies will both enable and strengthen implementation of the GLDC capacity development strategy (Annex 3.3), as will the close ties with the CGIAR Capacity Development Community of Practice.

A key initiative of GLDC will be the Innovation Fund that can provide resources and stimuli for capacity development aligned with GLDC objectives.

1.10 Program management and governance

The governance and management of GLDC follow recommendations of the IEA (April 2014). A single, balanced Independent Advisory Committee (ISC) reports directly to the ICRISAT Governing Board on the performance of the program. The ISC has a maximum of 12 members, including seven non-CGIAR (partner) members and five CGIAR members, who are *ex officio*, including the ICRISAT Director General (DG). A sub-committee of the independent members can provide advice to CRP Management and the Governing Board. The ICRISAT Governing Board has fiduciary and legal responsibility and accountability for implementation of GLDC. The Chair of the ISC will be nominated and voted by the ISC membership, and will have a term of two years.

The CRP Director is a 20% role undertaken by the ICRISAT Deputy Director General-Research (DDG-R), who will be supported by a full-time Program Manager and ICRISAT administrative and communication resources. This cost-effective arrangement is fully endorsed by partners and has precedence in the governance arrangements for Phase II CRPs WHEAT and MAIZE.

The CRP Director will report to the ICRISAT DG and will chair the Research Management Committee (RMC) where responsibility for GLDC implementation resides. The RMC has *circa* 14 members, including five Flagship Leaders, the Senior Gender Scientist, three Center Focal Points (recommended as DDGs, rotating annually) and the CRP Director. Leadership of the Flagships are FP1: IITA, FP2: CSIRO, FP3: ICRAF, FP4: ICRISAT and FP5: ICRISAT. In addition, the RMC will include four non-CGIAR partners. The RMC is primarily responsible for the establishment, execution and monitoring of the CRP research portfolio, strategy, workplans and annual budgets.

Overall FP management will be the responsibility of the FP Leader to whom (co-)leaders of CoAs functionally report. At the time of proposal development, FP Leaders are confirmed, but not CoA Leaders. Deferred filling of CoA Leader roles until closer to implementation will enable non-CGIAR partners to nominate for these positions. CoAs can be co-led. *Curriculum vitae* for select staff are provided in Annex 3.8.

The FP and CoA leaders will spend at least 40% of their time working on GLDC, funded from W1, W2, W3 and bilateral projects – W1/W2 budget allocates 40% to FP and 20% to CoA leadership roles. These CRP leadership positions combine management responsibilities with active research leadership. Budgeting and reporting is to be done in a consultative and transparent manner. Systematic FP efforts will be made to jointly raise W3/bilateral funding to fill CoA gaps and to deliver essential deliverables for GLDC.

GLDC management will be reviewed after 12 months operation to ensure the governance structure supports good decisions made in a transparent, fair and efficient manner to position GLDC for success.

1.11 Intellectual asset management

The GLDC strategy abides by the CGIAR Principles on the Management of Intellectual Assets (CGIAR IA Principles)[94] and their Implementation Guidelines. The primary outputs of the program are technologies that are International Public Goods (IPGs) that will be disseminated according to agreed practices of the CGIAR for effective translation of research outputs to impacts. There are examples of innovative Intellectual Property (IP) management within GLDC, as with the multi-stakeholder public-private partnership of the HPRC[95] and the Agribusiness and Innovation Platform (AIP)[96]. These constitute GLDC expertise in managing its germplasm and in private-sector partnerships for the use of cutting-edge technology for rapid delivery of high impact. GLDC will manage issues of IP with integrity, fairness, equity, responsibility and accountability in all Flagship Programs wherever it operates.

1.12 Open access management

GLDC will adhere to the CGIAR Open Access and Data Management Policy[97] and be guided by the CGIAR BigData Platform for timely and widespread dissemination of the results of its R4D activities. GLDC will leverage the existing primary databases and platforms of its various participating Centers. The main database for experimental planning, analysis and reporting will be Dataverse[98]. In addition, GLDC will use other specialized and shared databases such as the Breeding Management System (BMS)[99], Grin-Global, aWhere, ESRI webGIS platform to make available its results to the global research and development community.

1.13 Communication strategy

GLDC communications will contribute towards four specific objectives: i) uptake on new technologies; ii) building broader awareness of solutions; iii) resource mobilization; and iv) effective coordination among all partners. This should not be a replication of the Centers' communications but instead be developed along with each participating Center, partners and the FP leaders. Communications for resource mobilization will require strategic communications focused on the higher level big issues that the CRP is addressing as well as promoting the 'value added' by the CRP. Effective communications among all partners will require internal communications tools and activities to be put in place. This will be important to ensure two-way engagement across the different disciplines, countries and organizations. The GLDC Integrated Communication Strategy will be implemented by communication specialists and ~10% of W1/2 budget will be directed towards explicit communication activities.

1.14 Risk management

The GLDC Theory of Change articulated a set of anticipated risks and proposed mitigation strategies (Section 1.3). This articulated strategy is linked to associated risks and mitigations in each FP. That said, a major risk is funding instability and scale. The project can adjust its ambition with respect to scale, but the variability of W1/W2 funding will impact significantly on success. Mitigation will be dependent on successfully marketing GLDC as a prospectus for bilateral funding, attractive to donors because of its vision, target beneficiaries, stakeholder network, innovative interventions and track-record in delivery.

The social and political volatility in some target countries interferes with the planned trajectory of the R4D pipeline in these countries. This either creates delays in execution or curtails research for a prolonged period of time. Mitigation can occur through research in areas with similar agroecologies within other target or spillover countries of the program.

1.15 CRP budget narrative

The proposed five-year budget (2018-2022) for GLDC is \$413M, with \$84M allocated to 2018 (Tables 8-11). The annual budget includes \$11.5M for W1/W2 in 2018, increasing by 5% pa. thereafter, and so totaling \$64M over 5 years (15% total budget). The balance of \$349M is to be funded by W3 and bilateral projects (85% total). Approximately \$403M is allocated to FPs (including the GLDC Innovation Fund and Research Leadership roles) and \$8.9M for Management Support Costs.

Table 8: Total CRP budget by flagship (US$)						
Flagship	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
FP1. Priority setting & impact acceleration	5,592,859	7,502,108	10,563,735	5,235,607	5,224,387	34,118,696
FP2.Transforming Agrifood systems	16,676,699	12,252,425	13,121,479	10,316,826	10,452,062	62,819,490
FP3.Integrated Farm and Household Management	23,156,464	20,665,078	14,402,919	15,737,428	15,561,191	89,523,080
FP4.Variety and Hybrid Development	24,880,178	28,776,330	33,193,829	39,004,131	38,427,461	164,281,929
FP5.Pre-breeding and Trait Discovery	10,555,166	10,933,774	7,997,239	7,457,611	7,522,764	44,466,555
Total*	**80,861,366**	**80,129,715**	**79,279,201**	**77,751,603**	**77,187,865**	**395,209,750**
CRP Management	1,619,250	1,700,000	1,785,000	1,874,000	1,968,000	8,946,250
Flagship/CoA Leaders	600,000	630,000	662,000	695,000	730,000	3,317,000
Strategic Research Grant	1,000,000	1,050,000	1,103,000	1,158,000	1,216,000	5,527,000
Grand Total	**84,080,616**	**83,509,715**	**82,829,201**	**81,478,603**	**81,101,866**	**413,000,000**

* The slight annual decrease in total CRP funding reflects the uncertainty in forward bilateral projections.

Table 9: Total needed CRP budget by sources of funding (US$)						
Sources of Funding Needed	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
W1+W2	11,500,000	12,075,000	12,679,000	13,313,000	13,979,000	63,546,000
W3	33,037,968	17,843,437	12,182,554	7,916,233	8,153,568	79,133,760
Bilateral	39,542,648	53,591,278	57,967,647	60,249,370	58,969,297	270,320,240
Other Sources	-	-	-	-	-	-
TOTAL FUNDING PLAN	**84,080,616**	**83,509,715**	**82,829,201**	**81,478,603**	**81,101,865**	**413,000,000**

Table 10: Total secured CRP budget by sources of funding (US$)						
Sources of Funding Secured	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
W1+W2 (Secured)	11,500,000	12,075,000	12,679,000	3,313,000	13,979,000	63,546,000
W3	27,316,888	13,053,960	5,709,791	170,000	170,000	46,420,639
Bilateral	20,593,079	11,439,067	7,566,474	1,960,490	1,407,490	42,966,600
Other Sources	-	-	-	-	-	-
TOTAL SECURED	**59,409,967**	**36,568,027**	**25,955,265**	**15,443,490**	**15,556,490**	**152,933,239**

Table 11: Funding gap by sources of funding (US$)						
Funding Gap Over/(Under)	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
W1+W2 **	-	-	-	-	-	-
W3	(5,721,080)	(4,789,477)	(6,472,764)	(7,746,233)	(7,983,567)	(32,713,120)
Bilateral	(18,949,556)	(42,152,221)	(50,401,216)	(58,288,853)	(57,561,791)	(227,353,637)
Other Sources	-	-	-	-	-	-
Total Funding Gap	**(24,670,636)**	**(46,941,698)**	**(56,873,980)**	**(66,035,086)**	**(65,545,358)**	**(260,066,757)**

** As per the guidance received from SO, we have assumed our W1 and 2 funding needed as secured.

CRP Management and Support Costs

At the program level, GLDC intends to set apart $1.6M pa. W1/W2 (13.9%) for 2018 towards management and cross-cutting initiatives – a total of $8.9M for the period 2018-2022 (Table 12). The Management budget includes $0.2M pa support for FP and CoA Leaders for their administrative roles. A further $0.6M pa is allocated to FP and CoA Leaders from FP research budget allocations (Table 8) to cover their research leadership roles – their total budgeted allocations are 40% FP and 20% CoA Leaders.

Table 12: GLDC management and cross-cutting budget (US$)

CRP Management budget items	2018 (to grow @ 5% pa) USD
Program Management Unit staff: 0.2 Director; 1.0 Program Officer; 0.2 secretary)	110,000
PMU travel & operations: visit research/partners; attend CGIAR meetings; PMU Office supplies & costs.	100,000
Administrative support: ICRISAT support for financial, admin services	350,000
Flagship and CoA Leaders Admin Management: 0.1 FP, 0.05 CoA time allocation. Further allocations (0.3 FP; 0.15 CoA) are provided as part of FP budgets	209,250
Gender, Youth, Capacity Development Coordination: 2 x 0.4 FTE, travel, representation at CGIAR	160,000
CRP RMC operating costs: 2-3 meetings pa; travel; representation at CRP	200,000
ISC costs: honoraria, travel, annual meeting	90,000
Monitoring & Evaluation, Impact assessment: 0.5 M&E Officer, meetings, commissioned IA studies	150,000
Internal audit & external reviews: programmed as required	100,000
Communications: 1.0 FTE contribution from ICRISAT Communications team, website, publications, briefs	150,000
TOTAL	**1,619,250**

GLDC Innovation Fund (Strategic Competitive Research Grant)

A sum of $1.0M per annum (with 5% pa growth), out of the $11.5 M of W1/2 budget per annum, is planned for the GLDC Innovation Fund, adding up to $5.5 M for the period 2018-2022. This will be administered with specific criteria – see section 1.7 on partnerships for further details.

CRP Financial management principles

GLDC will follow a transparent process of governance and financial management. The allocation of W1/W2 resources to Centers and partners will be decided by the ISC based upon recommendations of the CRP Director following a consultative process. Considerations will include strategic use of W1/W2 funds to leverage the W3 and bilateral funding, contributions by Centers and partners, performance in achieving the stated goals of the CRP, ability to generate W3 and bilateral resources to support the CRP and other considerations that the ISC may deem appropriate to maximize the contributions of the CRP to the SLOs.

FP Leaders will have the authority, ratified by the CRP Director, to approve mapping of W3 and bilateral under agreed guidelines. Instances of conflict will be discussed in the RMC and resolved in the best interests of the CRP program. FP Leaders will manage their budgets, with the authority to track, report and revise as necessary. The MEL system used in CRP-DS, and currently being adapted for GLDC, will be an important tool that supports real-time tracking of projects and budget use.

Budgeted Costs for certain Key Activities

The aggregated estimates for proposed expenditure on cross-CRP priorities and M&E are provided in Tables 13 and 14. These represent an initial estimation of the contributions from the W3/bilateral projects mapped to the CRP plus the specific budgeting at the CRP-level from W1/W2 for cross-cutting activities. Hence, an estimated annual amount of $8.4M, or a 5-year total of $42.5M, is directly allocated to these initiatives – approx. 29% of the total 5-year budget of the program. An estimated $3.7M will be invested in annual M&E activities across CRP projects and $0.14M in annual impact assessments.

Table 13: Estimated annual average budget for select cross-GLDC initiatives (US$)	
Cross-cutting issue	**Annual cost (US$)**
Gender	3,000,000
Youth	1,000,000
Capacity development	4,000,000
Impact assessment	200,000
Intellectual asset management	5,000
Open access and data management	20,000
Communication	200,000
Total	**8,425,000**

Table 14: M&E investments in GLDC (US$)						
M&E investments	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
M&E	**3,745,000**	**3,757,500**	**3,770,630**	**3,784,410**	**3,798,880**	**18,856,420**
Under the MSC budget	100,000	105,000	110,250	115,760	121,550	552,560
Innovation Fund	150,000	157,500	165,380	173,650	182,330	828,860
Under flagship budgets	3,495,000	3,495,000	3,495,000	3,495,000	3,495,000	17,475,000
Impact assessment	**188,114**	**190,614**	**193,244**	**196,004**	**198,894**	**966,870**
Under the MSC budget	50,000	52,500	55,130	57,890	60,780	276,300
Innovation Fund	-	-	-	-	-	-
Under flagship budgets	138,114	138,114	138,114	138,114	138,114	690,570

FLAGSHIP PROGRAM 1 (FP1): PRIORITY SETTING AND IMPACT ACCELERATION

FP1.1 Rationale and Scope

Smallholder agriculture in the drylands of sub-Saharan Africa (SSA) and South Asia (SA) is characterized by low adoption of improved agricultural technologies, poor market access, inefficient value chains, weak social institutions, social inequity, high risks and degraded natural resources[100]. The research in FP1 aims to enhance the relevance and gender-equitable impacts of GLDC research through improved targeting and priority-setting based on foresight and *ex-ante* impact analysis, learning from adoption and impact studies, strategic and transformative gender research and identifying priority value chain opportunities to address market failures.

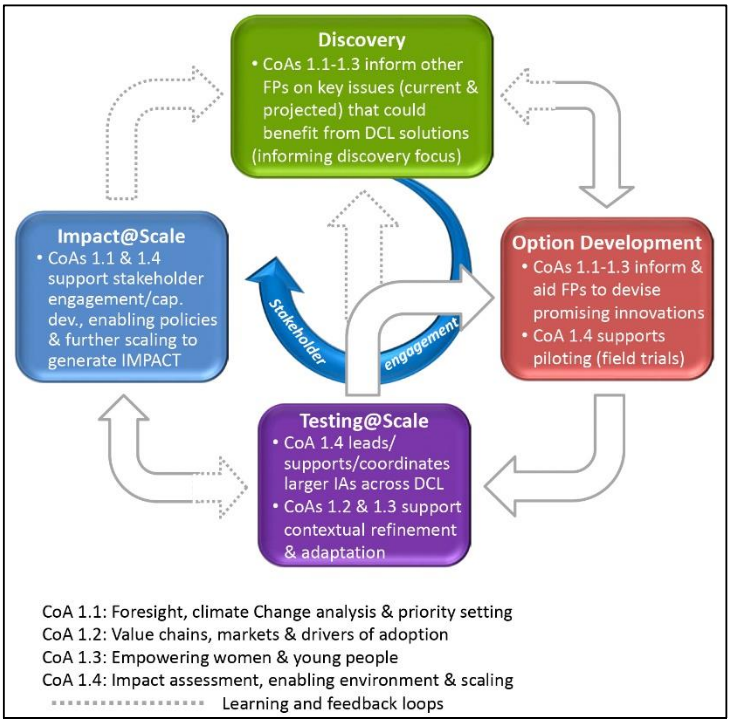


Figure FP1.1: The role of FP1 in GLDC through its cluster of activities (CoAs), the interaction with other GLDC FPs and cross-cutting areas, and with key stakeholders. Solid arrows indicate the research for development process, which flows from discovery and innovation development to testing and scaling of innovations in order to contribute to impact at scale. The dotted arrows are feedback and learning loops to refine and further focus GLDC's research agenda. Stakeholder engagement (i.e. with public, private sector and other development actors) is crucial and increases through the research cycle process.

FP1 will ensure that GLDC conducts inclusive, demand-driven research that responds to household and smallholder farmer needs, market demand and local and national priorities, and is designed to enhance GLDC's ability to focus its efforts and resources in order to achieve greater impacts. Figure FP 1.1 illustrates how this will be achieved through interaction within FP1 in close collaboration with FPs 2-5.

One of GLDC's primary objectives is to conduct research on new and innovative ways to address the grand challenge of underperforming agri-food systems and how they can be transformed into well-functioning systems at scale with greater productivity, profitability, and economic benefits from market demand and linkages, value chain development and improved grain legume and dryland cereal technologies and management practices.

Pre-proposal foresight and *ex-ante* analyses of different lines of research were conducted with the objective of informing priority-setting decisions. This preliminary work will continue in GLDC to refine the country, crop and thematic priorities using more rigorous methods and wider stakeholder workshops and consultations for a more refined and comprehensive set of research themes, including crop-livestock system technologies, quality improvement research and value chain innovations. The priority assessment aims to further refine the countries, crops, traits and agronomy, as well as the institutional innovations and value chain upgrading options that generate the highest and most inclusive gains for smallholder farmers. FP1 will extend and apply the approach successfully used by CRP-RTB[101].

FP1.2 Objectives and Targets

The overall objective of FP1 is to ensure that GLDC research is demand-driven, outcome-focused, inclusive and scalable with high potential for large impact contributing to the SRF and SDGs. Building on previous achievements, FP1 will generate evidence and support learning on GLDC innovations with the largest development impact. FP1 will facilitate these processes across all GLDC FPs and thereby achieve:

- Improved targeting and responsiveness of research to end-user demands for accelerated scaling and impact of research outputs;
- Development of more inclusive technologies and related innovations; and
- Dissemination of evidence to enable scaling up

The specific issues to be addressed include:

Foresight, climate change analysis and priority setting*:* Foresight and *ex-ante* impact analyses will be continued and enhanced to refine and characterize the target agroecologies and lines of GLDC research that are likely to have high payoffs and where the research will be most relevant. The work takes into account climate change, demographic trends and socio-economic changes affecting supply, demand and trade and also examines the distributional benefits of new technologies and management practices. For example, foresight analysis will provide insights into the changes in diets and consumer preferences with urbanization and income growth that would have important implications for GLDC research to respond to such trends.

Climate change is one of the major drivers to which continued attention must be paid especially with dryland agri-food systems being particularly vulnerable. This requires analyses of the implications of climate change taking into account the characteristics and variability in target agroecologies in order to improve the long-term resilience of production systems, strengthen their adaptation capacities and reduce risks and shocks. Rigorous foresight and *ex-ante* impact assessment also involves expert and stakeholder consultations and aims to guide GLDC research prioritization. Research questions include:

- What are the desired (by different stakeholders) sustainable development outcomes in the target areas and what are the plausible outcomes under different future scenarios?
- Which set of interventions or lines of research and new technologies and management practices would have the greatest impacts on food and nutrition security, poverty reduction and sustainable natural resources management under a changing climate?
- In which geographies will the research be most relevant?
- Which lines of research would have the greatest benefits for women and the youth?

Value chains, markets and drivers of adoption: Consumer and end-user demands for GLDC crops span from rural subsistence households in developing countries to advanced urban health food markets in the developed world, including a wide range of expectations and demands for produce characteristics. These varying market demands, meeting rural household needs and developing the value chain that links both of them are of great importance for target households[102]. However, there are bottlenecks such as poor infrastructure and institutional barriers limiting market outlets and farmers' access to inputs such as seed and fertilizer. Understanding the drivers of adoption and dis-adoption and how technologies are modified by farmers themselves in adaptive processes is crucial to facilitate scaling of innovations and will add value to the analysis of adoption constraints. New approaches to tracking the adoption of technology will be piloted as a basis for systematic analysis of factors affecting adoption. Work will be undertaken to clarify policy and institutional measures that either impede or encourage adoption, with emphasis on seed systems.

- What are the underlying preferences affecting demand for agricultural technologies and produce across the various target groups and how can these be used in technology development, dissemination and ultimately to enhance adoption?
- Which value chains offer potential for improving household incomes, nutrition, economic growth and social inclusion, and in which should GLDC invest in targeting?

Enhancing gender integration and social inclusion in the drylands: Gender research is designed to support GLDC in pursuit of integration, inclusion and equity among female, male and youth beneficiaries and stakeholders, to strengthen the relevance and targeting of research outputs and enhance development impacts. Ensuring inclusion and participation of men, women and young people in research and value chain development is crucial for accelerating impact. As a strategy for gender integration in the whole CRP, gender research questions are proposed for FP2-FP4 while CoA1.3 offers the platform for strategic gender research questions on norms of women participation, youth in the drylands and understanding the nexus between nutrient dense cereals/ legumes and malnutrition.

Women are increasingly taking responsibility to head households when men migrate to urban areas in search of employment. The main source of labor in dryland farming has been women labor. There are unique cultures, in GLDC target regions, whose norms and practices still limit the participation of women in public domains because of religious or social norms. Hampering if/how women can interact with agents of change. Women are an important constituency in legume and cereals farming systems, and increasingly, they need to be able to access knowledge and skills about improved varieties, practices and value chains. Research questions about women include:

- What and how do social/gender norms and power relations influence women's participation, decision making and practices in the legumes and cereals systems?
- What are the core values, norms and practices that need to be taken into account when working with women on legumes and cereals innovations in the drylands?
- What role can inclusive, innovative, learning and action systems play to leverage change?

Young people's embeddedness in families, social networks and communities, as well as norms and expectations related to age and gender, influence the exercise of agency[103] as well as livelihood decisions and outcomes[104]. Research questions about youth include:

- What are the local contextual factors and social differences and how do they interact to shape the diverse pathways by which young men and women engage with in legume and cereals systems in the drylands?
- What opportunities exist to enhance gainful participation of the youth in cereals/legumes value chains?
- What is the potential of ICT/Digital agriculture?

***Enabling environments and scaling to accelerate impact*:** To support innovation development and adoption, the CoA analyzes the policy and institutional environment at implementation sites and identifies appropriate interventions. Achieving impact at scale requires research (science of scaling) and the innovations need to be tested across a range of contexts in order to generate evidence of potential impacts at scale. Research questions include:

- What are the enabling conditions underlying effective uptake and wider spread of innovations and new technologies and how can these be promoted to support scaling-up efforts?
- What are the policy processes underlying effective uptake of innovations and new technologies and how can these be supported efficiently and effectively?
- What characteristics of underperforming agri-food systems are enabling or constraining market, policy, institutional and technological options and how do these relate to livelihoods and sustainability in different contexts?
- What are the economic, social, and environmental impacts of GLDC technologies?

FP1 will work closely with other FPs across the GLDC target areas, but especially with FP2 where action research is to be undertaken in specific value chains in collaboration with NGOs and the private sector.

FP1.3 Impact pathway and Theory of Change

Lack of information about the likely future of agri-food systems under climate change and technological advances in agriculture often hinders visioning, goal-setting and planning of agricultural research and development. Consequently, priority setting in agricultural research is often short-term, incoherent, and influenced by vested interests. The FP1 research agenda, therefore, is built around in-depth scientific *ex-ante* impact and foresight analysis of food production, demand and prices under alternative technology, socio-economic and climate change scenarios aimed at guiding GLDC research strategy. In order to respond to diverse stakeholder needs, participatory research complements and feeds into foresight modeling. Through this FP, foresight analysis and priority setting will become accessible, quicker and more comprehensive to agri-food system actors. This priority-setting informs the other FPs to develop appropriate and demand-driven innovations. FP1 also consists of *ex-post* assessment and continuous evaluation, drawing lessons from other flagships' outcomes. The combination of priority setting and impact evaluation will support agri-food system actors to accelerate the adoption and impacts of GLDC technologies and innovations Figure FP 1.2.

By focusing on emerging trends and markets and considering stakeholder priorities (CoA1.1, CoA1.2), the program aligns with diverse household and market realities, stakeholder objectives (including end-user demands) and targets business opportunities. Focus on gender and youth (CoA1.3) develops mechanisms for inclusive collaborative interventions which are to be translated into practice in the other FPs. In parallel, understanding of household decision-making processes promotes development of inclusive technologies and innovations which respond to stakeholder needs and expectations. Further, FP1 identifies key system level-barriers of agri-food system regimes with stakeholders (CoA1.4) to create conducive agricultural policy environments across the countries where the program operates. A key assumption is that if collaboration and participation are promoted early in the process (CoA1.1 and CoA1.4), then this will encourage stakeholder engagement and co-ownership throughout the program. Further, a transparent and consultative process of priority assessment will ensure commitment of the national and regional stakeholders to the program. Finally, adoption and cost-effective scaling options will be studied (CoA1.2 and CoA1.4) and applied in the other FPs. In collaboration with CRP-PIM, these studies will generate lessons on GLDC's overall impact on smallholder livelihoods in the target as well as spillover countries of SSA and SA.

Through its *ex-ante* and *ex-post* assessments, the FP contributes to sub-IDO (i) '1.2.2 Reduced market barriers' through connecting different stakeholders, highlighting market demands and setting the stage for a more conducive enabling environment (ii) '1.3.2 Improved livelihood opportunities' through targeting of household needs and identifying market opportunities and (iii) 'D1.4 Increased capacity for innovation in partner development organizations and in poor and vulnerable communities' through comprehensive capacity development at local and organizational level.

The impact pathway rests on four assumptions:

- Stakeholders will take up the opportunity of the established priority-setting platform and use it effectively for engagement, information exchange and discussion of results. This process will lead to more inclusive priorities, which will better reflect stakeholder needs and increase their commitments.
- The feedback provided by FP1 to FP2-FP5 as well as to the wider stakeholder community is used to develop appropriate and demand-driven breeding priorities, agricultural technologies, marketing arrangements and inclusive approaches. This will in turn improve targeting and increase impacts.
- Gender will be understood and successfully prioritized into all FPs such that the resulting interventions are responsive to gender & social inclusion.
- The hands-on field level research will attract political will and commitment of policy makers to create an enabling environment and capacity of national and regional partners. Such commitment will lead to increased human and financial resources to evaluate and scale up GLDC-generated technologies and innovations.

To mitigate potential risks underlying these assumptions, management must put into place systematic priority setting, engagement and targeting processes as well as mechanisms to ensure that the other FPs use feedback from FP1 to design and refine research. Besides, GLDC management is to establish an incentive mechanism to promote best practice in gender research across FPs aimed at achieving greater gender equitable research and development outcomes.

Although this FP does not provide direct employment for women and youth, it helps to create the enabling institutional and policy environments for scaling inclusive business models (FP2). As researchers feed scientific evidence from these FPs into policy processes, this FP will use political networks to set conditions for job creation on farms and in value chains. To become convincing, the evidence must address the current lack of interest of youth in agriculture. Doing so will only work in partnerships with youth organizations linking rural and urban areas, such as Young Professionals in Agriculture and Rural Development (YPARD), which the program actively pursues.

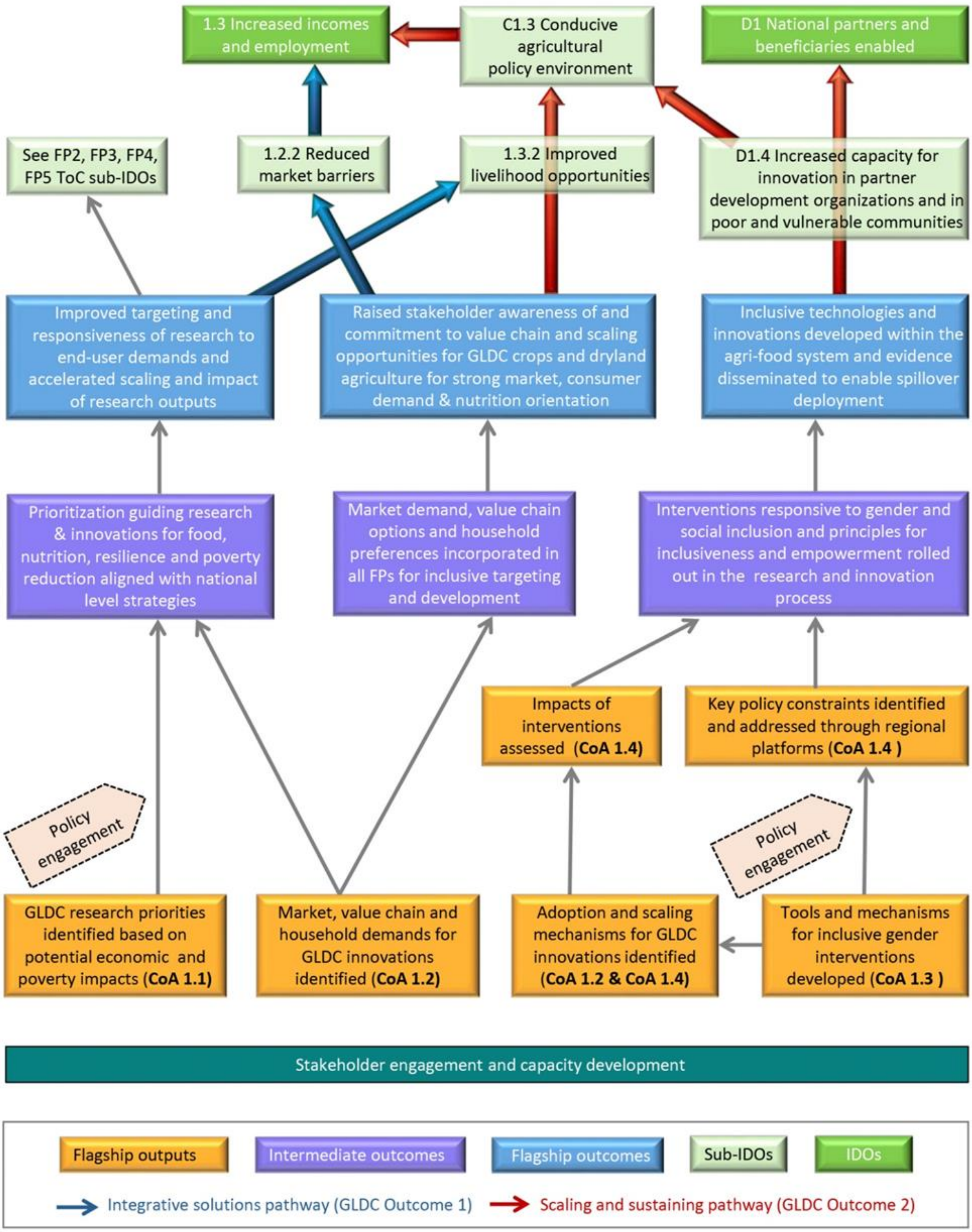


Figure FP1.2: FP1 Impact Pathway

FP1.4 Science quality

Pre-proposal foresight and *ex-ante* analysis for targeting and prioritization will be extended during the first year of GLDC. This will be complemented by *ex-ante* yield impact analysis of promising and alternative GLDC technologies building on the methods and experiences of the Global Futures and Strategic Foresight (GFSF) in CRP-PIM. The tools developed under the GFSF project were successfully used by the CoA1.1 team to quantify impact of promising groundnut, chickpea, pearl millet and sorghum technologies on yields under different climate change models[105] and assess the effects of weather extremes on regional food security[106].

The potential synergies and conflicts between the objectives of profitability and resilience as simultaneous targets have been demonstrated[107] and provide a basis to further analyze the timing of synergistic innovations and the channels which could facilitate approaches based on the simultaneous consideration of market demands and farmer preferences. Several scientists in FP1 participated in the SPIA-led project, Diffusion and Impact of Improved Varieties in Africa (DIIVA)[108] and contributed to the widely recognized publications[109] on the effectiveness of crop improvement, adoption and impacts of improved varieties in food crops in sub-Saharan Africa. FP1 scientists have the experience, partnerships and networks, through the projects they are engaged in or leading, to enrich GLDC in its delivery of quality science.

Tropical Legumes III[110]*:* The TL III project (2015-2019) develops and delivers legume cultivars with market and agronomic traits preferred by smallholders. As proposed in FP1, the project priorities were defined following a systematic and participatory approach involving economists, breeders and implementing partners. Innovative approaches, such as the use of DNA fingerprinting technique to identify and track the adoption of improved varieties in farmers' fields, will be undertaken to measure adoption and welfare impacts of improved varieties. This will inform priority setting processes through better quality estimates and will also provide credible evidence of technology uptake and impacts of grain legumes.

HOPE 2[111] (2015-2020): Harnessing Opportunities for Productivity Enhancement of Sorghum and Millets in Sub-Saharan Africa and South Asia focuses on the development, dissemination and adoption of improved seed and crop management practices for sorghum and millets in six GLDC target countries. Closely aligned with FP1 research agenda, the project takes a systematic approach to adoption to create the enabling conditions that will drive adoption and provide feedback on what works and why, helping align research outputs with farmer demands.

Africa RISING[112]: The Africa Research in Sustainable Intensification for the Next Generation program is supported by USAID and comprises three projects led by IITA in West, East and Southern Africa and ILRI in the Ethiopian Highlands. The objectives are to identify and evaluate demand-driven options for sustainable intensification and to evaluate, document and share experiences with approaches for delivering and integrating innovation for sustainable intensification and align perfectly with the FP1 agenda. Development objectives include (i) creating opportunities for smallholder farm households within Africa RISING action sites (Ghana, Mali, Tanzania, Malawi, Zambia and Ethiopia) to move out of poverty and improve their nutritional status and (ii) facilitate partner-led wider dissemination of integrated innovations for sustainable intensification.

FP1.5 Lessons learned and unintended consequences

An *ex-ante* impact study conducted in Nigeria[113] measured the overall economic gains as well as the equity effects of alternative commodity research programs and showed that grain legumes and dryland cereals programs, e.g. cowpea, sorghum, millet, soybean and groundnut, generate greater economic benefits to poor households compared to a number of other commodities, e.g. fish and livestock. With a rate of return of 81%, each dollar invested in cowpea research, for example, generates US$53 worth of benefits for the poor, relative to US$99 for all households. With a rate of return of 72%, each dollar invested in soybean research generates US$46 worth of benefits for the poor, relative to US$70 for all households. Poor households in Nigeria thus capture 66% of the benefits from soybean research.

Adoption studies have shown that the availability of information, which has long been recognized as the main barrier to adoption, cannot replace the need for farmers to test new technologies in their own fields before full adoption. This implies that the content of the information provided should be further fine-tuned and adjusted to the farmers' requirements. While awareness and seed supply are critical constraints to adoption, low adoption of improved varieties may also indicate that improved varieties lack the attributes valued by farmers and end users. There remains a knowledge gap in understanding constraints to adoption for specific crops in specific countries. Adoption studies repeatedly highlight that one key driver of adoption is access to output markets. Regions with high demand, good market access and attractive output prices have witnessed soaring adoption rates, such as chickpea in Ethiopia[114] and in Andhra Pradesh, India[115] . These trends can be heavily influenced by policies either hindering or supporting the process, e.g., sorghum beer in Kenya[116] or groundnut exports from Malawi[117]. The case of groundnut in Malawi points to the need to respond to the demands of all parts of the value chain. After a drastic drop in exports due to newly introduced quality standards in foreign export markets, Malawi was able to restore its strong export market based on quality intervention along the whole value chain from farmer to export companies.

Given the critical importance of output markets, the analysis of consumer demand highlighted the huge potential in some countries/regions[118]. For instance, demand for sorghum outstrips supply in Ethiopia and Uganda while in Kenya and Tanzania the consumer market is extremely small and alternative uses such as sorghum for feed and fodder offer better potential. In South Asia, postrainy season (*rabi*) sorghum is increasingly valuable for fodder and half of rainy season (*kharif)* sorghum grain goes for non-food uses. Furthermore, while processors are willing to pay a quality premium, focusing purely on economic 'competitiveness' is not appropriate in the dry areas with underperforming agri-food systems where farmers spread risk by growing a range of cereals and legumes combined with livestock rearing. Commercialization or less labor intensive processing tools aiming at increased competitiveness and profitability of the production may disempower women if men take control over income from these crops which are mostly considered 'women's crops'. At the same time, research has shown[119] that this is not necessarily the case and even after commercialization, women still feel in control of the crop and associated incomes even though men show increased interest in the production. Finally, the increase in fodder demands due to rising consumption of animal source food in many parts of the world leads to increasing use of crops for fodder (especially sorghum). If not carefully considered in the research process, this competition for nutritious food grains could have adverse effects on the nutrition of the human target population who often cannot afford meat.

FP1.6 Clusters of Activities (CoA)

CoA 1.1 Foresight, climate change analysis and priority setting

The substance of priority setting in Phase I was evaluated with an objective of drawing out implications for Phase II using product lines as the organizing construct for delineating the research portfolio, each involving one or more easily identifiable prospective technologies[120]. CoA 1.1 will continue and enhance the pre-proposal *ex-ante* impact and foresight analyses for targeting and prioritization[121] during the first year of GLDC. Standard *ex-ante* economic impact evaluation of research using the economic surplus model[122] will be complemented by *ex-ante* impact analysis of alternative GLDC technologies in collaboration with CRP-PIM using the IMPACT system of integrated models and building on the methods and experiences of the GFSF work consisting of bio-economic modelling tools linking site-specific or geo-spatial crop modelling with economic modelling[123]. The work applies *ex-ante* impact assessment methods to a range of research and technology and management options and uses technical and market-related information including expert estimates obtained through wider expert and stakeholder consultations. Research and technology options identified in other FPs, e.g. farm management options (FP3) and available and new technologies (FPs4-5), to address particular constraints will be evaluated based on their potential rates of return as well as economic, environmental (e.g. biodiversity, soil and water conservation, etc.) and poverty reduction impacts using *ex-ante* impact and quantitative foresight methods. Value chain interventions (FP2) will be evaluated based on their potential impacts on the efficiency of GLDC value chains (e.g. changes in value capture by producers) and associated impacts on household incomes and poverty. Priority setting will also be informed by food supply, demand and prices projections under climate change and other socio-economic drivers of change such as technology, population growth, urbanization and changes in diets (strong links to PIM).

Overall, CoA 1.1 will provide the evidence base for priority setting and targeting alongside CoAs 1.2-1.4 and will serve as a platform for FP1 to provide a coordinated feedback to GLDC to guide priority setting. FP1 envisions that such a transparent and consultative process of priority assessment will ensure commitment of the national and regional stakeholders to the program.

CoA 1.2 Value chains, markets and drivers of adoption

The target beneficiaries of GLDC research are engaged in subsistence production, but they also sell parts of their produce to market outlets and so the households are integrated into the cash economy. These markets include more distant markets that often offer higher prices and local markets which are essential for rural households, their income and nutritional status. In addition to the important local market outlets, growing demand for healthy food options by urban and peri-urban consumers will receive specific attention for its role as a profitable niche market but also as a driver for longer term changes in eating habits by the whole population as experienced in more developed markets over the past decade[124]. The analysis of ongoing initiatives like the Smart Food campaign will generate valuable lessons in this area.

Thus this cluster combines the analysis of a) local, regional and international market demands for GLDC products and their characteristics; b) input and output value chain effectiveness at national and regional scales; and c) household preferences for new technologies and practices within their wider on- and off-farm livelihood systems. The value chain framework and the structure-conduct-performance approaches will be used to identify key constraints and opportunities along the chain aiming for increased competitiveness in production, marketing and processing. The key clients for these outputs are FP2 Transforming Agri-food Systems and FP4 Variety and Hybrid Development where, respectively, action research interventions within agri-food and seed supply systems must be chosen from candidate GLDC value chains.

Successful scaling of any technology also requires a detailed understanding of the drivers of, and constraints to, adoption at the household and farm level. A careful consideration of the often heterogeneous target group(s) and their livelihood systems is critically important. Keys to successful scaling include analysis of target group segregation within the continuum of market- and subsistence-oriented farmers[125], deepening understanding of the end-user's demands for product and technology attributes and resulting benefits, and what makes an effective technology an attractive one for rural households and value chain actors.

Potential tensions and trade-offs between market demand and farmer needs will be investigated in the context of the underlying goals and objectives of households as well as their information requirements and corresponding dissemination channels. While the importance of GLDC crops in the farm households' cropping portfolio is established, understanding further dimensions of smallholder livelihood diversity in terms of crop-tree-livestock systems is still lacking. Likewise, the analysis will disaggregate adoption patterns across different plot managers and their status within the household and add consideration of intra-household dynamics to establish a deeper understanding of the adoption process and impacts on women and the youth. Because widespread adoption requires behavior change, methods beyond 'classical' adoption studies will be used from fields such as behavioral economics and psychology (e.g., choice experiments), marketing (consumer decision theories and market segmentation methodologies), communication and other fields that target the understanding of human behavior and decision making.

CoA 1.3: Gender integration and social inclusion in the drylands

Participation of beneficiaries in the process of innovation and technology development ensures more inclusive growth and equitable distribution of benefits from research and extension. When development agents engage with communities, it quickly becomes apparent that culture and social norms play a critical role in determining whose voice is heard in the expression of preferences, whether women, men or young people can participate and to what extent; as well as who has control of, or access to, what resources. Communities are organized around cultures and norms that lead to differentiated outcomes and, in some instances, interventions provide disservice to certain social groups. Although young people's challenges in agriculture can overlap with the challenges of adult men and women farmers, they do have unique challenges (e.g. lack of land rights at their age) tied closely to their aspirations (with some aspiring to exit agriculture, while some are forced by circumstances or choose to settle into agriculture), the opportunity structures (supportive institutions, processes) they have in their communities, and the transitional nature of this stage of life. It is thus critical to understand what this means in terms of the place of women and young people in the dryland society and the potential of attaining positive outcomes from GLDC products.

CoA 1.3 will undertake strategic gender research to understand and test participation of women and youth in GLDC value chains as well as in the delivery of technologies and practices within innovation systems. A key question is whether such innovation systems interventions will lead to inclusion, empowerment and growth. On women, the role played by social/gender norms in influencing decision making and participation in the cereals and legumes innovations at farm and post farm will be investigated. Of special interest will be practices, norms and core values around mobility and public space participation, seed use and replacement, varietal use and replacement, knowledge acquisition in public spaces, engagement with markets and value chains.

On the youth, GLDC will focus on understanding the 'youth in the drylands' – who they are, who is staying in agriculture, who is leaving agriculture, who is coming back to agriculture once they left and the pathways they follow in engaging with agriculture with a view to targeting them for engagement in cereals/legume value chains; understanding the opportunity structures they have, assessing/testing the sectors of the legumes and cereals value chains that have the highest potential for the youth to engage and benefit, and testing support systems that lead to the youth engaging and benefiting from legume/cereals value chains. The role of ICT/digital agriculture in enhancing the participation of the youth in the value chains will be investigated. Capacity building on gender analysis will be integrated at graduate/postgraduate level as well as implementing partners.

CoA 1.4 Enabling environments and scaling to accelerate impact

The purpose of CoA 1.4 is to facilitate and accelerate the scaling of GLDC technologies and innovations to achieve impact at scale, as well as to support the evidencing of this impact. This will involve (a) dedicated research to identify enabling conditions and specific scaling approaches required for such scaling to take place; and (b) the provision of support and tools to GLDC research teams to facilitate meaningful stakeholder engagement throughout the research cycle and assess and synthesize the impact of GLDC innovations and interventions.

GLDC aims to improve the performance of agri-food systems for GLDC crops. Many of the causes for underperformance relate to the wider policy environment, e.g. poor regulation and distortions of agricultural input and output markets. In coordination with CoA 1.1, FP2, and CRP-PIM, CoA 1.4 will support work with key country-level decision-makers and other stakeholders to identify, prioritize, and address key policy constraints impeding the development of targeted GLDC value chains, coupled with the development, testing, and scaling of contextually appropriate solutions.

Particular efforts will be made to generate evidence on what works for scaling and under what conditions, with the resulting learning scaled out to other GLDC regions. Key scaling partners, such as AGRA, CRS, and Syngenta Foundation, as well as the private sector, will also be engaged. This work requires understanding the local context and engaging key decision-makers (including farmers) in a meaningful way throughout the research-to-impact cycle, including the development and systematic comparison of promising extension approaches. This will be complemented with focused communications work in collaboration with GLDC's communications team to share the resulting lessons to influence wider policy and practice and, in turn, achieve impact at scale. Experimenting with different interventions for overcoming key constraints affecting targeted GLDC value chains (e.g. contractual arrangements between producers and buyers) is an example of a key opportunity for both generating learning and facilitating scaling. Considerable progress has been made in recent years in the field of behavioral economics on how to incentivize or "nudge" behavior change[126]. CoA 1.4, together with the other CoAs of FP1 and FP2-3, will integrate this learning and the associated experimental approach.

In addition to identifying approaches to accelerate, intensify, and scale impact in collaboration across the GLDC FPs, CoA 1.4 will further directly undertake, as well as support, GLDC's research teams to generate evidence of adoption and impact of GLDC technologies and innovations. Support for these efforts will be sought from key partners instrumental in supporting rigorous impact studies, such as SPIA and the International Initiative for Impact Evaluation (3ie)[127]. The resulting evidence and scalable lessons will be used to inform wider policy and practice and, in turn, leverage greater impact.

FP1.7 Partnerships

In order to deliver on FP1's objectives, a wide range of partners will be involved in the implementation. This will range from high-end academic research partners at globally recognized institutions, to scaling partners, private sector partners to build strong business models for remote areas and policy makers. Links have been established and collaboration agreed with CRPs PIM, CCAFS, A4NH, and other AFS-CRPs (e.g., LIVESTOCK, FTA, MAIZE, RTB, WHEAT). Collaboration between FP1 and Priority Setting and Scaling FPs of other AFS-CRPs will negotiate similar methods and approaches including gender and social inclusion. CoA 1.1 will also partner with the Harvest Choice initiative at the University of Minnesota which works on targeting and priority setting. CRP-PIM will be a valuable partner in foresight modeling and *ex-ante* analysis including methods and tools development for research on upgrading value chains and impact assessment of commercialization on gender equity. CoA 1.3 will participate in the CGIAR gender network and the GENNOVATE studies[128].

Non-CGIAR partners will be identified and selected based on identified gaps in competencies and experiences and build on existing well-functioning partnerships in relevant CRPs and W3/bilateral projects. Throughout FP1 but especially under CoA 1.4, policy makers and scaling partners will be identified and selected through a stakeholder mapping exercise in target countries. This will include national and local government; regional organizations (e.g. APAARI, NEPAD, ECOWAS); non-governmental organizations such as AGRA, CRS and Syngenta Foundation; private seed companies; farmer and consumer organizations; and development agencies. International university partners include Michigan State, Penn State, Illinois, Missouri, Virginia Tech, Swedish University of Agricultural Sciences, and Purdue. The Gender and Agriculture Network is partnering with Pennsylvania State University to support and train gender researchers and postdocs including the GLDC gender team.

Building on past research and scaling efforts to leverage existing models, FP1 will collaborate closely with projects and programs targeting the scaling of innovations relevant for GLDC. This will not only enable GLDC to utilize existing networks to spread insights and lessons learned but also policy messages aimed at generating commitment for scaling successful innovations across wider areas. With regard to comparative advantage, the GLDC partners have long-standing experience working in the targeted agri-food systems and regions and will align its R4D impact with the regional and national development strategies.

FP1.8 Climate change

CoA 1.1 has a strong climate change focus and it will undertake climate change impact analyses in targeted agri-food systems and agroecological regions. In view of the link between weather and crop productivity, much of the analytical work carried out by CoA 1.1 using the IMPACT model and the Agricultural Model Intercomparison and Improvement Project (AgMIP) is relevant to the analysis of climate impacts on agriculture. IMPACT is linked to crop and water models that in turn use results from General Circulation Models (GCMs) to project the impact of climate change on crop yields, harvested area, production, consumption, prices and trade of a range of agricultural commodities. Climate change without adequate adaptation could nearly double projected increases in global prices and area for major crops by 2050, with potentially significant implications for food security and the environment[129]. The research will assess the potential for new technologies and investments to reduce adverse impacts of climate change. Different crop-based technologies, management and policy adaptation options will be evaluated on the basis of their potential to improve farm profitability, reduce production and price fluctuations and food and nutrition security risks and to increase the resilience of these vulnerable smallholder farming systems. The research includes foresight and scenario analyses and *ex-ante* analysis of the potential impacts of climate change and variability. *Ex-ante* and foresight studies will facilitate evaluation, targeting and prioritization of different production system intensification options. This information will be fed to the other FPs and CoAs, thereby leading to improved focus on the interventions with the highest potential impacts.

FP1.9 Gender

Gender analysis will be mainstreamed within the CoAs of this FP. Methods of including scenarios for women in foresight modeling, women's adaptive capacities in dealing with climate change and accounting for gender preferences in priority setting will be mainstreamed in CoA 1.1. Making value chains and markets work for women and young people will be a priority area of assessment under CoA 1.2. Furthermore, the drivers of household decisions to adopt or dis-adopt will be analyzed while emphasizing intra-household dynamics of this decision-making process and ensure levels of disaggregation that allow specific gender questions to be answered. Furthermore, market demands and their relationship to the associated value chains will identify entry points for women and young people and highlight operational modalities that will ensure their continued or increased empowerment along the chain. The research focus of CoA 1.3 will be strategic, addressing overarching gender research questions. CoA 1.4 will focus on institutional and policy level factors that enable women and young people to participate and gain from innovations in the targeted agri-food systems at scale. For FP1, gender mainstreaming will ensure that prospective research outputs are gender-equitable and empower women.

FP1.10 Capacity development

Capacity development in FP1 includes training of national- and international PhD students and postdocs conducting their research within GLDC and being jointly supervised by GLDC researchers and partner institutions. Other components will be training packages (short courses, summer schools, curricula development) to disseminate methods and tools designed with partners that are potential agents of change. Examples of key gaps in the capacity of national and regional partner institutions are in the area of gender research and development strategies as well as the coordinated value chain analysis and the effects of climate change and related risks. These are ideally suited for training packages and will form the backbone of the development strategy for this group of partners. Capacity development of GLDC researchers and partners will be achieved during the process of CRP-wide, impact-focused learning and specific training on gender analysis. Partnerships with advanced research institutes as well as mentoring relationships will be forged in different cutting edge areas under each CoA. Specifically, advances in foresight modeling, gender analysis methodologies, innovative approaches to measuring adoption and impacts on poverty reduction and approaches to the science of scaling.

Innovative methods of data collection and analysis, such as computer-assisted personal interviews, will be streamlined and expanded across GLDC and trainings will be organized where necessary. A community of practice exchanging ideas and providing a forum for trouble shooting is already established and will be broadened. FP1 will also engage in capacity development for the use of modern tools such as mass media (like the farmer TV program *Shamba Shape up*) which have already been used in phase 1 as (based on initial text message based feedback) efficient tool to transfer knowledge to a wide audience. Through detailed feedback on their efficiency in raising awareness and influencing adoption, GLDC will use them effectively to reach the targeted audience. These tools will also raise greater awareness amongst the wider stakeholders and consumers, which is critical for their engagement commitment especially in CoAs 1.1 and 1.4.

FP1.11 Intellectual asset and open access management

FP1 will strive to use models that are building on open source software. All research data in GLDC will be maintained for public use as stated under Sections 1.11 and 1.12 above. The Lead Centre, ICRISAT and IITA as leader of FP1 maintain all their data products using different state-of-the-art data platforms/applications based on the type of data. Dataverse is the primary repository to share different types of data sets and all data platforms and repositories used are compliant with the CGIAR’s standard interoperability protocols and standards.

FP1.12 FP management

FP1 is led by Dr Arega Alene, senior agricultural economist with IITA. He will be supported by a team of experienced agricultural economists (all with strong links to CRP-PIM), including Dr Swamikannu Nedumaran, Dr Sika Gbegbelegbe, Dr Kai Mausch among others. Dr Esther Njuguna, a gender specialist with ICRISAT and Dr Karl Hughes, Head of the Monitoring, Evaluation and Impact Assessment unit of ICRAF are also key members of the FP1 team.

FP1.13 Budget summary

Flagship Program 1 :Priority setting & impact acceleration						
Funding Needed	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
W1 + W2	993,690	1,043,400	1,095,480	1,150,320	1,207,800	5,490,690
W3	2,016,100	1,116,800	765,500	-	-	3,898,400
Bilateral	2,583,094	5,341,947	8,702,815	4,085,225	4,016,525	24,729,606
Other Sources	-	-	-	-	-	-
Total Needed	**5,592,884**	**7,502,147**	**10,563,795**	**5,235,545**	**5,224,325**	**34,118,696**
Funding Secured						
W1 + W2	993,690	1,043,400	1,095,480	1,150,320	1,207,800	5,490,690
W3	2,016,100	1,116,800	765,500	-	-	3,898,400
Bilateral	1,715,181	1,369,719	1,152,180	196,200	174,400	4,607,680
Other Sources	-	-	-	-	-	-
Total Secured	**4,724,971**	**3,529,919**	**3,013,160**	**1,346,520**	**1,382,200**	**13,996,770**
Funding Gap						
W1 + W2	-	-	-	-	-	-
W3	-	-	-	-	-	-
Bilateral	(867,913)	(3,972,228)	(7,550,635)	(3,889,025)	(3,842,125)	(20,121,926)
Other Sources	-	-	-	-	-	-
Total Gap	**(867,913)**	**(3,972,228)**	**(7,550,635)**	**(3,889,025)**	**(3,842,125)**	**(20,121,926)**
Line Item						
Personnel	1,972,636	2,640,905	3,690,288	1,865,433	1,853,008	12,022,270
Travel	340,596	476,668	683,531	310,533	307,113	2,118,441
Capital	279,357	289,956	336,198	267,472	269,452	1,442,435
Other Supplies and Services	1,244,024	1,661,191	2,335,013	1,156,445	1,169,957	7,566,630
CGIAR	203,718	289,171	443,155	188,032	185,804	1,309,880
Non CGIAR	839,953	1,181,846	1,713,218	782,534	775,637	5,293,188
Indirect Cost	712,600	962,410	1,362,392	665,096	663,335	4,365,852
Total Budgets	**5,592,884**	**7,502,147**	**10,563,795**	**5,235,545**	**5,224,326**	**34,118,696**
Core Partner						
ICRISAT	4,685,521	6,650,986	9,705,164	4,324,076	4,272,853	29,638,600
IITA	163,632	140,766	176,276	127,664	155,971	764,309
ICARDA	257,309	245,777	236,075	271,174	275,220	1,285,554
CSIRO	486,422	464,619	446,280	512,631	520,281	2,430,233
Total Budgets	**5,592,884**	**7,502,147**	**10,563,795**	**5,235,545**	**5,224,326**	**34,118,696**

FLAGSHIP PROGRAM 2 (FP2): TRANSFORMING AGRI-FOOD SYSTEMS

FP2.1: Rationale and scope

Post-farm marketing, trade and processing of agricultural commodities produced by smallholder farmers offer pathways to poverty reduction, food and nutritional security, resilience and sustainability impacts[130]. Market opportunities within dryland cereal and grain legume agri-food systems provide incentives for the adoption of new on-farm and post-farm technologies that will boost both productivity and sustainability[131]. Yet many of these opportunities remain unrealized because of failures in the wider agri-food systems: missing or underdeveloped value chains and input and output markets, weak policy enabling environments, underdeveloped nutritional literacy, ineffective organizational policies and practices and a lack of focus on organizational and institutional development to position key stakeholders for market-facing opportunities[132].

Flagship Program 2: Transforming Agri-food Systems (FP2) focuses on resolving challenges to enable, at scale, step-changes in the off-farm utilization of dryland cereals and grain legumes. FP2 will address these challenges by making use of decision support/modelling tools, big data analytics, business engagement and incubation processes, systems and institutional analysis tools and, in collaboration with FP1, evaluation and learning approaches.

Critical in considering the enabling environment of GLDC agri-food systems, FP2 must partner with businesses, NGOs, civil society and other stakeholders. Gaining mutual ambition and investment of enacting and scaling partners is essential for the realization of crop utilization opportunities and the potential of these to be catalytic in driving wider agri-food systems transformation. The GLDC Innovation Fund (US$1 million pa) will be used to take advantage of emerging opportunities and new partnerships during the implementation process. Analysis of market and policy trends and drivers conducted by FP1 will frame the targeting of opportunities. Further, FP2 will collaborate closely with FP1 and CRP-PIM to identify issues in the policy-enabling environment that need attention in relation to selected opportunities. FP2 will provide signals to FP4 and FP5 on priority crop traits and opportunities around seed and input systems arising from emerging and future market demands. FP2 will rely on FP3 to test the on-farm implementation of proposed innovations.

Promising opportunities already exist for step-changes in the off-farm utilization of dryland cereals and grain legumes:

- Relative export performance index shows that Ethiopia has high potential among legume-exporting countries. In 2012, 17% of Ethiopia's US$1 billion food exports were legumes[133]. This creates the opportunity to expand farming of chickpea to meet international demand and strengthening partnership between export companies and the Ethiopian Institute of Agricultural Research (EIAR) who, with support of the CGIAR, has released high-yielding chickpea varieties.
- The Indian Government has set targets for the establishment of Farmer Producer Organizations (FPO) as a way of both collectivizing production and for developing near-to-farm, value-adding opportunities. Successful FPOs can attract further targeted investment from the National Bank for Agriculture and Rural Development (NABARD) and other institutional support agencies. With funding from NABARD, ICRISAT has helped establish 16 FPOs in the southern States of India by providing handholding and mentoring support and development of sustainable business models. The emergence of FPOs in drylands not only collectivizes smallholder farmers, but also provides opportunities to develop partnerships with urban retailers and strengthen value chains to service urban markets where there is a growing awareness about traceability of foods and the nutritional value of crops such as sorghum and millets. FPOs also allow validating and promoting agri-tech start-ups that can plug the gaps in the supply chain, especially in the back-end where decision support systems can play a major role in enabling smallholder farmers to take informed decisions. Through value-addition, a related opportunity exists to position FPOs as suppliers of processed and semi-processed foods to Government initiatives such as the Indian midday meal scheme that targets nutritional security for school children from poor households.

- In Nigeria, currency depreciation, price and import regulations have provided incentive for major breweries and confectionaries to substitute sorghum for imported barley and wheat, with an annual industrial demand for sorghum estimated at several hundred thousand metric tons. ICRISAT has developed malting and other varieties of sorghum in the region, although they are currently not widely adopted. ICRISAT is already partnering with breweries, flour mills, grain traders, farmer organizations and seed suppliers to both introduce these new varieties to farmers but also to create, using inclusive digital solutions, a secure and traceable value chain that ensures the quality of the grains supplied to industry[134].
- In Tanzania, a set of partnerships between research organizations, the extension services and seed companies, coupled with the creation of producer-marketing groups, supported the introduction of improved varieties of pigeonpea. The new variety was adopted on 25,000ha, tripled yields and created a strong export market, producing an additional 1.3 tons per hectare or 33,000 extra tons – delivering approximately US$33 million in extra value to smallholder farmers[135]. The opportunity exists to scale the expansion of this export-orientated approach by helping crowd-in other farmer groups, input and market players and expanding interest in the range of dryland crops.
- In India, Tata Consultancy Services and Microsoft have invested in rural data platforms that align to their wider business interest in providing decision and logistical solutions to companies. These platforms provide an opportunity for data management to support production and market planning and forecasting, health and nutrition surveillance and interventions, and monitoring of market and social performance of different interventions. The real opportunity is that the platform provides a focal point for partners across the agri-food system to collaborate and coordinate efforts and develop synergies between different but synergetic interventions and business opportunities[136].
- While linking agriculture, nutrition and entrepreneurship, ICRISAT is engaging with the State Government of Telangana in India to provide nutritious food products based on millet and pulses (Nutri Food Basket) to improve the nutritional and health status of the State's tribal population. A key component of this intervention is to provide primary processing units at the farm level, and further incubating women entrepreneurs to operate the processing units, besides producing and supplying the Nutri Food Basket[137].
- In Senegal and Nigeria, ICRISAT partners with MANOBI-AFRICA and other private and public organizations to incorporate Earth Observation and *in-situ* IoT technologies into mAgri™, an existing value chain orchestration platform connecting, in smallholder contract farming, maize, peanut, rice and sorghum producers with banks, insurers, input providers and agro-industries[138]. This innovation action will help reduce finance institutions cash-out and increase availability of credit to smallholders, reduce persistent climate risk through more robust and affordable agricultural insurance contracts, and improve tactical management of nutrient deficiencies and post-harvest losses for increased productivity, harvest quality, smallholder income and welfare.

The approach of FP2 will be to select concrete opportunities as an arena for formal research to offer advanced tools, models and analytics to support investors in agri-food systems to develop and apply solutions in order to realize opportunities or overcome constraints. These solutions can include production and post-production technology applications, novel business models, design of post-harvest infrastructure, value chain innovations, social organization arrangements, novel partnerships, equitable benefit-sharing agreements, improved governance and institutional arrangements and organizational and public policy options.

Critically these solutions will be developed and applied at multiple levels of the agri-food system: at the level of the enterprise or social intervention, at the level of the value chain or social development program and at the level of organizational and public policy. While the unlocking and incubation of some of the opportunities will have technology commercialization at its core, others will resemble social marketing, business development services to build the capacity of enterprises to service new markets, or technical assistance to existing public or civil society platforms. ICRISAT-AIP, a public-private partnership initiative, is a pioneering Research Theme that works by upscaling technology and research outcomes through agribusiness ventures and advocating sustainable interventions with partners so as to benefit smallholder farmers, youth and women in rural communities. AIP aims to connect with other stakeholders in the agri-innovation and entrepreneurship ecosystem to foster growth of agribusiness ventures and sharing of knowledge and information to help in improving livelihoods of rural communities and enhancing the contribution of the non-farm sector to local economic development. FP2 also aligns with ICRISAT's Smart Food Initiative[139] where strategic marketing and policy and market engagement is being used to raise awareness of the nutrition, market and farmer livelihood benefits from sorghum and millet production and consumption, implemented through partnerships such as the Nutri-Food Basket projects.

The overarching research question for FP2 is "*what processes, practices and tools and institutional arrangements unlock crop utilization opportunities and catalyze the transformation of agri-food systems in dryland ecologies?*".

The incubation and unlocking of the selected opportunities under CoA 2.1 forms the central 'action research' activity of FP2. It will focus on marshaling expertise, analysis and practical support to overcome constraints and the application of solutions where agri-food system opportunities are identified by GLDC scaling-out partners – SEWA, AGRA, CRS, GAIN, Farm Africa, Microsoft and MANOBI-AFRICA, among many others (Table 7). Such partners already run large development programs in GLDC target agroecologies and they are committed to inviting in FP2's formal research expertise to access modern crop varieties, technical advice, formative/summative evaluation and cross-program learning. CoA2.1 action research is not research-led but will be demand-responsive to impact opportunities that demonstrate quantitative returns to R4D investment.

CoA 2.2, led by CSIRO, will support CoA2.1 through provision of practical, generic tools, models and processes to assist in the creation of solutions. These include value chain modeling, business canvass tools, partnership-broking tools, policy dialogue and engagement tools, feasibility study methodologies, stakeholder analysis tools and agri-food system analysis tools[140,141,142]. While the central purpose of these tools is to support the progression of the selected opportunities, these tools will also be international public goods (IPGs) in their own right. CoA2.2 will also have important capacity strengthening outcomes, both in terms of building decision-making and analytical skills of key stakeholders, but also in terms of building networks and relations across different dimensions of the agri-food system.

The third companion activity, CoA 2.3, will identify bottlenecks within agri-food systems that restrict the realization of opportunities being addressed in CoA 2.1. Analysis will also identify and prioritize intervention points that need to be the focus of action and solutions in CoA 2.1. Activities will include targeted market and policy studies (undertaken in collaboration with FP1 and CRP-PIM where appropriate) and investigation of the nature of existing bottlenecks to innovation in the agri-food system in which the opportunity is embedded. This will involve exploring patterns of partnership, organizational incentives, practices and norms, roles and capabilities of key actors, the nature of governance arrangements and the political economy of change processes. In collaboration with FP1.4, CoA 2.3 will evaluate the impact effectiveness of different solutions and intervention that FP2 is using to stimulate different dimensions of agri-food system change and impact. Finally, CoA 2.3 will play a learning function for FP2, deriving scalable lessons on how the realization of opportunities can be advanced in ways that are catalytic in agri-food systems in different contexts, including how to best implement inclusive services from solutions created in the pre-competitive space (CoA 2.2). Peer-reviewed published learning is another critical IPG contribution of FP2.

FP2 will draw strongly on the GLDC Innovation Fund in order to respond to emerging opportunities.

FP2.2: Objectives and targets

The goal of FP2 is to strengthen agri-food system mechanisms to respond and adapt to context-specific and evolving needs of women, men and young farmers, and value chain and governance actors. It will deliver on multiple SLOs by catalyzing agri-food system changes that stimulate and support the expansion of production, value addition and trading of dryland cereals and legumes. To achieve these goals, FP2 will actively support agri-food system stakeholders in achieving the following objectives:

- The development, adaptation and application of a range of decision support, business development, systems analysis and stakeholder engagement tools needed to unlock dryland cereal and legume utilization opportunities.
- Improved capacity of agri-food system stakeholders to use the aforementioned tools.
- The development, in collaboration with key agri-food systems actors and stakeholders, of business models, organizational and institutional innovations, and partnerships and governance arrangements that link farmers to input and output markets and that support the development of equitable, transparent and sustainable value chains.

- The establishment of functional links between emerging consumer and other agri-food system demands and crop improvement and related production and post-production research.
- An assessment of the social, economic and environmental impacts of FP2's agri-food system interventions and implications for future investment and the policy-enabling environment.
- Development of scalable lessons on the suite of tools, interventions, capacities and processes that are effective in realizing dryland legume and cereal utilization opportunities in ways that are catalytic in agri-food systems transformation in different contexts.
- Promote agribusiness opportunities and scale-out models using the Innovation Fund that can address the gaps and enhanced market participation of smallholder farming communities in the value chain.

FP2 intends to achieve impact through provision of underpinning research expertise to scale-out partners that seek systemic change and the development of integrated design solutions to address market gaps and enhance market opportunities. The Flagship envisions positive impact on beneficiaries across different segments of value chains in the target countries. The various segments of the beneficiaries are conservatively estimated to be in the range of: (i) 1,000,000 women and children benefitting from exploring AFS opportunities in terms of improved nutrition; (ii) 400,000 farm women labor benefitting from improved post-harvest technologies; (iii) 800,000 households and 5,000 traders using improved post-harvest handling and storage technologies, (iv) benefits from entrepreneurship development and diverse enterprise opportunities will benefit SME entrepreneurs – 1,000; (v) 10,000 young people – in particular young women – trained on business development skills; and (vii) 1,000 value chain stakeholders benefitting due to new linkage of processors to markets. These shall feed into the SLOs towards achieving the overall targets projected (Table 5) as part of achieving the IDOs aligned to the CGIAR SRF.

FP2.3 Impact pathway and Theory of Change

FP2 focuses on GLDC value chain opportunities and identifying and overcoming agri-food chain lock-ins. The logic of FP2's first impact pathway is that supporting the acceleration of off-farm utilization opportunities through technological, business, market, institutional and policy innovations will encourage increased and better targeted investment and interventions by the private and public sectors and civil society organizations. This is notably done through incubation and generation of inclusive business and investment models.

In the second impact pathway, FP2's approach will strengthen links between critical market, research, policy and consumer stakeholders (e.g. through setting up multi-stakeholder platforms) and in doing so will increase the collective capacity to drive and govern agri-food system changes that respond to farmers, business and society's needs and will stimulate research responses that support these. By catalyzing these wider transformational changes in agri-food systems the FP will contribute to create the enabling conditions and capacities for sustained impact at scale into the future.

FP2 designs and tests interventions with a significant potential to contribute to profitable GLDC value chains by drawing on leverage points identified by FP1. On the other hand, FP1 evaluates FP2 incubation initiatives and anticipates their scaling effects. While FP2 will pursue direct collaboration with FP3 to ensure marketable farming system products, it will maintain indirect linkages with FP4 and FP5 through FP1. In collaboration with FP1, FP2 will provide signals to FP4 and FP5 on priority crop traits arising from emerging and future market demands.

By stimulating innovation in practice, FP2 will amongst other contribute to the IDOs of (i) increased income and employment through stimulating diversified employment opportunities with specific emphasis on women and youth; (ii) in partnership with FP1, improved enabling environment by working toward a more favorable general business setting through policy platforms that support innovation; (iii) enabling of national partners and beneficiaries through collaboration, capacity building and development of adequate tools (Figure FP 2.1).

The theory of change underlying the work of FP 2 is based on the following assumptions:

- The success of selected incubation experiences depends on the ability of agi-food system actors to create space for testing inclusive agribusiness models. FP2 will help define the essential financial, technical and social conditions for incubation.
- Selected incubation experiences are scalable within and across countries through durable but resilient networks of change agents.

- The regional and global movement towards inclusive business stimulates sufficient interest in value chain models taking into account broader societal needs among gatekeepers. Foresight modelling in FP1 to provide the necessary scientific evidence to key decision-makers in the public and private sector.
- Context-specific experiences can be generalized to generate wider-applicable models and generate systems innovation.
- Initiatives such as policy engagement and other platforms and incubation facilities sustain themselves after the program.
- Communication of success stories and user-friendliness of ICT tools developed under FP2 will play a critical role in scaling impacts. Led by partners (MANOBI-AFRICA, Microsoft), FP2 will test and further develop communication tools, such as TV-shows, SMS-services and Apps to reach out to new potential incubation actors.

Achieving impacts through activities under FP2 depends on stakeholder engagement and potential of localized incubation initiatives to inspire other initiatives. Therefore, FP2 will collaborate closely with its development partners to engage with the ministries of economy and development, chambers of commerce, and private sector interest groups in each of the countries. Innovative business incubation models, new post-harvest processes and technologies, innovative value-added food products linked to consumer/market demands will be developed and tested to incubate, promote and support SME business enterprises.

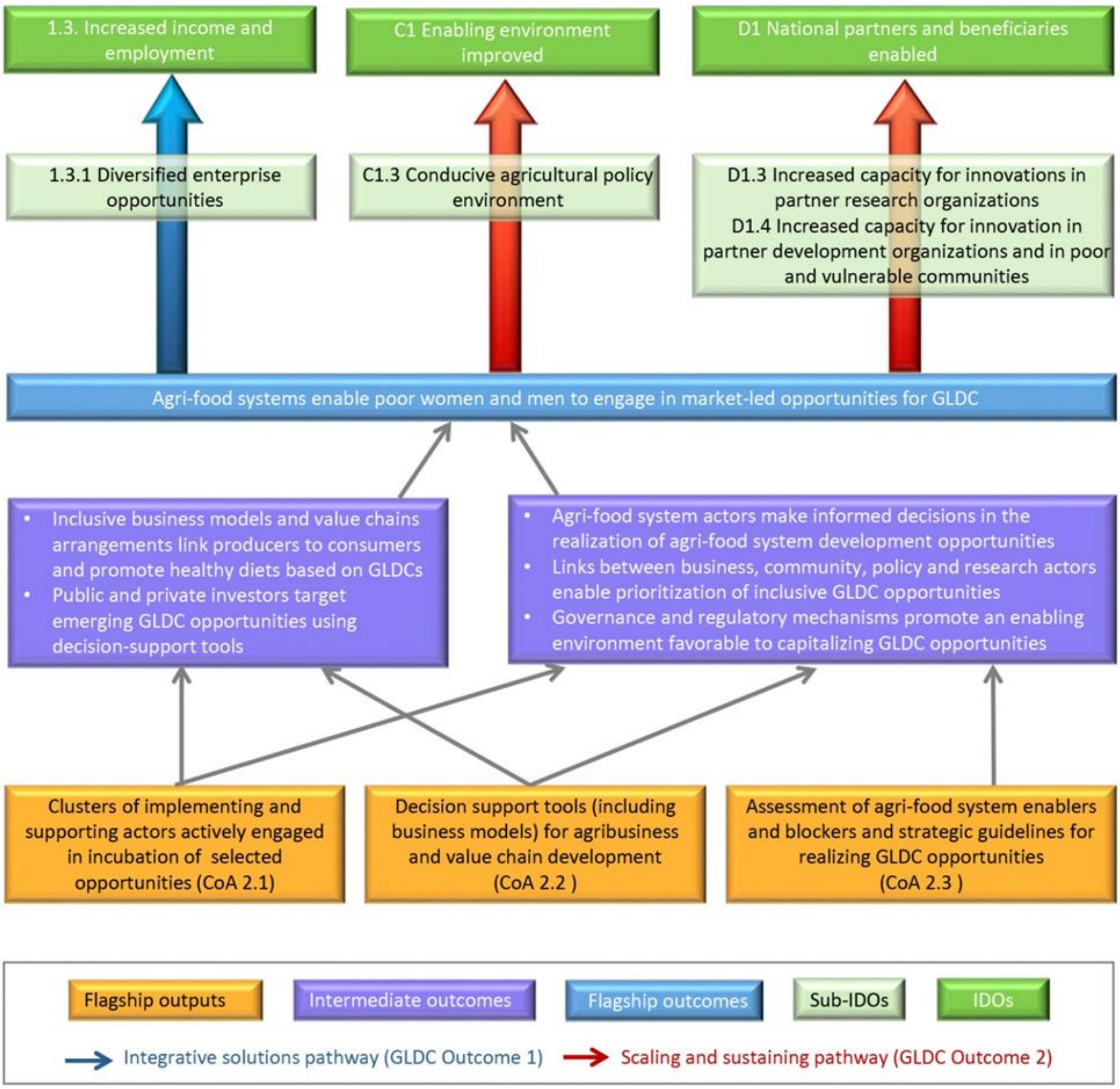


Figure FP2.1. FP2 Impact pathway

FP2.4 Science quality

FP2 brings powerful conceptual framings and tools to the challenge of leveraging emerging market and other opportunities for dryland cereals and legumes and the smallholders who produce them. Critical is an overarching research framing that recognizes that these opportunities are embedded in wider agri-food systems (Box 1). These systems determine patterns of agricultural production, value chain practices and performance, as well as consumption patterns and food and nutritional security and environmental consequences[143].

Box 1. Agri-food system definition[144]: "*an interconnected web of activities, resources and people that extends across all domains involved in providing human nourishment and sustaining health, including production, processing, packaging, distribution, marketing, consumption and disposal of food. The organization of agri-food systems reflects and responds to social, cultural, political, economic, health and environmental conditions and can be identified at multiple scales, from a household kitchen to a city, county, state or nation*".

Recognizing that GLDC opportunities are embedded in agri-food systems opens up new research enquiries and intervention approaches and provides a broader, systemic perspective on the way scaling takes place. Key analytical and operational insights include the following:

- The unpredictability and non-linearity of cause-effect relationship in agri-food systems innovation and change processes necessitates taking a learning or processed-based approach to intervention design and implementation. The value of using predictive models as boundary objects to help stakeholders explore intervention options can explicitly address uncertainty in decision-making[146].
- The role of institutional arrangements, routines and practices is recognized in shaping partnerships and networks, patterns of governance, the effectiveness of markets in distributing benefits and in determining the capacity of stakeholders to respond to triggers and shocks. These arrangements and norms are often "rusted on", causing inertia and missed opportunities, pointing to the importance of institutional innovation in effort to incubate new opportunities[147].
- Niche or pilot interventions in agri-food systems – e.g. the development of new agro-processing enterprises – can achieve scale and sustainability when coupled with efforts to cascade wider systems change (values, behavioral changes, incentives, policies and capabilities)[148].
- Multi-stakeholder platforms that span multiple scales (farm to policy) can help catalyze agri-food system innovation by aligning public and private agendas and by more clearly defining the role of research in wider change processes[149]. Platforms can also form a focus for learning and capacity-building across scales.

Primacy in FP2 research is not to further elaborate the agri-food systems concept *per se*, but rather to use the concept to frame action and learning on how opportunities can be realized in ways that catalyze wider agri-food systems changes. The framing is sufficiently broad to provide scope to combine the power of a range of analytical tools and capacities that align with the agri-food system perspective:

Hard systems modeling tools: value chain bio-economic models for decision support in the development of equitable and sustainable value chain[150,151] , logistics analysis tools to understand the performance of transport, delivery and support networks for smallholder farmer inputs (e.g. seed) and outputs (e.g. grain)[152].

System change models and frameworks: agricultural innovation systems analysis to diagnose and design the patterns of partnership and practice needed to enable innovation[153]: multi-level perspectives on systems transitions to help design interventions to cascade systems changes and scaling[154]. Agri-food system lock-in analysis to identify practice, capacity and policy bottlenecks and to guide mitigation interventions[155].

Business development tools: methods to design the value proposition for a business opportunity (business "canvasses"); methods for customer engagement and market testing; and communication and marketing approaches.

These tools are already well developed and in R4D use by FP partners. However, their power lies in the ability of FP2 to cluster and combine these around a common purpose of unlocking and incubating GLDC opportunities at scale. The application of these tools and perspectives also creates a unique science agenda of exploring, in an action research mode, what suite of tools, interventions, capabilities and enabling environment can cascade pervasive changes in GLDC agri-food systems that support broader scale objectives of poverty reduction, food and nutritional security and environmental sustainability.

FP2.5 Lessons learnt and unintended consequences

The rapid urbanization, digital revolution, value chain innovations, the emergence of inclusive business models and a renewed emphasis on nutritional security are presenting new opportunities for smallholders to produce nutritionally dense GLDC crops. For example, the rapid expansion of supermarkets in both Africa and Asia is creating new value chains that could connect smallholder producers with urban markets[156]. Dryland ecologies offer a range of high value natural products whose development may be facilitated by globalization, providing access to niche markets for eco-friendly products that, by using trademarks, can earn premium prices[157]. At a more local scale, emergency relief interventions can be designed to build new value chains around local produce and capacities[158].

However, powerful stakeholders and multiple intermediaries in value chains can skew benefits away from poor producers and provide few incentives to reduce environmental externalities[159,160]. Alternatively, attempts to stimulate community-based rural agro-processing enterprises often struggle to build entrepreneurial capacity and often falter, or remain at a pilot scale, due to competition from the organized sector, a weak understanding of market demands or due to regulatory, policy and institutional issues that rural enterprises on their own are unable to tackle[161]. Even where value chains are established to link smallholder producers to markets, market failures (such as monopolies, illegal rent-seeking, excessive taxation, side-selling or withholding fair prices from women) can inflate end-user prices or deflate producer prices[162].

FP2.6 Clusters of activities

FP2 will achieve its goals via three interlinked clusters of activity. CoA2.1 will tackle the realization of diverse range of large-scale GLDC opportunities, supported and informed by the tools and analysis in CoA2.2 and CoA2.3. Consequently, CoA2.2 will identify, develop, build and deliver tools that support decision-making and implementation of at scale innovation. CoA2.3 will undertake diagnostic studies of the agri-food system in which GLDC opportunities are embedded, to guide the design of interventions in CoA 2.1, and will implement analysis and evaluation to learn "what works" by observing resultant experiences. CoA2.3 takes particular note of the effectiveness of a suite of tools, interventions, capacities and processes in different contexts and the policy, institutional and market influences that enable or block innovation at scale.

CoA 2.1 Incubating and unlocking opportunities at scale

This CoA undertakes action research focused on the realization of carefully selected at-scale crop-utilization opportunities. The selection of these opportunities will be guided by:

- The portfolio of existing post-farm, scaling out development being implemented by core partners;
- Priorities set by FP1 CoA 1.2 and their analysis of market trends and drivers; and
- The need to explore opportunity incubation in a range of contrasting contexts: degree of market orientation, development of new markets versus expansion of existing ones, input supply networks versus farm output; social enterprises versus conventional market players; NGOs versus private sector.

The Flagship will initially focus its attention on identified opportunities that core partners are working on, for example:

Farmer Producer Organizations (FPOs): in support of FPO development, primary millet and pulse processing units run by the local communities are being introduced by the Indian Government. The opportunity focuses on spreading processing technology outcomes to wider markets by offering incubation support to agribusiness start-ups. This builds on and expands successful commercialization of millet and sorghum-based value added products by providing business incubation support to women lead enterprises by AIP-ICRISAT.

The long-term aim is to empower smallholder farmers with the appropriate technologies and connect them to a strengthened business ecosystem to maximize the remuneration from their farm produce.

Microsoft Intelligent Cloud Platform: provides an opportunity for BigData Management, Advanced Analytics and Artificial Intelligence, to unlock insights and assist in production and market planning and forecasting, health and nutrition surveillance and interventions, and monitoring of market and social performance of different intervention. Azure is generally available in 36 regions around the world including three data centers in India and plans announced for four additional regions, including Africa. This will enable higher performance and support requirements and preferences regarding data location. The real opportunity is that the Intelligent Cloud platform can provide a focal point for partners across the agri-food system to collaborate and coordinate efforts and develop real-time synergies between different but synergetic interventions and business opportunities using insights. ICRISAT is working with Microsoft in piloting a DSS for farmers in India[163].

CRS Pathway to Prosperity initiative: CRS is actively engaged in GLDC value chains in a number of SSA countries, including a large USDA-funded soybean project in Tanzania (Soya ni Pesa[164]) and a large Food-for-Peace project in Malawi (UBALE[165]) which is strengthening farmer participation in the pigeonpea, groundnut and cowpea value chains, and promoting doubled-up legume systems.

In order to incubate and implement on-the-ground at-scale innovation that is driven by market opportunities, it will be necessary for CoA2.1 to marshal and apply skills in business systems. These skills include knowledge about how to match a particular opportunity with an appropriate business model; methods to design the "value proposition" for a business opportunity (business "canvasses"); methods for customer engagement and market testing; and communication, marketing approaches and business incubation. CSIRO and ICRISAT have been pursuing these approaches in recent years as part of technology and business incubation programs; for example innovation acceleration program[166] in CSIRO and ICRISAT-AIP. CoA2.1 will draw on this experience and the methods associated with it in the incubation of selected opportunities.

The CoA2.1 outcome is business models, organizational and institutional innovations, partnerships and governance arrangements that link farmers to input and output markets and that support the development of equitable, transparent and sustainable value chains. Its will achieve this by creating clusters of implementing and supporting actors actively engaged in incubation of selected opportunities. The CoA 2.1 outputs are:

- Feasibility studies and business plans for identified crop-utilization opportunities.
- *Ex-ante* appraisals of impacts and trade-offs of identified crop-utilization opportunities.
- Technical and nutritional appraisals of food processing and product development options targeting identified crop utilization opportunities, focusing on addressing malnutrition, hidden hunger and lifestyle diseases.
- Appropriate post-harvest management practices and other technology solutions for identified challenges associated with targeted GLDC opportunities.
- Benefit-sharing arrangements in value chains.
- Platforms and other multi-stakeholder engagement mechanism that align agendas and priorities to support agri-food system transformations associated with identified crop utilization opportunities.
- A set of validated and scalable business models, and associated institutional arrangements that are inclusive, economically and environmentally sustainable and that contribute to the nutritional security of poor women, children and men.

CoA 2.2 Tools, models and processes to support at-scale innovation

The tools and processes from CoA 2.2 are those required to support the implementation of at-scale innovation. Through adapting and refining such tools and processes in the course of the CRP, a multi-disciplinary user-friendly toolkit of IPGs is created. The tools include agri-food system / innovation system lock-in analysis, innovation system diagnosis and learning, value chain bio-economic models[167,168], logistics analysis tools to understand the performance of transport, delivery and support networks for smallholder farmer inputs (e.g. seed) and outputs (e.g. grain)[169]; geospatial farm production models to quantify the distribution of farm produce[170]; earth observation to monitor smallholder farm operations and performance;

technology adoption predictions[171]; foot-printing and lifecycle analysis[172]; experimental learning tools; and household surveys linked to economic models to predict food demand, dietary profiles and market size and stakeholder performance analysis. Many of these tools are currently under development by CSIRO, the CGIAR teams and partners and will be refined and delivered to meet a range of potential applications during the course of GLDC.

In a similar vein, the development of a tool to conduct *ex-ante* impact assessment is particularly important to evaluate trade-offs among different, and often, competing performance measures (social, nutritional, economic and environmental). While value chain analysis[173] has provided researchers and practitioners an entry point to characterize and describe these systems, it has been limited in its ability to provide *ex-ante* quantitative insights on the impacts of revealed potential interventions[174]. However, recent innovations have been made in the application of system dynamics (SD) models in value chain analysis, whereby the processes of the value chain are modeled alongside their interactions with markets, production patterns and challenges, investment options, and various types of social behavior and phenomena[175,176]. By modeling the value chain in this fashion, alternative scenarios can be run to look at the impact of different value chain interventions on the profitability and performance of the system, teasing out impacts for different value chain nodes and typologies of chain actors (e.g. small vs. large farms).

The analytical tools and business systems will together provide FP2 teams in CoA 2.2 the means to analyze and deliver at-scale innovation opportunities. The CoA2.2 outcome is that the capacity of value chain and other AFS actors is improved to make informed decisions in the realization of agri-food system development opportunities. Cluster outputs are:

- Decision support tools for agri-business and value chain development
- Decision support and analytical frameworks for predicting and promoting nutrition, gender and sustainability outcomes in value chain development.
- Analytical frameworks that diagnose agri-food system constraints that prevent the realization of crop-utilization opportunities and that prioritize interventions to address these constraints.
- Policy and other stakeholder engagement tools.
- Capacity building exercises to improve the skills of value chain and other agri-food system actors to apply tools and frameworks developed by this CoA.

CoA 2.3 Systems analysis and learning for at-scale innovation

CoA2.3 has three linked roles. The first is to undertake targeted diagnosis of agri-food system constraints associated with opportunities identified in CoA2.1 and to prioritize interventions and actions. The rationale of this diagnostic analysis is that by identifying wider agri-food systems bottlenecks and missing partnerships and capacities associated with CoA 2.1 opportunities, interventions can be targeted that can trigger a cascade of system changes that will not only help scale CoA 2.1 interventions, but also create the capacities and incentives for further investment by the public and private sectors in emerging GLDC opportunities. Underpinning this rationale is pioneering multi-level approaches[177] and multi-stakeholder engagement and scaling research[178].

Secondly, the at-scale incubation of opportunities in CoA 2.1 will provide the opportunity for CoA 2.3 to develop lessons about how agri-food systems change can be catalyzed. Research methods for this include case studies and comparative analyses with feedback loops into the design and adaptation of CoA 2.1 interventions. Key research questions include:

- What needs to change in order for a localized opportunity to realize at-scale impacts?
- What suite of tools, interventions, capacities and processes are involved in realizing these opportunities in different contexts? and
- What contextual factors (policies, institutions and markets) enable or block the scaling process?

How can stakeholders identify critical change triggers in agri-food systems and what are the triggers and tipping points for bringing about these changes?

The third role of this CoA is evaluation and impact assessments of CoA 2.1 interventions to better quantify and understand the intended and unintended consequences of agri-food system changes that the Flagship is catalyzing. This will be undertaken in collaboration with FP1 and CRP-PIM.

Cluster outputs are:

- A critical assessment of agri-food systems conditions that constrain or enable the incubation of selected opportunities in dryland agroecologies and the identification of triggers and tipping points associated with wider agri-food system change.
- Identification of opportunities and mechanisms that enhance the role of women and youth in dryland value chains.
- A set of lessons and strategic guidelines on the suite of tools, interventions, capacities and processes involved in realizing dryland crop utilization opportunities in different contexts and that catalyze agri-food system innovation.
- Evaluation and impact assessment of CoA2.1 interventions to quantify actual and predicted intended and unintended consequences on poverty reduction, equitable access to value chain opportunities, and nutritional security.

FP2.7 Partnerships

The basis of FP2 is that it is working on the direct interface of research application and scaling. Therefore it strongly depends on partnerships with organizations who have the mandate and the capacity to implement technological and institutional innovations. FP2 will collaborate with academic, public, private, civil society and international development organizations which are identified case by case on the basis of rigorous stakeholder analyses. Identified partners are listed in Table 7.

The Flagship is entering a rather new field of agri-food system R4D within the CGIAR. Strong partnerships are essential for ensuring highest quality and significance of research and its impacts. It has to be seen in this context that the Flagship is led by CSIRO which has an outstanding record of developing agri-food system innovations and scaling tools[179]. Critical is further connections to CRP-PIM in the field of developing policy, market and cooperative agri-food system innovations. CRP-PIM also contributes strong diagnostic experience. Latest ICRISAT recruitments as well as the establishment of the Digital Agriculture Theme and experience of its AIP strengthens expertise in developing scaling tools. The development of technical solutions under CoA2.2 will be done in intensive collaboration with FP3, FP4 and FP5 as well as the other AFS CRPs.

FP2.8 Climate change

Climate change has traditionally not been accounted for in post-farm gate or input systems applications. Most analysis has been focused on the impact of climate change and variability on farm production and the natural resource base. However, variable production supply can have profound impacts on demand for inputs and the supply and quality of farm outputs. This has consequences for risk management, credit worthiness, and raises the need for strategies to adapt. In FP2 there is an opportune chance to integrate climate change considerations into the impacts and adaptation of systems beyond the farm boundary. This will be done through accounting for climate impacts on the biophysical elements of the analytical models (CoA2.2); selecting use cases in CoA2.1 that cover at-risk agroecologies; and in CoA2.3 taking explicit account of climate change as a driver or opportunity for innovation at-scale.

FP2.9 Gender

FP2 proposes to offer ‘social organization arrangements and novel partnerships’ as part of a suite of methodologies to stimulate post-farm processing, marketing and trade of dryland cereals and legumes with a view of enhancing legumes/ cereals productivity and sustainability in the drylands. This is an opportunity for GLDC to consider ‘gainful engagement of women in legumes/cereals value chains’ as well as contributing to the ‘engaging the youth sensitive rural transformation’.

Rural women may not be able to participate in the ‘typical free market systems’ but F2P is committed to bringing out their earning potential in the legume and cereals value chains. Women provide a significant amount of labor in legume and cereals production, as well as the family care and community maintaining responsibilities; which limits their time/possibility to engage with markets, especially if they have to move away from home. Some of the GLDC target regions are in social cultural contexts whose norms and practices still limit the participation of women in public domains because of religious or social norms[180], hampering their possibility of engaging with the markets directly. Women in the drylands are increasingly taking responsibility to head households when men migrate to urban areas in search of employment[181], and need to generate income from their agricultural activities. When women generate income, they are also more likely to spend on household needs – food, school, medical needs, clothes – which challenges their ability to reinvest in businesses thereby impacting on sustainability of businesses. With sensitivity to these constraints, FP2, in collaboration with FP1/PIM/Gender Platform will design and test social organizational arrangements that support women's earning potential, monitor impacts of these arrangements on women's empowerment, on household and community power relations and sustainability over time.

The term 'youth' is often applied as if young people are one social category that is homogenous. Increasingly, its appreciated that 'young people have multiple identities, are dynamic and at a transition'[182]. Based on geographical regions they are in, the opportunity structure in their social-economic-political environment, and their embeddedness in families, social networks and communities, as well as norms and expectations related to age and gender, their agency and capacity to engage with 'various sectors of the value chains' for business development will differ. FP2 is committed to re-socializing understanding of 'youth of the drylands', and designing and testing organization arrangements, novel partnerships and pathways of engaging with the 'various/different categories of youth' in strategic areas of the legume/cereals value chains (from farming to trade) and contributing to 'youth sensitive rural transformation' of the drylands.

FP2.10 Capacity development

FP2 framing sees capacity development occurring at three distinct levels. At one level, the capacity of project partners will be enhanced to conduct system diagnoses, identify system innovations and develop scaling tools. This dimension will target in particular NARES partners but also implementing civil society and Government partners. In doing so they will be enabled to identify and exploit opportunities beyond the CRP.

At the second level, State, NGO and international implementing partners will be enabled to use and then apply scaling tools and business processes to various use cases.

At a third level, the capacity of the whole innovation system to identify and realize at-scale innovation will be developed. Partnerships forged between the CGIAR Centers, external partners, NARES, NGOs, and the for-profit sector will create a greater chance for this to happen. Moreover, identification of the enablers and constraints means that various actors in the innovation will become sensitized to these, and thereby avoid the trap of local lock-in.

FP2.11 Intellectual asset and open access management

Other than research data, the key intellectual assets are likely to be associated with facilitation of entrepreneurial activities and innovative concepts/products and technologies linked to CoA 2.2. Access to IPGs generated under FP2 will be provided to stakeholders by following the model of the ICRISAT-AIP. The research partners will provide prototype innovations, knowledge and expertise, training and co-location with researchers for close interaction. The interested entrepreneurs will fine-tune the prototypes as per demand and take them to market, including bearing the market risks and reaping the rewards involved.

FP2.12 Flagship management

FP2 is led by Dr Andy Hall (CSIRO). Dr Hall is a science and technology policy analyst with a longstanding interest in the nature of innovation processes and polices in Asia and Africa. Most of his research and advisory has been on improving use of agricultural research for innovation in national and international agricultural research organizations and investments. FP2 includes researchers skilled in agricultural innovation systems research from CSIRO, Drs Chris Downs and Kanar Dizyee, and the CGIAR, Drs Michael Hauser, Kiran Sharma, Bussie Maziya Dixon and Thomas Falk. The team will include representatives from a range of partner organizations, e.g. Dr Geoff Heinrich (CSR), from those listed in Table 7.

FP2.13 Budget summary

Flagship Program 2 :Transforming Agrifood systems						
Funding Needed	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
W1 + W2	1,242,113	1,304,250	1,369,350	1,437,900	1,509,750	6,863,363
W3	8,449,519	4,633,345	5,490,625	5,153,994	5,218,518	28,946,001
Bilateral	6,985,037	6,314,815	6,261,489	3,724,964	3,723,825	27,010,130
Other Sources	-	-	-	-	-	-
Total Needed	**16,676,668**	**12,252,410**	**13,121,465**	**10,316,858**	**10,452,093**	**62,819,494**
Funding Secured						
W1 + W2	1,242,113	1,304,250	1,369,350	1,437,900	1,509,750	6,863,363
W3	4,449,342	1,310,742	1,166,667	-	-	6,926,751
Bilateral	3,760,471	2,569,155	1,992,823	179,400	174,400	8,676,249
Other Sources	-	-	-	-	-	-
Total Secured	**9,451,926**	**5,184,147**	**4,528,840**	**1,617,300**	**1,684,150**	**22,466,362**
Funding Gap						
W1 + W2	-	-	-	-	-	-
W3	(4,000,177)	(3,322,603)	(4,323,959)	(5,153,994)	(5,218,518)	(22,019,250)
Bilateral	(3,224,566)	(3,745,660)	(4,268,666)	(3,545,564)	(3,549,425)	(18,333,881)
Other Sources	-	-	-	-	-	-
Total Gap	**(7,224,743)**	**(7,068,263)**	**(8,592,625)**	**(8,699,558)**	**(8,767,943)**	**(40,353,132)**
Line Item						
Personnel	5,842,667	4,647,833	4,444,174	3,640,431	3,653,710	22,228,815
Travel	731,944	662,807	807,716	451,158	452,171	3,105,796
Capital Equipment	708,784	240,062	547,029	189,994	190,705	1,876,574
Other Supplies and Services	4,191,794	2,775,530	3,335,749	2,856,145	2,867,887	16,027,105
CGIAR	537,951	391,784	377,317	281,054	293,857	1,881,963
Non CGIAR	2,540,637	1,990,009	1,952,244	1,608,635	1,687,059	9,778,584
Indirect Cost	2,122,891	1,544,385	1,657,236	1,289,441	1,306,704	7,920,657
Total Budgets	**16,676,668**	**12,252,410**	**13,121,465**	**10,316,858**	**10,452,093**	**62,819,494**
Core Partner						
ICRISAT	7,901,283	4,147,881	3,583,850	899,186	880,658	17,412,858
IITA	7,250,194	6,524,774	7,961,544	7,777,478	7,921,521	37,435,510
ICARDA	228,620	236,800	236,248	245,860	247,317	1,194,845
CSIRO	1,296,571	1,342,955	1,339,823	1,394,334	1,402,598	6,776,281
Total Budgets	**16,676,668**	**12,252,410**	**13,121,465**	**10,316,858**	**10,452,093**	**62,819,494**

FLAGSHIP PROGRAM 3 (FP3): INTEGRATED FARM AND HOUSEHOLD MANAGEMENT

FP3.1 Rationale and scope

Smallholder farming systems need to intensify if they are to feed the increasing human population without compromising natural resources. They currently provide the majority of grains (41% maize, 86% rice, 66% sorghum, 74% millet), milk (75%) and meat (60%) in the tropics[183]. These systems also provide 15% of the nitrogen inputs for crop production via nitrogen legume fixation and manure amendments[184] and employ millions of people on farms, in formal and informal markets, in processing plants and other strands along value chains[185,186,187]. These predominantly cereal-legume-tree-livestock farming systems consist of complementary components managed by rural households to provide staple food, marketable commodities, income, feed, manure, fuelwood and workpower. Smallholder farms and households can exhibit resource use-efficiency, higher productivity and sustainability, if well integrated[188].

In the mixed crop-livestock systems of the semi-arid and sub-humid tropics, sorghum and millets are important staple cereals grown in rotation or as intercrops[189] with grain legumes. The choice of these crops by farmers is due to their ecological suitability to dryland agriculture and critical attributes given the projected impacts of climate change[190]. These crops are complementary for balanced diets: cereals provide starch while grain legumes are rich sources of protein, low in saturated fat, as well as possess important micronutrients like zinc, folate, calcium and tocopherols[191]. South Asia (SA) and sub-Saharan Africa (SSA) have the highest estimated number of individuals with some form of undernutrition, with more than 300 million malnourished representing about 19% of their populations[192]. Besides being nutritious, grain legumes, in rotation or as intercrops, introduce nitrogen into low-input agroecosystems[193]. Of the two processes through which atmospheric N_2 is converted into biological substrates available for growth of other plants, namely N_2 fixation and N rhizodeposition (decomposition and decay of nodules and root cells and exudation of soluble N compounds by plant roots), the latter alone can contribute between 4% to 71% of total plant N[194].

Despite the synergies of cereal-legume-tree-livestock integration, unsustainable resource use in many dryland agroecologies has resulted in alarming rates of land degradation, over-exploitation of natural resources, loss of production and biodiversity[195]. New insect pests, diseases and weeds have predisposed dryland agri-food systems to a greater dependency on inputs including pesticides, herbicides and antibiotics[196]. Hence, there is an urgent need to improve the capacity of these systems to cope with the 'grand challenges' of the 21st century[197] while taking advantage of opportunities (e.g. new market demands, new varieties and management systems, improved delivery systems of climate information) by building resilient and diverse agri-food systems that contribute to poverty reduction and ensure nutritional security[198]. This increased capacity for innovation will need to occur within the context of rapid urbanization, changing aspirations of men, women and youth affecting labor supply, water scarcity, land degradation and climate change[199]. Such challenges require greater investments to enhance the resilience and sustainability of these agri-food systems.

FP3 will primarily focus at the field, farm and household levels with the integration of on-farm systems and household livelihood management into the one flagship concerned with management decision making by women, men and youth[200]. Improved on-farm agronomy and livestock husbandry will leverage the advantages of improved varieties (sourced from FP4) to ensure the full systems synergies of sorghum and millets, when grown in rotation or intercrops with grain legumes and integrated with livestock. Commodity outputs need to contribute into increasingly functional value chains (FP2 goal). Smallholder households balance available resources to ensure continued on-farm production meeting their diet, income and livelihood requirements[201]. FP3 research offers the inquiry and analytical tools that can provide context-specific options for better integrating field, farm and household decisions that are responsive to the challenges of the dryland agroecologies. In doing so, FP3 will contribute to the SLOs on poverty reduction, improved natural resources and ecosystem services, and improved food and nutritional security. It will overlap with the GLDC cross-cutting themes on climate change, gender and youth, capacity development and address questions relevant to BigData and ICT. This can only be realized by adopting an innovative approach to researching and optimizing GLDC-based farming systems that function as a whole in response to farmers' livelihoods and markets. FP3 will provide the platform to translate crop-specific research into tested, farmer-led cropping systems that improve overall system performance to include not only production efficiency but also risk management, resilience, inclusiveness, profitability, acceptability and improved nutrition. The FP will also guide and feedback into priority setting (FP1) based on the identification of emerging problems at the farming and household systems levels.

The FP3 strategy for scaling out is through partnerships, particularly with NARES partners and their extension services, and with NGOs who have large development mandates (e.g. GAIN, AGRA, CRS, CARE and others). The GLDC Innovation Fund is specifically tuned to leveraging these scale out partnerships. In turn, FP3 offers formal research inquiry and analytical tools – e.g. stakeholder surveys, climate/soil/crop/herd parameter databases, APSIM farming systems model, Integrated Assessment Tool (IAT) for household decision-making, iThink™ value chain models – that provide i) insight into where scale-out investment is warranted[202]; ii) diagnostic analyses that explain system performance with/without innovations[203]; and iii) system-level learnings across multiple case studies[204]. Addressing issues beyond the farm and household levels will rely on collaboration with CRPs WLE, PIM, FTA and CCAFS.

The hypothesis posited by FP3 is that agroecologically-adapted, functional, diverse and emerging GLDC-based agricultural production systems will generate the agricultural, ecosystem and household returns required to achieve sustainable and resilient futures for the drylands. FP3 will address crop, tree and livestock management issues that are common to the drylands where the majority of GLDC crops are found.

Links to grand challenges

Climate variability and change are major challenges facing agri-food systems, especially in rainfed production areas at the farm scale. This predisposes smallholder farmers to risks associated with household nutritional security and income generation. Efficient use of resources through the adoption of sustainable and resilient agricultural practices, and the inclusion of diverse stress-tolerant crop varieties with short duration and improved nutrients (N) use efficiency will enhance adaptation and contribute to mitigating the effects of climate change. FP3 will be closely linked to FP4 to increase accessibility to locally adapted farmers' preferred varieties. It will work with the integrating CRPs that includes CCAFS to evaluate the impact of climate change on dryland agroecosystems and WLE to evaluate the interactions between farm-scale cropping systems and larger scale land and water management systems.

Dryland farming risks can be reduced by exploring crop, tree and livestock diversification and intensification options of food, fodder and feed systems through rotations, intra-specific and intercrop diversity, sequential crops and improved short-season dryland cereals and grain legumes. This will be complemented by better management of abiotic and biotic stresses and the safe use of crop protection products for reduced adverse effects on the environment.

Land degradation needs to be addressed by moving to more resilient and resource conserving production systems. With locally adapted crop, tree and livestock solutions, this flagship will contribute to restoring degraded lands and the efficient use of scarce water resources for sustainable and productive agroecosystems. FP3 will emphasize this via close connections with WLE and FTA sharing common land health surveillance and restoration monitoring tools and methods (for instance LDSF, Revised Universal Soil Loss or RUSLE, etc.), and scaling up strategies for land restoration at farm to landscape scales.

This FP will contribute to the global targets set for the GLDC and those that are proposed for a safe operating space through sustainable and diverse crop-tree-livestock systems that contribute to net reduction in greenhouse gas emissions, reduced land degradation, improved water and nutrient use efficiency, increased agrobiodiversity, including reduced and safe use of crop protection products.

FP3.2 Objectives and targets

The goal of this flagship is to capacitate stakeholders such that they can improve the productivity, profitability and sustainability of smallholder farming systems using on-farm and in-household innovations to ensure household nutritional security and enhanced income generation through integrated crop, tree and livestock production systems. Its specific objectives are:

- To design, test and scale improved crop-tree-livestock management options and their interactions to optimize productivity and enhance resource use-efficiency;
- To increase the productivity and agro-biodiversity in farming systems and strengthen household livelihoods through improved nutrition and dietary diversity;
- To increase the climate resilience of farming systems through integrated soil, crop, water and nutrient management approaches;
- To manage and conserve the natural resource base and close nutrient cycles to avoid soil fertility losses; and
- To use (with FP1 and FP2) Innovation Platform (IP) approaches to identify opportunities for value chain enhancement.

FP3 will include and build on a portfolio of mapped projects (representing > US$15 million in 2018) such as Drylands Development Program (DRYDEV) for enhanced food and water security for rural economic development (ICRAF 2013-2019); increasing agricultural productivity and incomes through bridging yield gaps (ICRISAT 2013-2018); increasing food legume production by smallholder farmers (ICARDA 2013-2018); enhancing food and nutritional security and improved livelihoods (ICARDA & ICRISAT 2016-2019); integrating crop genetic diversity into NRM in East Africa and Nepal (Bioversity); IPM with the legume innovation lab and cowpea scaling up projects in West Africa (IITA 2013-2018); Sustainable intensification of key farming systems in West Africa Sudan-Sahelian zone and Africa RISING (multi-institutional 2017-2021). The estimated W3/bilateral funds from these projects for 2017 amount to US$14.9 million.

Geography and beneficiaries

Of the 14 target and 15 spillover countries identified for GLDC, FP3 will continue to select with partners, key Agri-Food System (AFS) CRPs and other FPs a limited number of research sites to implement an integrated system research approach coupled with an out scaling strategy. Building on the work of the Phase I CRPs, FP3 will focus on the following integrated research sites: Rainfed ALS – Ethiopia, India, Sudan and Uganda; Agro-pastoral ALS – Burkina Faso, Mali, Niger, Kenya, Tanzania and Nepal as spillover countries; and Irrigated ALS – Nigeria. These include nine primary target countries, one spillover country and one research-hub country.

The direct beneficiaries of the CRP will be male and female resource-poor smallholder farmers, youth and other marginalized groups. Farmer associations, innovation platforms, NGOs, private-public partnerships, local and national governments will be assisted to take up, support and disseminate the newly integrated crop-tree-livestock options in their policies, strategies and activities as part of a transformative process towards sustainable intensification and diversification of agricultural production. NARES, local research and extension organizations will play important roles in adapting outputs to farmers' conditions.

FP3.3 Impact Pathway and Theory of Change

The purpose of FP3 is to understand and support farming systems transitions to accommodate GLDCs in response to growing market demand (Figure FP3.1). Capitalizing on existing knowledge on IPM, intra- and intercropping and improved farmer's system management practices, this FP additionally strives toward closing yield gaps and diversifying crop productions for balanced diets through improved agronomic and animal husbandry practices (sub-IDO 1.4.2) by taking a farm system perspective. Development of low-cost mechanization options suitable for increased resource (labor) use efficiency is a prerequisite for making such systems attractive and is thus a major focus of the FP. Leveraging the dual purpose of GLDC as food and feed, livestock-GLDC integration is explicitly addressed.

At first sight, the proposed R4D agenda addresses farming system challenges for which solutions exist. Therefore, emphasis will be placed on the integration of existing solutions against novel biophysical and social challenges. The reduction of biotic and abiotic stresses not only contributes to achieving a higher productivity but also provides an opportunity for farmers to reduce the use of pesticides and herbicides and thereby addressing health concerns. In this regard, FP3 will seek active partnerships with CRP-A4NH.

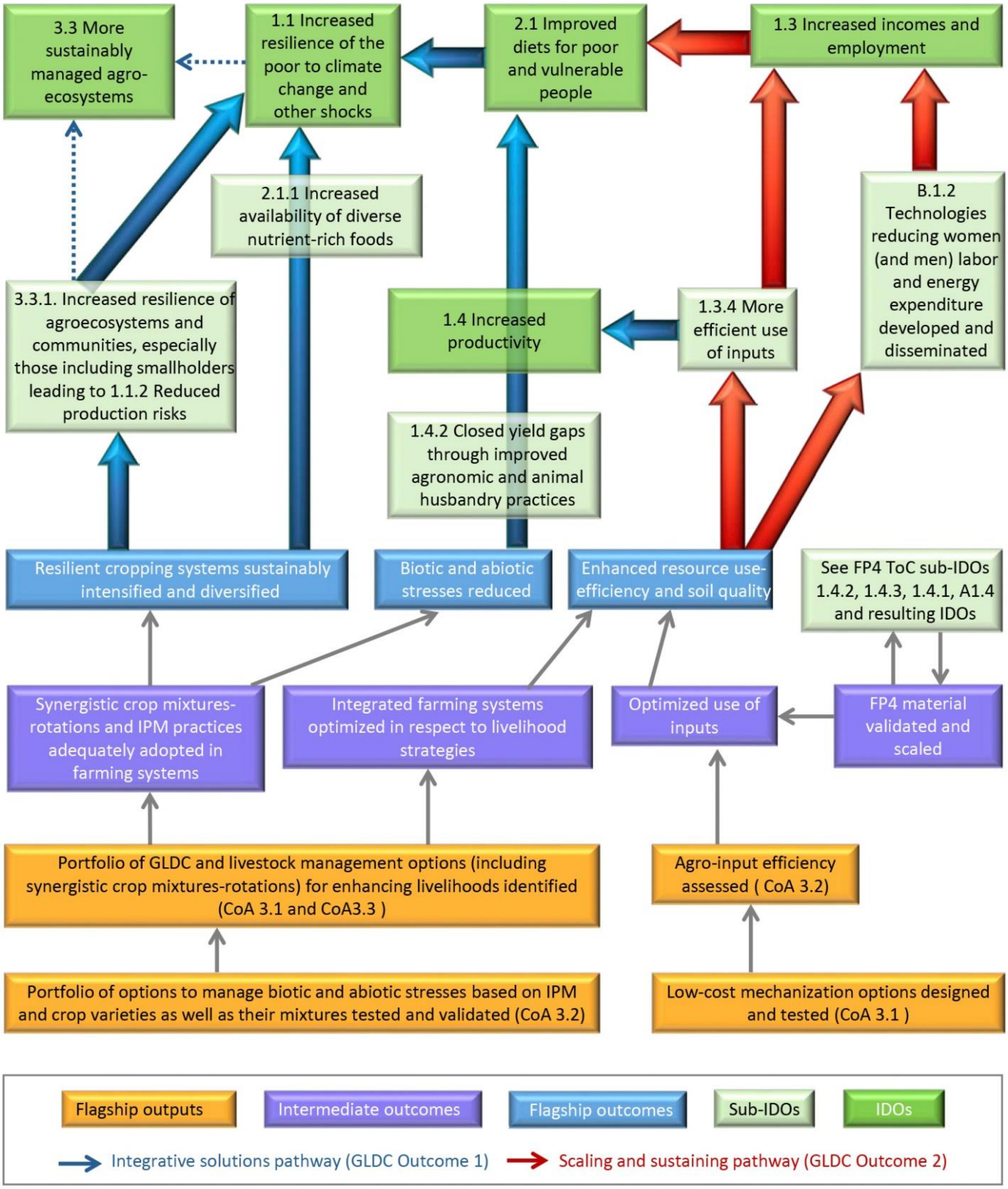


Figure FP3.1. FP3 Impact pathway

The FP contributes to (i) improved diets for poor and vulnerable people (IDO 2.1) through farmers integrating GLDCs in farming practices, increased resilience of farmers to climate change and other shocks (IDO 1.1) through diversification and management of biotic and abiotic stresses (ii) increased productivity (IDO1.4) and more sustainably managed agroecosystems (IDO 3.3) by maximizing synergies within farming systems (crop – livestock integration, nitrogen fixation, organic and mineral fertilizer applications, micro dosing, etc.), reducing biotic and abiotic stresses and alleviating the workload through low-cost mechanization and through this (iii) increased income and employment opportunities jointly with FP2 (IDO1.3) by freeing up time for non-farm activities and reaching more efficient use of inputs, translated into savings.

Key assumptions underlying FP3's ToC are:

- There is a demand for improved farm performance by farmers and their political representatives. This demand will be scrutinized against novel challenges, notably changing landownership, changing weather conditions, and pressure on land through urbanization.
- Traditional solutions to economic challenges exist and through different stakeholders research and extension will make available new knowledge and technologies.
- Behavioral change toward adoptions of improved GLDC-practices is possible through novel and context-specific learning approaches. Together with agricultural extension and advisory services, researchers will further develop these approaches to increase adoption and adaptation.
- In collaboration with civil society, farm transition models will be developed that are culturally, socially acceptable, gender- and age-sensitive (importance of inputs from FP1) and compatible with other farm and non-farm livelihood activities.

In order to achieve the FP outcomes it is crucial for the developed tools and models to be practically applicable, adapted to farmers' needs and contexts and affordable with a low cost-benefit ratio. Recurrent consultation of the target group (notably through participatory research) and working towards achieving those criteria during the intervention (in collaboration with FP1) is therefore essential for FP success in terms of impacts.

FP3.4 Science quality

FP3 aims to improve the farming system performance by producing information, knowledge, guidelines and new combinations of technologies and practices that contribute to increased nutritional security and income generation through functional, diverse and emerging agricultural value chains[205]. Crop variety options from FP4 will be used in integrated farming systems to generate climate-resilient technological innovations for the agri-livelihood systems that GLDC targets.

Harnessing *genotype x environment x management* interactions (GxExM) for yield that have characterized CGIAR work to date, FP3, in collaboration with FP2 and FP4, will use participatory approaches to better target interventions on land, water, crop, tree and livestock diversity management via a focus on *options x context = farming system performance*[206]. The system performance includes aspects of total farm productivity, resources use efficiency, post-harvest loss reduction, social acceptability, equity and adaptability to contextual changes. By involving key stakeholders, deeper knowledge of the social and ecological context beyond farm scale will be taken into account. This includes knowledge on the constraints, opportunities, who, where, what and how, to prioritize intervention options acknowledging heterogeneity that helps increase overall performance of agri-food systems. System performance will be analyzed not only in terms of yield and quality gap reductions, but also include how better land, water, crop and livestock diversity management can contribute to profitability and resilience to climate change, pest and pathogen biotype changes and market risks[207].

Critical assessments of risk management and acceptability will be included so that decision-making tools will be generated at various scales in the design of better production systems and natural resources management options[208]. This will involve links with the integrative CRPs that include WLE and FTA to upscale farm results to landscapes and PIM in terms of integrating on-farm and off-farm agriculture related data into economic models.

Within the agroecologies of GLDC, global spatial-temporal trends will be identified in land and water productivity and iteratively feed these back into the other GLDC flagships, especially FP1 for foresight analyses (Table FP3.1). A library of case studies of options x context data will be developed to support national and international policy decisions on the management of GLDC-AFS.

By linking with programs such as inter alia*,* the World Overview of Conservation Approaches and Technologies (WOCAT) and other CRPs, the outputs will have global relevance. This will lead to the creation of a community of practice to develop agro-information system standards and best practices so that diverse pieces of sub-systems can complement each other. An important component of these analyses will be the Earth Observation Systems and spatial big-data analytics to help identify and prioritize extrapolation domains thus contributing to CGIAR's effort on BigData. Near-real-time satellite remote sensing imaging coupled with climate and in-situ observations (met stations and cell phone feedback) will allow stakeholders to tailor the rural advisory and early warning to farm production dynamics. Linking these informatics will help improve input- use efficiency and lead to more informed decisions on sustainable land, water, crop and management practices[209]. Interactions across scales should be carefully evaluated as intervention at farm scale can have consequences (desirable or undesirable) at landscape scale and vice versa[210].

FP3 recognizes that productivity increases through improved technologies do not necessarily translate into livelihood improvements for the rural poor without considering socio-economic-ecological, policy and institutional contexts. For this to happen, FP3 will adopt a participatory approach involving the participation of multiple stakeholders in a way that feedbacks are incorporated in the process of development and adoption of sustainably intensified GLDC-based agricultural systems[211]. To ensure that productivity-enhancing technologies also deliver nutritional and environmental benefits, a combination of technical and social innovations have to be developed using trans-disciplinary and integrated research approaches and methods.

FP3 will produce the following IPGs:

- Climate-resilient efficient integrated management practices for enhanced productivity of improved crop varieties, tree cultivars, livestock breeds, water, land and nutrients to adapt to variable and changing climates and farming systems in dryland settings.
- Diversification and intensification of the production systems through suitable expansion of crop/livestock systems and crop variety/cultivar, livestock breed (with the Livestock CRP) and agronomic options.
- Integrated biotic and abiotic (SLM) stresses management strategies for improved productivity and ecosystem services delivery.
- Integrated assessment models for system-level analysis to enable better targeting of interventions along the value chain.

FP3.5 Lessons learned and unintended consequences

Traditional agricultural research has studied the relationship between land and livelihoods mainly from the perspective of the production of goods along agri-food value chains. The challenges of climate change, resources degradation and human-ecosystem interactions raise the broader issue of how mixed cereal-legume-tree-livestock systems can be managed for increased productivity through (not in spite of) the preservation and enhancement of the ecosystem services[212]. That requires stakeholders to be capacitated with new approaches to analyze, understand heterogeneity and risk of technology success or failure in mixed farming systems[213]. The limited capacity for valuing the land and the services it provides undermined the ability to perform trade-off analysis of the impacts of interventions. To strengthen this ability requires a better knowledge, monitoring and evaluation of the ecosystem services provided by land and novel mechanisms to value and reward the production of these services for the benefit of the rural poor. That is why, the GLDC propose to build on the *options x context = farm performance* approach as a progression on the *GxExM* approach based on lessons learned from system research CRPs phase I. This will be combined with WLE's efforts to develop tools that link farm level productivity resilience to the landscape level one.

Phase 1 work of Dryland Systems (DS) and WLE found that the portfolios of sustainable farming system options and their adoption drivers are scale- and context- specific implying a need for a more circumspect analysis of what works where and when and for whom[214]. This research will inform the work on varieties/hybrids in FP4 and 5. Concurrently the livelihood context will be characterized at household-farm, village and landscape levels (within FP2 and with WLE). The context-specific portfolio of options includes technical, institutional/policy and market levers.

For communication and knowledge sharing, FP3 will explore the use of modern gender-responsive ICT including mobile and community media to scale out its outputs. This will include contextualized advisory notes on crop varieties, water, pests and disease management via mobile phones where real-time monitoring of land and water is now available. Innovation platforms linked across flagships will be an important medium of communication and knowledge sharing.

FP3.6 Clusters of Activities (CoA)

CoA 3.1 Cropping systems management

Crop-livestock are complementary in feed, workforce, manure and income all of them if well integrated contribute to optimizing the overall farm level productivity[215] and resilience[216]. Mixed cereal-legume-tree-livestock systems are regarded as risk management options in the face of changing and variable climate[217] but also for cost reduction through N inputs from the legume[218]. Both types of crops are sources of starch, protein and micronutrients for balanced diets of the rural populations[219] while legumes provide opportunities for income generation[220]. For all the above mentioned reasons, this cluster will focus on options for crop and crop variety mixes, rotations and management to increase productivity and enhance resource use-efficiency and soil quality. In addition, to reduce drudgery and increase labor-use efficiency, low-cost mechanization options will be developed with partners (NARES, NGOs and private industry) including two-wheel tractors for land preparation and planting, threshers, drying equipment and milling machines.

Questions to be addressed include: (a) How do agroecology, enabling conditions, market opportunities and farming systems determine options for natural resource management that will result in more resilient, profitable and nutritiously secure livelihoods? (b) What patterns of land use optimize productivity while conserving natural resources? (c) Which low-cost farm-mechanization options improve productivity, labor-use efficiency and reduce drudgery, particularly for women and youth? (d) What modalities can be used to promote adoption of research outputs, including the role of the private sector, rural entrepreneurs, farmers' organizations and policies, and how can this be scaled out?

Outputs: (a) Suitable synergistic systems in rotation for crop intensification and diversification with intra- and intercrops/sequential crops based on the length of the growing period assessed; (b) Suitable dual-purpose and disease-resistant cultivars to improve systems productivity and fodder identified and made available; (c) Inclusion of annual legumes and diverse locally adapted crops into dryland systems that enhance ecosystem services assessed; (d) Gender and age-sensitive small-farm mechanization options to conserve scarce natural resources and labor-efficient crop management options for enhanced productivity and profitability under dryland systems assessed; and (e) Collective arrangements and business models to enhance access to technologies including low-cost farm mechanization developed.

Expected outcomes: (a) Sustainable and profitable cropping systems tested at large scale in participating countries; (b) Farmers in designated areas use improved cropping systems technologies developed by the program to optimize profitability and system sustainability; (c) Stakeholders use results to promote diversified, profitable and sustainable crop-livestock systems; (d) Improved soil health, agro-biodiversity, food and nutritional security under marginal dryland systems tested at large-scale pilot areas; and (e) Efficient farm operations promoted by NARES to improve productivity and reduce post-harvest losses, (f) Increased labor use efficiency through appropriate mechanization.

CoA 3.2 Innovations for managing abiotic and biotic stresses

Abiotic stresses, especially temperature extremes, floods and drought, require a better understanding of the interactions between components of the system to be able to adjust the crop and genotype selection and management options to specific local conditions[221]. This cluster will focus on testing and modelling these interactions to design farming systems that are more climate-resilient and productive. It will achieve this by developing integrated soil, crop, water and nutrient management approaches and by reducing risk through diversifying sets of crop varieties/cultivars (from FP4 and 5). The threat of biotic stresses such as insect pests, diseases and weeds is predicted to worsen with climate change. Integrated Pest Management (IPM) as an ecosystem approach will combine different strategies and practices to grow healthy crops and minimize the use of pesticides (considering profitability and markets via CoA 3.3). This CoA will assess the impact of climate change on biotic stresses and on the efficiency of IPM options on varieties (including transgenic), crop varietal mixtures under various farm management practices (CoA3.1). The CoA will be linked with the Genebank CRP to improve accessibility and use of diverse materials.

Questions to be addressed include:

For integrated soil, crop, water and nutrient management*:* (a) How can soil-water-crop-nutrient modelling, coupled with geo-informatics and appropriate ICT applications help identify entry points and address site-specific issues at the household level for improved decision making at the farm level? (b) How and where do conservation agriculture and diversity of tree/crop varieties/cultivars and livestock breeds contribute to natural resource conservation and sustainability? (c) How will the use of crop and other residues for either soil improvement or livestock feed be considered as part of livelihood strategies and interacting value chains of crop and animal products? (d) How can the benefits of biological nitrogen fixation be increased? (e) What information do farmers need to integrate the use of available inputs in order to improve farming system performance and close nutrient cycles?

For Integrated Pest Management: (a) What are the knowledge gaps with respect to biotic stresses and environment interactions as mediated by climate change? (b) How can farmers make informed decisions about IPM options to be deployed to suit locally and regionally different agronomic and environmental conditions? (c) What are the best gender and age-sensitive options for integrating community-based organizations and the private sector for scaling out IPM? (d) Which cereal and legume crops and varieties/cultivars in intra and inter-cropping or sequential cropping with allelopathic effects can be introduced to control diseases and suppress weed growth? (e) What policies need to be in place to support the use of IPM?

Outputs for integrated soil, crop, water and nutrient management: a) Interventions, recommendations, models and sustainability indicators for efficient and balanced use of water and nutrients for increased production and climate-resilient productive cultivars for use in intra- and inter-cropping (in collaboration with FP4/FP5 and WLE FP5) identified; b) Synergies and trade-offs on a range of scenarios on technological interventions and resource constraints through modelling analyzed; c) Technical fact sheets for agro-inputs, including their efficacy and profitability assessed by women and men farmers.

Outputs for Integrated Pest Management: (a) Improved knowledge and models to evaluate climate change impacts on biotic stresses dynamics and incidence developed; (b) A basket of efficient, economically profitable and socially acceptable IPM options along with simple operational instructions provided by gender-sensitive ICT tools.

Outcomes for integrated soil, crop, water and nutrient management: (a) NARES use research outputs for improvements at farm level in pilot areas; (b) Male and female farmers make use of new adapted crop varieties/cultivars to enhance crop and livestock productivity and ecosystem services; (c) Improved decision-making capacity at community, regional and national levels increase water-soil-crop management options using the knowledge generated.

Outcomes for Integrated Pest Management*:* (a) Women and men scientists, extension agents and private sector are deploying sustainable IPM options against biotic stresses; (b) Farmers are making informed decisions based on their knowledge of IPM; and (c) Policy makers develop laws and policies conducive to the development and deployment of IPM options, including biosecurity aspects.

CoA 3.3 Testing, adapting and validating options

This "on-the-ground" cluster of activities will integrate, adapt and validate the impact of GLDC innovations (e.g. based on *ex-ante* impact assessments and evaluations conducted under FP1) at field and farm levels as well as at landscape scales through collaboration with FP2, CCAFS and WLE and their contribution to CGIAR SLOs. This research recognizes the importance of the scale effects that amplify or impede the impacts of adoption by individuals, households and communities. Multi-stakeholder engagement will play a crucial role in ensuring the viability, adoptability and scaling up of the innovations; hence the participation of individual stakeholders in learning platforms will be an imperative. Initial prioritization of interventions will be derived from the priority setting activities of FP1, with lessons learned under this CoA feeding back to strengthen on-going systems analysis and modeling as decision support. The cluster will link closely with the activities of CoA 3.1 and 3.2 on synergistic cropping systems, and efficient use of land, water and nutrients to improve crop, tree and livestock systems productivity and farm income. The outputs of this flagship become the intervention scenarios to be tested in an integrative modeling environment with WLE and subsequently scaled. Steps to achieve these outputs include (1) aggregating sustainability metrics on individual interventions[222]; (2) analyzing the trade-off frontiers of farm scale options and assessing the competitiveness of new technologies against competing enterprises and their impacts on whole household incomes/cash flows and on risk management strategies considering climate change, family labor, post-harvest losses and consumption preferences using household bio-economic modeling such as CSIRO's integrated assessment tool or IAT[223], the modeling exercise to also evaluate potential of options considering post-harvest losses component targeting increased food availability and farm income; (3) Spatial analysis of the impacts of these interventions at the landscape level with spatially explicit agro-environmental models (e.g., WLE's Mapping Ecosystem Services and Human Well-Being[224,225]). The modelling platforms (household, crop and livestock) will be used to better understand temporal and spatial dynamics and therefore trade-offs and risk.

Table FP3.1: Linkages of FP3 to other FPs of GLDC.

Cluster of Activities	FPs	FP3 role	Collaborating FP role	Outputs; added value
3.1 Cropping systems management	All FPs	Assembly and testing of cereal and legume crop combinations in integrated crop-tree-livestock systems.	FP4 and FP5 for germplasm; FP1 for scenarios and priority setting; FP2 for socio-economic and value chains fit of options.	Combined work will result in better targeting and fitting of options to farm realities.
3.2 Innovations for managing abiotic & biotic stresses	FP4 and FP5	Interventions, recommendations, models and sustainability indicators for efficient use of natural resources and nutrients; better and safer control of pests and diseases.	FP4 and FP5. Provision of improved stress-tolerant germplasm; inputs into scenario assessments by FP1 and FP2 in responding to markets and value chains.	Integrated natural resources and nutrient management approaches that reduce risk and improve input-use efficiency including agro-chemicals to meet functional markets.
3.3 Testing, adapting and validating options	FP1 and FP2	Complementary in enabling environment to facilitate innovations and adoption; integrated assessment and validation of FP2 interventions and feeding back to FP1 prioritization.	FP1 and FP2 value chains, demand, constraints and prioritization; impact analysis and strategies for adaptation.	Complementary perspective on the role of markets, household resources and preferences in enabling the environment for intensification/ diversification; multi-scale evaluation of promising options.

With the two other CoA in FP3, this CoA will facilitate a coordinated set of action research activities targeted to different context-specific farming system types. The aim here will be to enhance food and nutritional security and systems resilience through appropriate integration of cropping systems, tree and livestock using improved technologies, climate information, resource management, post-harvest loss reduction options and markets. These activities will also identify, in collaboration with CoA 2.1 (testing within value chains) and FP1, complementary innovations that are required in an enabling environment to facilitate innovations and adoption at the household and community scales. The impacts of livelihood enhancing interventions on ecosystem services delivery and flow across spatial and temporal scales will be assessed. Trade-off analyses will seek to identify optimum strategies for implementation, explicitly testing emergent complementarities and conflicts at both household (GLDC) and landscape levels (WLE). This CoA will be complemented by FP2 identifying options for integrating into value chains and whole agri-food system. Engaging with multiple stakeholders and Innovation Platforms will facilitate the design and implementation of research in development over larger scaling domains. Using the indicator and sampling frames developed by FP1, farm and household level data generation and reporting will be built-in for concurrent monitoring and feed back to all the FPs.

Outputs: (a) Context-specific equitable portfolios of farm household activities, enterprises and management practices supported by market, led by innovations and enhancing livelihoods (for women, men, marginal groups) while minimizing negative externalities developed; (b) Evidence that interventions at household level in the systems context are key for beneficial impacts on CGIAR sub-IDOs at scale generated; (c) Understanding the influence of social-ecological systems on livelihood systems in GLDC target agroecologies improved; and (d) Key stakeholders made aware of trade-offs and synergies at scale and skilled to use alternative innovations and livelihood strategies to achieve sustainable and resilient futures for the drylands.

Outcomes*:* Tested, adapted and validated options applied for sustainable intensification and livelihood diversification by farmers and strategies for mitigating externalities at scale are in place.

FP3.7 Partnerships

Core CGIAR partners of FP3 are ICARDA, IWMI, ICRISAT, IITA, ICRAF, and Bioversity. However, other partners include CRPs MAIZE, WHEAT, WLE, FTA, PIM and RICE. Non-CG Center partners include FAO, UNEP, USAID, USDA, GEF, IFAD, CARE, AFESD and GIZ. FP3 will continue to foster strong partnerships with national programs of the participating countries, as well as with SROs such as CORAF/WECARD in West Africa. FP3 will also maintain current partnerships with advanced research institutions (CSIRO, CIRAD and IRD), organizations and collaborative research programs such as the USAID-funded Feed the Future Legume Innovation Lab.

FP3.8 Climate change

Options for improved land, water and crop management will be researched under the variable climatic patterns expected in the targeted regions[226]. Climate change impacts are expected to include more severe and frequent droughts and flooding requiring a broad span of approaches to water management including rainwater harvesting, storage, better targeted irrigation systems coupled with trials on adapted germplasm from FP4 and FP5. This research will add to what farmers are already doing in terms of adapting to climate change via changing cultivation practices, sowing times and marketing arrangements[227]. Studies will be conducted on the effects of *climate change x land degradation* interactions on soil moisture regimes, the use of different combinations of cereal and leguminous crop and woody species to access nutrients (including secondary nutrients and micronutrients) and water deeper in the soil profile[228]. These will be combined with options to alter crop-livestock systems such as stocking rate and grazing systems, diet quality, different livestock breeds or species looking at the income and productivity from alternative strategies that will be developed under FP5 and the Livestock CRP[229]. Improved soil-water-crop management will increase the resilience of production systems to climate change and decrease their sensitivity to extreme events[230].

FP3.9 Gender

To attain the impacts aspired for in FP3, members of households and communities will interact with change agents to learn, test, adapt and adopt new cropping systems, options for managing abiotic and biotic stresses and validating different options through an intense knowledge sharing and learning process. A key gender issue, women's participation, takes central stage in consideration of FP3 activities, as do issues of labor, access and decision-making for key resources.

Some of the GLDC target regions are in social cultural contexts whose norms and practices still limit the participation of women in public domains because of religious or social norms[231], hampering if/how women can interact with agents of change. This is despite women providing a significant amount of unpaid labor in seed management, field production, processing and distribution of dryland cereals and grain legumes. With responsibility for these labor-intensive tasks, women experience chronic 'time-poverty'[232].

Women in the drylands are increasingly taking responsibility to head households when men migrate to urban areas in search of employment[233], and require support in these new roles. Differential access to resources leads to gender gaps in production, crop yields and incomes. The main source of labor in dryland farming has been women labor, with needs for long hours of work each day (drudgery) as they have triple roles of production, reproduction and community service.

To attain gender-responsive impacts, FP3 will adopt a “DO NO HARM” approach to gender analysis on two fronts: women’s participation and women’s labor. The FP3 team intends to challenge (not perpetuate) the social inequalities that lead to the non-participation of women in knowledge enhancing/access activities. It will design, test and adopt innovative approaches leading to reaching more women with knowledge and skills around new varieties and management options. HE4SHE approaches – working with men to support women participation, will be tested. FP3 will also be intentional in monitoring the labor/time use requirements of the FP recommendations on women and girls and where feasible, developing/promoting labor-saving machinery to compliment the recommendations.

FP3.10 Capacity development

Capacity development goes hand in hand with knowledge management. FP3 recognizes the need to integrate many types of knowledge including informal and formal, local and scientific, and building representative partnerships with national programs[234]. These combinations will determine who requires capacity development and who should undertake it. Thus farmer-to-farmer training, field schools, farmer competitions as well as formal training to build capacity will be used. Conferences, workshops and seminars are critical in sharing experiences, passing on knowledge and will be used at country, regional and cross regional levels. The multi-country structure of FP3 offers invaluable opportunities for South-South cooperation for capacity building and for producing results with broad applicability and replicability. Key to the success of FP3 will be its interactions with other AFS CRPs (i.e. MAIZE, RICE and WHEAT) in which the introduction of the grain legumes and dryland cereals technologies would significantly improve the resilience and profitability of these major commodities. Joint knowledge exchange will take place within the integrated research sites and through joint initiatives within target countries that are common to CRPs. This will occur through specific FPs associated with systems and agronomy research in each of the aforementioned CRPs.

FP3.11 Intellectual asset and open access management

The monitoring, evaluation and learning platform developed by CRP-DS[235] encourages open access and is already being customized for use by GLDC. FP3 will work closely with and for local communities. Free Prior Informed Consent (FPIC) guidelines will be followed for carrying out research with local communities to ensure that they are aware of and in agreement with the information collected and its use. This includes names of farmers and communities as authors on appropriate publications when they are part of the research team.

FP3.12 FP management

FP3 is led by Dr Jules Bayala, an experienced scientist in areas of ecopysiology, agroforestry and climate change with ICRAF. He is supported by a team of experienced agricultural researchers, including Drs Boahen Steve, Manuele Tamò and Shalander Kumar. The FP3 team will coopt members of participating partners (Table 7) to bring broader experience in cropping systems, crop production ecology, scaling and development programs, including Anthony Whitbread, Ermias Betemariam, Julie Dusserre, Saaka Buah, Fergus Sinclair, Laurent Cournac, Ingrid Oborn and Göran Bergkvist.

FP3.13 Budget summary

Flagship Program 3 : Integrated Farm and Household Mnagement						
Funding Needed	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
W1 + W2	1,904,573	1,999,850	2,099,670	2,204,780	2,314,950	10,523,823
W3	9,404,695	4,656,967	927,804	454,804	461,078	15,905,432
Bilateral	11,848,463	14,014,973	11,378,333	13,072,353	12,779,703	63,093,825
Other Sources	-	-	-	-	-	-
Total Needed	**23,157,730**	**20,671,790**	**14,405,807**	**15,732,021**	**15,555,731**	**89,523,079**
Funding Secured						
W1 + W2	1,904,573	1,999,850	2,099,670	2,204,780	2,314,950	10,523,823
W3	9,404,695	4,656,967	450,673	-	-	14,512,335
Bilateral	6,282,716	3,013,629	1,954,889	716,990	663,390	12,631,614
Other Sources	-	-	-	-	-	-
Total Secured	**17,591,984**	**9,670,446**	**4,505,232**	**2,921,770**	**2,978,340**	**37,667,772**
Funding Gap						
W1 + W2	-	-	-	-	-	-
W3	-	-	(477,131)	(454,888)	(461,078)	(1,393,097)
Bilateral	(5,565,747)	(11,001,344)	(9,423,444)	(12,355,363)	(12,116,313)	(50,462,211)
Other Sources	-	-	-	-	-	-
Total Gap	**(5.565,747)**	**(11,001,344)**	**(9,900,575)**	**(12,810,251)**	**(12,577,391)**	**(51,855,308)**
Line Item						
Personnel	7,110,272	6,442,174	5,783,968	6,234,935	5,945,048	31,516,397
Travel	1,063,834	938,640	767,501	829,114	790,304	4,389,393
Capital	445,515	485,075	494,299	370,558	369,861	2,165,308
Other Supplies and Services	4,226,746	3,935,321	3,505,886	3,883,279	4,082,994	19,634,226
CGIAR	606,152	511,296	402,318	465,349	460,087	2,445,202
Non CGIAR	6,785,632	5,765,596	1,681,211	2,005,027	1,987,778	18,225,244
Indirect Cost	2,919,579	2,593,688	1,770,624	1,943,759	1,919,659	11,147,309
Total Budgets	**23,157,730**	**20,671,790**	**14,405,807**	**15,732,021**	**15,555,731**	**89,523,079**
Core Partner						
ICRISAT	12,698,436	10,423,322	7,811,287	9,646,892	9,488,067	50,068,004
IITA	659,672	846,547	725,400	687,011	703,452	3,622,083
ICARDA	1,086,533	1,139,778	1,234,641	879,386	888,339	5,228,677
ICRAF	7,623,471	7,155,000	3,463,820	3,355,809	3,301,111	24,899,210
CSIRO	435,848	442,856	468,263	465,169	469,905	2,282,040
CIRAD/IRD	653,771	664,286	702,396	697,754	704,858	3,423,065
Total Budgets	**23,157,730**	**20,671,790**	**14,405,807**	**15,732,021**	**15,555,731**	**89,523,079**

FLAGSHIP PROGRAM 4 (FP4): VARIETY AND HYBRID DEVELOPMENT

FP4.1 Rationale and Scope

Flagship 4 (FP4), the GLDC mainstay of crop improvement, is premised on the proposition that a pipeline of modern varieties and functional seed delivery systems will enhance agricultural sector growth in developing economies of Africa and Asia[236]. FP4 contributes to meeting the GLDC goals by translating market and end-user priorities and agricultural investment plans, identified via FP1-FP3 and FP5, into productive and resilient varieties and hybrids that catalyze resilience, food, nutrition and income security and unlock market opportunities while reducing production risk. Three cereal -- sorghum, pearl and finger millets -- and six food legumes -- chickpea, lentil, cowpea, groundnut, soybean and pigeonpea -- are the prioritized crops. Resilient varieties and hybrids of these crops together with enhanced access through strengthened seed systems will significantly contribute to inclusive livelihood opportunities for smallholder agriculture and improved economies through higher productivity, market-oriented products and entrepreneurship.

Improving agricultural productivity is critical for the delivery of the Sustainable Development Goals (SDGs), the CGIAR SLOs, the African Union's CAADP for SSA, and the national development agenda of target countries. Activities in this flagship align very well to several programs of the AU-CAADP, including: Increasing Agricultural Productivity and Strengthening Nutrition and Food Security, Inclusive and Sustainable Agricultural Production and Accelerated Agricultural Growth and Enhanced Resilience to Climate Change and Improved Risk Management. Crop productivity improvement, now and in the future, will occur under complex and dynamic commodity supply-to-demand conditions, as impacted by climate change, water scarcity, demographics and technological and institutional opportunities[237]. The purpose of FP4 is to generate crop improvement innovations that catalyze productivity and production increases through modern varieties and functional seed systems, thereby enhancing food and nutrition security, market competitiveness and farming system resilience. Gender inclusion and needs of youth are integrated in breeding and technology delivery systems. FP4 has prioritized four trait clusters, namely: (1) productivity improvement that targets genetic gain[238], grain yield and resilience traits (abiotic and biotic stresses); (2) resource-use efficient and crop architecture traits, focused on reducing the cost of agronomy and drudgery; (3) traits demanded by markets, focused on user preferences for nutritional quality, post-harvest handling and value addition; and (4) traits that support agri-food system performance, most critically in enhancing the role of GLDC crops as feed/stover/forage for livestock. FP4 crop improvement activities are framed by product profiles that capture key demand attributes.

The target crops have specific significance to food, nutrition, income security and livelihood options for smallholder farming communities in the focus geographies. Increasing their productivity to even half their current yield potential will have significant implications for food, nutrition and income security[239,240]. FP4 thus hypothesizes that improved varieties, their related innovations and strengthened seed and knowledge delivery systems will catalyze achievement of the CGIAR IDO targets.

Over 60% of the agroecologies where GLDC crops are grown are impacted by climate change and poor crop production systems. This causes food shortages and price hikes that increase the vulnerability of the poor. Genetic improvement must be a cornerstone for addressing climate change through the development of resilient and productive varieties and innovations that carry production (input traits) to market (output traits). FP4 will integrate activities with FP2 and FP3 to develop options for narrowing yield gaps through sustainable intensification, and leverage FP5 to diversify the genetic base of varieties, through pre-breeding, genetic engineering and deployment of molecular tools availed via the CGIAR EiB Platform. FP4 will use high throughput phenotyping to accelerate variety development and harness doubled haploid technology for hybrid development. The flagship will classify its production systems through target population of environments (TPEs) in order to identify representative testing locations for precision selection, technology spillover and shuttle-breeding for speeded-up breeding cycles. FP4 will also explore crowdsourcing approaches that inspire and underpin new approaches for upscaling farmer-participatory seed innovation processes.

The key output of FP4, namely, productive, nutritious and resilient varieties, reinforce GLDC's contribution to the CGIAR SRF 21st century grand challenges of food security, health and nutrition, climate change and sustainable resources. Specifically, FP4 provides solutions for the grand challenges of (i) low productivity and profitability, and high-risk dryland agriculture, (ii) unlocks the value (nutrition, income and employment) in GLDC cereals and legumes for the growing rural and urban populations; and (iii) secures production systems against endemic and emerging challenges such as the climate change effects of drought, heat, associated biotic, abiotic stresses, including soil related factors, while underpinning the strategic positioning of production systems to secure livelihoods and economic development.

The focus crop by agroecology R&D investments of GLDC are framed by a number priorities: (a) The target ecologies are prone to climate change; (b) they have the fastest growing populations (sub-Saharan Africa 2.74%, South Asia 1.36%); and (c) the focus crops are central to livelihoods, with cereals supplying calories and proteins to humans and livestock, whilst legumes supply protein, calories and soil nitrogen. The majority of these crops are also considered women's crops (that is, managed by women) and other under-resourced farmers. Targeted improvement of these crops will therefore support the CGIAR gender, diversity and equal opportunity development efforts. FP4 envisions that new improved varieties will contribute to stabilizing production volatility, revitalizing soils, greater food diversity and support equitable market development especially by women and youth. Overall, this FP4 and GLDC vision of success, is critical to unlock opportunities for reinforcing livelihoods systems in the focus geographies.

FP4.2 Objectives & Targets

FP4 will support breeding of new varieties and hybrids that underpin sustainable intensification, diversification and increased productivity. CGIAR-originated varieties have in the past accounted for 35% (SSA) and 40-45% (South Asia) of annual yield gains[241]. Without these CGIAR varieties in developing economies, production would have been 7-8% less, food prices risen by 35-66%, food imports increased by 5% and caloric intake reduced by 4-7%[242].

FP4's target is to reduce the current yield gap of target crops to 30%, when integrated with effective land, labor and agrochemical use. To meet this target, a demand-driven breeding and deployment agenda that leverages CGIAR legacy investments (Phase I of CRP and others) and other complementary investments and partnerships will be implemented. FP4 will be streamlined and geared towards the development of cross-FP-defined breeding product profiles: (i) that result in efficient breeding cycles, harnessing heterosis, hybrid and doubled-haploid technologies where relevant, increased diversity and deployment of shuttle breeding; (ii) increased precision, automation and efficiency in data generation, greater mechanization and automation of breeding activities, and decision making through optimal phenotyping, open data warehousing and digital solutions that allow seamless use of BigData; (iii) undertake inclusive (gender and poverty) and efficient seed systems research that leverages agronomy and complementary knowledge and innovations (in concert with FP1-FP3, FP5).

FP4.3 Impact Pathway and Theory of Change

FP4 focuses on development and deployment of new resilient, productive and profitable varieties that are demand-driven, with products, knowledge and services that catalyze improvement in performance of GLDC agri-food systems and complement other cropping systems to increase farm productivity and diet diversity. The demand of farmers, users and markets are therefore the core drivers of GLDC breeding programs. Directly, these modern varieties supported by relevant agronomy will guarantee: (i) 30% yield gap reduction; (ii) Reduced pre- and post-harvest losses by at least 10%; (iii) Increased availability of selected nutrient dense GLDC crops. Indirectly, modern varieties will also enhance the household capacity to cope with environmental shocks and unlock enterprise opportunity especially for formal and informal seed systems and for women and youth (Figure FP 4.1).

In cooperation with FP2 and FP3, the potential impact of FP4 includes secured harvests, stabilized food supply and enterprise opportunities that improve rural incomes. Closely linked into the policy processes under FP1, FP4 will develop research-to-delivery approaches, techniques, platforms and strengthened R4D resources, product delivery models and partnerships for scaling as part of its capacity development for translating CGIAR produced global and regional agricultural public goods to national level at scale. Prioritized and targeted capacity development interventions for researchers, development agencies, farmer and civil society will be implemented. Innovations platforms, participatory variety selection, on-farm experimentation and testing as well as other demand-side research to end-use engagement forums will be continuously used to articulate new and or emerging demands. Depending on the needs of the hubs, the most promising engagement models will be chosen.

To be context-, site- and scenario-specific, FP4 draws on the overall foresight and priority setting conducted in FP1; FP2 for institutional and market programing and FP3 for testing scaling up, inclusivity (gender and diversity agenda refinement), impact delivery and acceleration; and FP5 for pre-breeding genetic gain technologies. FP4 works on 9 crop commodities and is designed to leverage: (i) demand prioritization that includes users and market opportunities and institutional arrangements around GLDC crops; (ii) technology commonalities and opportunities, such as common adaptability traits (biotic and abiotic stresses and production conditions), common biology and genetics, exploiting genomic synteny to share molecular tools and techniques; (iii) genetic engineering and double haploid for next-generation traits; and (iv) co-location in agroecologies for strengthening diverse value chains in the systems. These criteria ensure that a broader systems perspective is maintained from research to delivery. Must-have traits for all the crops such as drought and its related crop compensatory traits (e.g. early maturity) will be augmented with other prioritized input traits by crop, region and country.

Pre-breeding material and advanced molecular technologies from FP5 will be used to generate farmer- and market-preferred varieties through CoA4.1. CoA4.2 and CoA4.3 which aim at improving phenotyping and selection efficiencies. Through CoA4.4 models for nursery and seed management work with the aim of informing the “science of delivery” with respect to seed systems and allied knowledge and technologies, through strategic partnerships. Seed and technology delivery models such as the CIAT-led Pan African Bean Research Alliance (PABRA), the Alliance for Green Revolution in Africa (AGRA)-led Scaling Seeds and Technologies Partnership in Africa (SSTP), and large bilateral investments, will be studied and leveraged for scaling up models under CoA4.4. FP4 will leverage two CGIAR Platforms – Genebank and EiB, along with hybrid, doubled haploid and other rapid generation advancement technologies where heterosis has been demonstrated, for faster and more efficient breeding programs. Lessons and experiences from other CRPs where advanced technologies have been used for crops such as maize, rice and wheat will be explored. This way, FP4 provides a framework to test: (i) Accelerated and targeted breeding characterized by genetic gain and superior varieties; (ii) Capacity development of collaborating NARES to use cutting-edge technologies, analytical platforms and breeding management systems for program management, variety testing, release and deployment; and (iii) Efficient models for deployment of improved varieties and crop management solutions in the target agri-food systems.

FP4 will contribute to IDOs by generating technologies and knowledge, that when channeled through appropriate delivery systems, catalyze productivity increase with benefits to households, the environment and the economy. Regular inter-FP learning will inform reprioritization and impact delivery, building a repertoire of partnerships, experiences and lessons, reprogramming, research and delivery at scale. This will annually increase yields of target crops.

Key assumptions behind FP4’s theory of change are

- GLDC crops are essential for livelihoods of target geographies based on their rusticity, nutritional value and multifunctional roles and thus of interest to stakeholders/partners and CRP scientists.
- Relevant traits are in place and can be obtained through breeding networks to meet current varietal demand and future cultivation areas.
- Positive NARES and private sector receptivity; pre-requisite capacity and infrastructure exist that can be developed to underpin seed access and testing.
- Affordable decentralized seed systems can be initiated, incubated, commercialized and sustained in close collaboration with FP2.
- Smallholders plant the right GLDC varieties in the right ways in the right places with favorable weather/market conditions. Comprehensive capacity development involving key multipliers contribute to changing farmers choices.

- Targeting is inclusive and appropriate; extension system tailors innovations to differing contexts and groups.
- Climatic and other shocks to which targeted dryland systems are subject are not exceptionally severe.
- Resulting varieties are of sufficient quantity and quality and are actually consumed.
- Legacy investments of the CGIAR complementary investments exist and will underpin new technology generation and partnerships for R4D.

An essential condition for success is that developed GLDC varieties are appropriately matched to farmer priorities and market demands (FP1, FP2, FP3), additionally adoption must be actively promoted and followed up through collaboration with FP1. Because collaboration with FP1, FP2 and FP3 is crucial but insufficient for achieving anticipated FP4 outputs, private sector and civil society partnerships are pursued at local and national level.

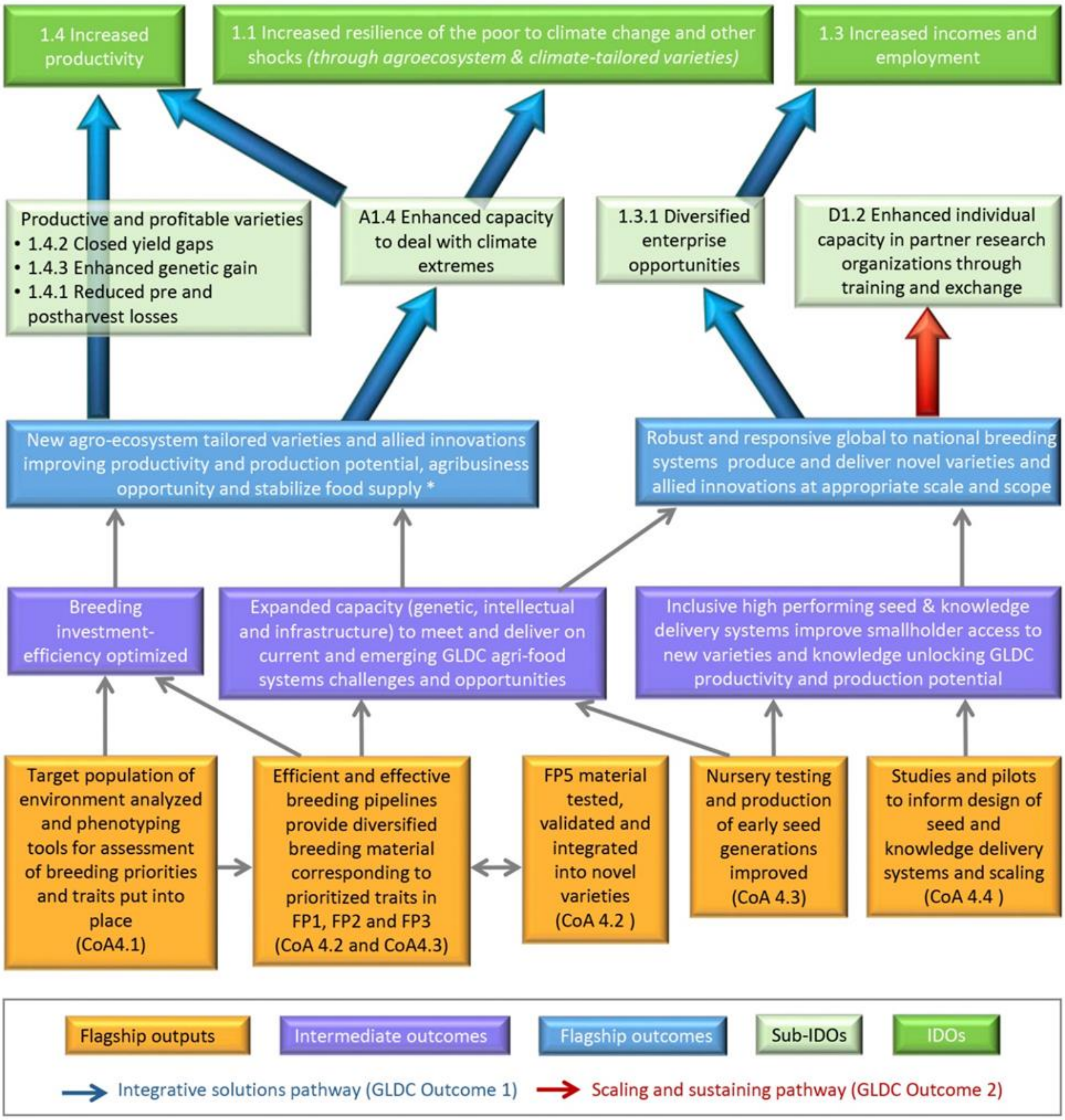


Figure FP4.1. FP4 Impact pathway

FP4.4 Science Quality

The gestation period (8-10 years) from trait prioritization to variety release, against a background of changing environments and economies, reduces the scale of impacts felt for most GLDC crops. So breeding pipelines must be fast-tracked. For SSA, where limited availability of improved varieties compromises productivity, breeding programs must escalate the development and delivery of well-targeted varieties at scale. Development and testing of Target Population Environments (TPE) using big data of climate and soil enables FP4 to work across crops and agroecologies to inform environment targeting and scaling out. FP4 recognizes that CGIAR is the key source of genetic material for most developing economies; hence investments are guided by five strategic questions:

1. What are the new and strategic demands on GLDC crops that need to be addressed and how can these inform GLDC breeding programs?
2. How can the development of a new generation of demand-informed resilient varieties be fast-tracked in target geographies and how can they be harnessed at scale?
3. How can the CGIAR and other global knowledge centers harness their repertoire of high-end science innovations and the improving NARES capability to increase efficiency of breeding pipelines?
4. How can the CGIAR crop improvement programs develop and deliver a new generation of varieties and agronomy that will secure and stabilize harvests under changing production environments and climate change?
5. How can access to improved innovations (seed and allied technologies) be augmented to complement improved varieties with benefits for food, nutrition and income security, while securing the natural resource base especially for smallholder agriculture?

FP4 will respond to the first research question through FP1-FP3 and the second using legacy CGIAR investments. Resilient and productive varieties, developed under the Generation Challenge Program[243], Tropical Legumes[244], HOPE[245] and other projects, will be released and promoted in the next 2-3 years. Although the third and fourth research questions are medium to longer-term issues for FP4 and FP5, and involve the exploitation of genomic and genetic resources (germplasm) to augment breeding programs, the key in the approach is alignment of activities related to this question to product concepts. Examples of such resources are molecular markers for key traits, germplasm resources (mini core collections, reference sets and elite germplasm for cereals and legumes), male-sterile lines for hybrid seed production (sorghum, pearl millet), introgression lines from wide hybridization (legumes e.g. groundnuts), and hybrid technology in pigeonpea. Hybrid technology for cereals will harness heterosis for yield stabilization in semi-arid environments, building on ICRISAT-piloted models in India on pearl millet and sorghum as the starting crops. Hybrids and promising germplasm for vegetable pigeonpea, pop-sorghum and confectionery groundnut to be tested are those directly needed by consumers and the food processing industry. This will drive demand for improved hybrid seed, given the strict proprietary requirements of the food industry. Research question five is a new area for the CGIAR, in which FP4 will leverage FP3, to clarify drivers and opportunities for delivery of new varieties at scale.

Table FP 4.1 Annual productivity gains due to adoption of improved varieties in selected target countries

Crop and Country	Yield in 2005 (kg/ha)	Yield in 2014 (kg/ha)	Annual growth rate (%)
Chickpea			
Ethiopia	1026	1913	6.43
India -Andhra Pradesh	1012	1439	3.58
Lentil			
Ethiopia	712	1390	7.72
Bangladesh	787	1260	5.37
Nepal	851	1100	2.89
India-Behar	705	1272	6.78
Pigeonpea			
Tanzania	730	901	2.13
Malawi	410	1310	12.32
Groundnuts			
Malawi	500	1100	12.5
[illegible]	[illegible]	[illegible]	[illegible]

FP4 seeks to secure at least a 1.7% genetic gain for the selected crops based on modern varieties. In Table FP 4.1, annual yield improvements of 10% have been demonstrated and form the legacy leading into FP4. In general, GLDC crops have not benefited much from advances that enhance genetic gains compared to other crops such as rice and maize1, 9. FP4 harnesses ongoing breeding pipelines to deliver new varieties in the short term while refining emerging priorities through FPs 1-3 for new varieties. CGIAR legacy tools such as the Integrated Breeding Platform[246], rapid generation advancement, double haploidy, genomic selection, high throughput phenotyping and genotyping, genomics and genetic resources, etc., will accelerate genetic gains. Shuttle breeding and genomics-enabled improvement including transgenics will be used to deliver a new suite of varieties and hybrids more precisely and efficiently to the target environments. FP4 will also introgress new variability generated through FP5 and other investments such as GCP-and the TLI, TLII and TLIII projects 12,13 to broaden the genetic base of varieties as well as improve phenotyping and selection intensity, with greater relevance for target environment, users and markets. Genomic resources (markers and genes) will be introgressed into farmer-preferred and adapted material to secure harvests[247]. FP4 will also improve experimental field conditions deploying cloud computing based data analysis and management as well as field plot management (mechanization, irrigation, better experimental design). A legacy of past and on-going R&D investments and several bilaterals on climate change and crop resilience research will be used.

FP4.5 Lessons Learned and Unintended Consequences

- **Trait identification and prioritization.** Breeding programs informed by demand from farm-to-fork, crop phenology, agroecological needs and suitable investment policies have greater opportunity to develop varieties that will expand production niches, enhancing adoption and market penetration.
- **Capacity for research to delivery**. NARES in target countries and agri-food systems vary in capability to generate and deliver innovations, being weakest in West Africa and strongest in Asia[248]. By exploring opportunities for mentorship between junior and senior scientists, in collaboration with universities and initiatives such as WACCI, FP4 will develop leadership and technical skills to improve research from planning to execution and delivery.
- **R4D enablers.** Women-based and or -dominated self-help groups are closely associated with R&D processes for these crops. This improves access to vulnerable members of communities and builds meaningful and long-lasting relationships with communities for R4D activities[10].
- **Technology delivery systems.** In most GLDC countries, limited capacity to produce early generations of seed, weak market incentives and inadequate quality assurance compound weak seed delivery systems. Thus a combination of informal and formal seed systems is needed to improve access to modern varieties[8].

FP4 will deliver new productivity enhancing varieties and hybrids that integrate with FP3 for delivery of management options. These varieties, among others, will be widely adapted to diverse agroecologies, the goal being to unlock opportunities for grain aggregation and fodder production from smallholder production systems. Such a process will encourage a shift towards popularly traded varieties, with a medium-to long-term consequence of losing genetic diversity and its attendant food and nutrition security challenges. In order to minimize genetic erosion, a diverse array of breeding materials will be developed and progressively deployed as informed by scaling and delivery studies of FP4 and FP1-FP3. FP4 and FP5 will leverage the Genebank platform to manage germplasm and variety deployment to mitigate genetic erosion. Leveraging the comparative strength of local access from ICRISAT Regional Genebanks (Kenya, Niger, Zimbabwe) will be particularly important for FP4 and FP5.

FP4.6 Clusters of Activities (CoA)

CoA 4.1: Environmental characterization and phenotyping

This cluster of activity is organized around two interrelated pillars: (i) analysis of the target population of environment (TPE); and (ii) establishment of phenotyping tools for assessing breeding priorities and traits. These pillars map to Module 4 of the CGIAR EiB.

Environmental characterization and scenario analysis: Major mechanistic crop models will be used to prescribe the set of target locations and future production environments (TPEs) where varieties and hybrids developed by FP4 and NARES will be grown. Prediction of genotype performance in a TPE informs selection by predicting future performance, averaged over several farms and seasons. The use of TPE is critical in rainfed and low resource-use agriculture, where seasonal weather variations, soil quality and depth, and management differences abound, causing GxExM interactions that hamper simultaneous genetic and agronomic progress toward improved system productivity and resilience. Yet phenotypic variation in target environments, genetic correlation and trait heritability in test and target environments determine selection efficiency and the size of realized genetic gain. This element is critical for modernizing GLDC breeding. Thus initially, due to the complexity and scale of GxExM work required for 9 crops, in diverse agroecologies and farming systems, CoA 4.1 will focus on groundnut because it is grown in West Africa, Eastern Africa, Southern Africa and South Asia to build a scalable system for other prioritized crops. The mechanistic crop models (Simple Simulation Model- SSM, APSIM, or SAMARA) will be used to (i) characterize TPEs for GLDC crops or crop groups and (ii) within each TPE, identify the genetics, agronomic practices, or their combinations that improve system productivity and resilience. This activity will also integrate modelling tools in decision-making by geneticists/breeders (FP4/FP5) and agronomists (FP3) in their work. For instance, end-user demand attributes for grain or crop residue of sorghum could be designed for particular TPE in South India, leading to higher return on investment than with a generic plant type[249]. And it will also support integration of modelling outputs by social scientists and economists for forecast modelling (e.g. global futures) or policy interventions. Environmental characterization will initially start in West Africa where two strategic partnerships exist, namely, IAVAO[250], an initiative of CIRAD in which ICRISAT, IRD and CERAAS partner with national programs in WCA, and LAPSE[251], an IRD laboratory in Senegal that collaborates with CERAAS and ISRA, aligned to regional initiatives of ECOWAS and WAAPP[252] .

Phenotyping: This activity aims to enhance genetic gains in GLDC crops by improving phenotyping quality. CoA 4.1 will support physiologists and geneticists to obtain precise information on aspects of a plant/crop in large populations, and breeders and agronomists to evaluate performance and management packages of breeding lines and candidate varieties in specific TPEs. FP4 will combine trait-based phenotyping with field-based phenotyping. High precision trait phenotyping, under controlled environment, will be shared with FP5, whilst field-based phenotyping will exploit FP3 field-sites. FP4 will create communities of practice on phenotyping that are supported by phenotyping hubs of Module 4 of the EiB[7] platform, thereby, enhancing automation and mechanization in high throughput phenotyping. Optimal statistical design, metadata standards and new precise statistical methods, which combine design information with spatial adjustment within and between trials, will be systematically deployed. Phenotyping nodes will be connected to cloud-based data warehousing and computing using the BMS, sharing data collected across the network and fostering meta-analysis. Phenotypic information will be generated to improve system modelling for better prediction of crop combination effects on system productivity/resilience. Ultimately, this activity will enable FP4 to enhance synergies between cereals and legumes by generating phenotyping data at affordable costs that allow improvement in system modelling predictions for both crop types.

CoA 4.2: Breeding Pipelines

FP4 leverages Phase 1 CRP outputs, for the first two years of GLDC guided at a high level by CAADP country investment plans for Africa and strategic thrusts in South Asia for trait deployment. In order to respond to these increasing and diversified demands for GLDC crops, it is imperative that efficient breeding pipelines be developed for rapid development of varieties and hybrids. These modern varieties and hybrids will be high yielding, well adapted to existing and evolving environments, resilient to climate change, have improved nutritional quality and meet requirements of farmers, consumers and industry. This CoA will thus develop efficient and effective GLDC breeding pipelines guided by Product Concept Notes (PCNs). For each of the GLDC target crops, a one-page PCN is available with whose content is informed by prioritized GLDC crop attributes identified through pre-proposal foresight and ROI analyses, ongoing feedback from FP1, FP2, FP3 and other sources (Table FP4.2). GLDC will target breeding of dryland cereals and legumes to supply feeds and forages for the rapidly changing livestock sector. Key traits such as stover and haulm quality, as well as digestibility, will be bred into these crops. Feed and forage traits to be included as complementary traits are defined in the PCNs.

GLDC breeding programs will use innovative methods (e.g. MAGIC) for targeted population development, utilize diverse characterized germplasm and genetic stocks, pre-breeding material, and transgenic events provided by FP5, to combine multiple traits proposed in the PCNs[253]. Genetic, physiological and/or biochemical mechanisms of target traits identified in FP5 will inform development of FP4 breeding strategies. Identified and validated diagnostic molecular markers and or candidate genes of desired traits and the genotyping platforms of FP5 will be deployed in marker-assisted selection and forward breeding.

Table FP4.2. Focus traits for improvement of GLDC crops by FP4 and FP5 interventions.		
Crop	**Traits for all target regions**	**Traits specific to target regions**
Chickpea	Drought and heat tolerance*, pod borer resistance; high protein, Fe and Zn content	*Ascochyta* blight resistance (ESA, CWANA), dry root rot resistance (SA), herbicide tolerance* (SA)
Cowpea	Drought tolerance*, aphid and Rhizoctonia resistance	Striga* (WCA); Alectra resistance (ESA)
Groundnut	Drought tolerance*, stem rot resistance, high oil content*, high Fe and Zn content, aflatoxin resistance	Resistance to rosette (WCA, ESA), Early leaf spot (ELS) resistance, fresh seed dormancy (SA)
Lentil	Drought and heat tolerance*; high protein, Fe and Zn content; earliness	Resistance to *Ascochyta* blight, rust and root diseases, water logging tolerance (Sub-Saharan Africa). Resistance to *Stemphylium* blight, rust and root diseases, herbicide tolerance, high biomass (South Asia)
Pigeonpea	Resistance to fusarium wilt, sterility mosaic disease and pod borer; high protein, Fe and Zn content	Resistance to sterility mosaic disease and pod fly (SA); resistance to *Cercospora* and pod sucking bug (ESA)
Soybean	Drought tolerance/escape; shattering, lodging, rust resistance	Seed size, Frogeye resistance, Biological Nitrogen Fixation, day length insensitive (SA and WA)
Finger millet	Drought tolerance, blast resistance; high Fe, Zn and Ca content	Resistance to Striga and downy mildew (ESA)
Pearl millet	Drought tolerance*, downy mildew resistance, high nutritional quality (Fe, Zn), low flour rancidity	Blast resistance (SA), Striga resistance* (WCA and ESA)
Sorghum	Drought tolerance*, nutritional quality (Fe, Zn), fodder digestibility	Striga resistance* (WCA and ESA)
Color codes for the traits: Abiotic stress, biotic stress, grain nutrition value and consumer preferred for market pull. * 'no-regret' traits		

Genomic selection will be used to improve breeding processes efficiency[254]. Double haploid technology will be used for rapid homozygosity in the crops where protocols are already available or will be developed in FP5 as appropriate. In other crops, rapid generation turnover (RGT) protocols (in vitro culture, photoperiod alterations, single seed descent, off-season planting/shuttle breeding, etc.) standardized in FP5 will be used to create multiple generations annually. The improved high throughput phenotyping platforms established in FP5 and current phenotyping facilities in CoA 4.1 will be used for precision phenotyping of abiotic and biotic stresses and nutritional quality. Early generation testing will be carried out in partnership with NARES at the representative sites in respective TPEs utilizing efficient experimental designs to identify promising breeding lines with desired combination of traits.

CoA 4.3: Product testing and release

Superior germplasm and breeding lines selected in CoA 4.2 will be evaluated at multi-locations in partnership with public and or private sector actors in respective TPEs to identify lines with stable performance and that meet yield and other trait targets. Promising lines and experimental hybrids will be entered into pre-release trials and national performance test by public and private partners and subsequently released as new varieties and hybrids in line with their national regulations. Farmer participatory varietal selection will be conducted to identify farmer and market preferred traits, a precondition for release in most countries. Where capacity of national partners is limited, CGIAR institutes will backstop development of variety release proposals and provide additional characterization data/information needed for that purpose. FP4 will strengthen the capacity of participating public and or private sectors to design, manage and support multilocation testing and variety release. Two mechanisms will be used to continuously inform the breeding strategy: (1) Hybrids- ICRISAT's Hybrid Parents Research Consortium (HPRC) for pearl millet, sorghum and pigeonpea will provide feedback on research priorities, share sites for shuttle breeding and early generation testing, and support rapid release and dissemination of hybrids. (2) Varieties- national partners will provide feedback from FPVS and on-farm and on-station data. BMS will used to manage data (pedigrees, nurseries and trials) and data sharing facilitated through an open access portal shared with FP5. The breeding program will train partner scientists and technicians, with special emphasis on empowering young women in integrated breeding.

CoA 4.4: Science of Scaling Seed Technologies

Rationale: Crop yields have increased in SSA by almost 50% since 1980. Adoption of improved varieties has been growing annually at 1.45%, covering 35% of the cropped area. In South Asia, the area under improved crop varieties is between 40-45%.

Capacity issues. Strong publicly funded NARES enable rapid diffusion of CGIAR-bred varieties. Legumes in Ethiopia is an example.

Major routing for GLDC. A small proportion of transactions (2.4-17.4%) of GLDC certified seed is routed by the private sector. GLDC crops are sown to less than 1% of certified improved seed sown.

CGIAR niche. Limited supply of early generation seed (EGS) undermines private sector roll-out of modern varieties. By producing EGS in Malawi, ICRISAT's Malawi Seed Industry Development Project unlocked the opportunity for seed companies to expand cropped area under improved groundnut by 34% over 5 years.

Box 2. Imperatives for scaling-up and out: Learning from the past. Sources: Walker, T.S and Alwang J. (ed) 2013 Crop improvement, adoption and impact of improved varieties in food crops in Sub-Saharan Africa. CGIAR and CABI International; ICRISAT's Hybrid Parent Research Consortium (HPRC)www.icrisat.org/pearl-millet.

The recent CGIAR-commissioned studies on diffusion of improved varieties (DIIVA for SSA) and (TRIVSA) for South Asia, show remarkable progress in adoption of improved varieties[8]. There are however marked differences among crops and countries. These studies access issues with access to improved seed of GLDC crops at scale, being influenced by demand and supply issues, weak institutions, unsupportive policies and variable agroecological factors. This CoA aims to improve access to improved seed by contributing to improvements in functionality of formal and informal seed uptake pathways.

The informal seed systems are indeed important, with recent studies showing up to 64% purchase of legume seed from the local markets[255]. The main strength of such systems is the wide access to locally adapted varieties but infusion of new materials is being missed out. Of interest, therefore, is developing and understanding innovative business models for OPV seed, including necessary links to seed treatment, new superior varieties, small pack sizes, revolving seed fund, and savings and credit systems to build a strong market for GLDC seed. Box 2 gives an example of an opportunity to improve GLDC seed systems. Most GLDC crop varieties are released by NARES whose institutional limitations impede production of early seed generations (basic/ foundation seed) for bulking into certified seed. A number of seed system models have been tested to improve access to GLDC seed. (1) The CGIAR in partnership with NARES has produced basic seed for bulking into certified seed by the private sector. ICRISAT's Hybrid Parents Research Consortium (HPRC)[256] is an example of this model; (2) CGIAR networks for market-oriented breeding, seed systems and technology dissemination have been created, such as the PABRA[257] model through which 13 million households have accessed new bean varieties from 2009 - 2013; (3) Private sector scaling out of modern varieties through large investments such as of AGRA's SSTP[258], HOPE, TLIII; and (4) Informal systems that use community seed production (for example, by community seed banks) of quality declared seed (QDS) or other locally certified systems. GLDC will strategically partner with AGRA to catalyze access to improved seed of GLD crops in Africa. AGRA will: (a) identify and support startups to supply seed based on farmer demand; (b) grow agro-dealer networks and their hubs, especially in rural areas to improve access to seed and inputs all year round, provide business development services; network them better, and provide credit and finance lines for operations and expansion of storage facilities; (c) create mass awareness of existing seed technologies (d) enhance the use of ICTs such as mobile phones, internet, videos, and interactive radio for scaling out; (e) improve the seed policy environment focusing on foundation seed, implementation of quality control measures for the seed and fertilizer industry.

FP4 will also implement two sets of mutually reinforcing sub-clusters of activities to gain insights for improving the functionality of underinvested GLDC seed value chains serviced through formal and informal systems, their seed flows and how they influence the pattern and dynamics of seed that farmers access, exchange and deploy in their farms:

- Leverage current seed system investments to study seed system scenarios of GLDC seed value chains to gain insights into constraints that seed value chain actors face to produce, make available and access quality seed of different varieties at the right time. It will inform the priorities, scheduling and partnership profiles needed to test and/or improve seed systems scaling models. This activity will be integrated with FP1-FP3 and will be conducted in the first year; and
- Test the effectiveness of new scaling models based on seed system scenario analysis, with known scaling methods used as counterfactuals. Risk averseness for investment in seed will be studied. ICT-augmented formal and informal systems will be tested to improve linkages between seed producers and buyers and study the HPRC model to scale out legumes, learning from dryland cereals.

These activities will initially commence with a prioritized set of GLDC crops that represent unique combinations of cropping systems x knowledge/technology delivery pathways (formal or informal systems) per region (Sahel, humid tropics, South Asia) in year I. Further, pilot scaling activities integrated with FP3, of selected GLDC crops, will focus on both formal and informal seed systems.

FP4.7 Partnerships

In addition to CGIAR Centers for crop improvement (ICRISAT, IITA, ICARDA, Bioversity) and core partners (CIRAD, IRD, CSIRO, each CoA will develop strategic partnerships with stakeholders drawn from local NARES to global centers of knowledge and innovation in the south (South Africa, South America, Australia and Asia) or the north (Europe, USA and Canada). The key partner categories to be engaged directly or indirectly include: (i) Technology generation partners such as WACCI based in Ghana, ARC (Sudan), CIRAD (France), DARS, Malawi, TARI (Tanzania), EIAR (Ethiopia), IAR (Nigeria), ICAR (India), IER (Mali), INRAN (Niger), ISRA/CERAAS (Senegal), IIAM (Mozambique), KALRO (Kenya), USAID Feed the Future Innovation Labs, NARO (Uganda), ZARI-Zambia and World Vegetable Center; (ii) Technology delivery/development Institutions such as AGRA, CRS, FAO and others; and (iii) Policy institutions such as African Union's New Partnership for Africa's Development (NEPAD); Forum for Agricultural Research in Africa (FARA); Asia Pacific Association of Agricultural Research Institutions, Africa Seed Trade Association and their national chapters and members of Seed Trader Associations in South Asia and the FAO. These partnerships will be used to broker new partnerships, resource mobilization, policy development and/or sharing facilities. By focusing on outcomes as well as outputs, FP4 stands a high chance of attracting support from many partners including policy organs and communities.

FP4.8 Climate Change

Under a four-degree rise in temperature scenario, modelling studies show that arable land reduction (35% for SSA) and reduction in yield of cereals (13–23%) will lead to food insecurity. FP4 will address the climate change threat via three biological domains: (i) investigate effects of temperature rise on shortening of phenological stages; (ii) study the effect of high temperature on reproductive biology; and (iii) investigate the effect of temperature on evaporative demand and plant water status in GLDC crops that are mostly drought-hardy but not necessarily temperature insensitive. Domain (i) focuses on phenotyping methods to measure flowering by remote sensing techniques to pinpoint flowering time and guide breeding and selection processes. Domain (ii) will develop an inventory of methods and approaches needed to compare previous efforts across crops to test the effect of high temperature on phenology and reproductive biology, and then use the inventory to design common methods across GLDC crops. Domain (iii) will receive the most attention because high temperature and low relative humidity, common constraints in GLDC agroecologies, will likely become worse in the future. FP4 will leverage ongoing and past work such as transpiration response to increased vapor pressure deficit (VPD) in pearl millet[259], sorghum[260], cowpea[261], lentil and chickpea, and high heat stress responses to seed set in pearl millet, along with high throughput phenotyping[262] that will be made available as a service module.

FP4.9 Gender

Women, mothers, children, youth and the elderly from GLDC ecologies are often disadvantaged in accessing technologies and livelihood opportunities. FP4's value proposition is to increase production, accessibility and consumption of nutrient-dense cereals and legumes for livelihood needs of the target demography. These issues require that gender-compliant implementation based on gender-focused priorities that leverage FPs1-3 and FP4-commissioned gender studies be done. These processes will clarify the emerging gender dynamics in technology, knowledge and information generation, access, utilization, and the power relations critical for success and impacts at scale for FP4 and GLDC CRP. Initially, based on phase I GL CRP gender studies[263], FP4 has prioritized four gender activities: (i) engage women and other community members in participatory variety selection to improve targeting of preferred traits in modern varieties; (ii) support domestic consumption and processing by tackling cooking and processing traits such as increasing shelf-life of pearl millet flour, decortication in sorghum, hard-to-cook qualities in legumes, spinach from legume leaves, and high density of essential nutrients; (iii) improve ease of pre- and post-harvest handling including the use of crop debris to feed livestock and fuel for cooking, saving time for women and other farmers and; (iv) leverage A4NH and other complementary CRPs to mitigate agriculture-related diseases and deliver nutrition outcomes; and (v) leverage the youth demographic dividend of GLDC economies through targeted interventions that deepen engagement in agribusiness using ICT-augmented activities in seed production and related agri-innovations that attract youth to agriculture.

FP4.10 Capacity Development

FP4 is comprised of two mutually reinforcing elements: (1) breeding pipelines delivering modern varieties; and (2) product cycle management focusing on seed systems and allied technologies, each element with varying capacity needs and strengths. On average, 10% (or 853.2 FTEs) of SSA's agricultural researchers are designated as plant breeders, with 1.4% (or 118.2 FTEs) designated as seed systems specialists, larger NARES having proportionately higher FTEs. Outreach scientists account for 2.8% or 231.2 FTEs). Women account for 24% of the FTEs up from 22% in 2011[264]. FP4 will work closely with university networks (see www.ruforum.org) in postgraduate education and research to train scientists. New technical skill sets, as well training of technicians and technology delivery agencies through short courses and internships will be done. ICT support for seed production agribusiness targeting youth and integration with FP2 and 3 especially on social and market dynamics for seed systems, will be done. These training activities will also leverage large bilateral programs where critical capacity gaps exist.

FP4.11 Intellectual Asset and Open Access Management

Many modern breeding products and inventions are under proprietary control. Hence patent and proprietary issues will be an important part of FP4 and indeed GLDC will ensure that institutions can access and use technologies under appropriate conditions. IP issues will be managed through various agreements to support access of germplasm by partners, national to regional. Most partners have their own institutional IP policies and in the case of CGIAR, institutional policies for material transfer and acquisition and publications will apply. FP4 will also: (i) raise awareness and ability to address IP issues within the projects; (ii) ensure that research results and IP assets are identified systematically and protected if necessary; and (iii) ensure that third-party IP is accessed and utilized in a fair and transparent way. To meet these needs, FP4 will develop within the overall GLDC strategy a common framework of IP agreements for the implementing partners. As part of this process, FP4 will make an initial IP assessment and "freedom to operate" exercise for each of its projects. FP4 will also leverage ICRISAT's IP team and GLDC program management due to their expertise in the region to form the basis of an IP Management Committee for FP4.

FP4.12 FP Management

FP4 is led by Dr Patrick Okori, a plant breeder and principal scientist in charge of groundnut breeding in East and Southern Africa, ICRISAT. Patrick was a Product Line leader in the CRP on Grain Legumes (CRP-GL). He is supported by a range of experienced scientists, including Drs Vincent Vadez, Michel Ghanem, Pooran Gaur, Shiv Kumar Agrawal, Godfree Chigeza, SK Gupta, Alpha Kamara, Chris Ojiewo and Esther Njuguna. The FP3 team will draw membership from committed partners (Table 7) with requisite skills, particularly in supporting the development of seeds systems, e.g. Louise Sperling (CRS) and Ian Barker (Syngenta Foundation).

FP4.13 Budget summary

Flagship Program 4 : Variety and Hybrid Development						
Funding Needed	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
W1 + W2	2,898,263	3,043,250	3,195,150	3,355,100	3,522,750	16,014,513
W3	9,798,804	6,011,875	4,343,725	2,264,851	2,431,471	24,850,726
Bilateral	12,173,679	19,723,165	25,657,184	33,386,632	32,476,030	123,416,689
Other Sources	-	-	-	-	-	-
Total Needed	**24,870,745**	**28,778,290**	**33,196,059**	**39,006,583**	**38,430,251**	**164,281,928**
Funding Secured						
W1 + W2	2,898,263	3,043,250	3,195,150	3,355,100	3,522,750	16,014,513
W3	8,077,901	4,545,001	2,672,051	127,500	127,500	15,549,953
Bilateral	6,278,714	3,252,300	2,223,900	669,500	220,900	12,645,314
Other Sources	-	-	-	-	-	-
Total Secured	**17,254,878**	**10,840,551**	**8,091,101**	**4,152,100**	**3,871,150**	**44,209,780**
Funding Gap						
W1 + W2	-	-	-	-	-	-
W3	(1,720,903)	(1,466,874)	(1,671,674)	(2,137,351)	(2,303,971)	(9,300,773)
Bilateral	(5,894,965)	(16,470,865)	(23,433,284)	(32,717,132)	(32,255,130)	(110,771,375)
Other Sources	-	-	-	-	-	-
Total Gap	**(7,615,868)**	**(17,937,739)**	**(25,104,958)**	**(34,854,483)**	**(34,559,101)**	**(120,072,148)**
Line Item						
Personnel	9,561,480	11,052,157	12,518,597	14,760,389	14,537,637	62,430,260
Travel	1,458,869	1,813,319	2,048,346	2,448,195	2,416,387	10,185,116
Capital	673,943	560,679	676,164	743,347	860,725	3,514,858
Other Supplies and Services	5,225,518	5,871,515	6,946,869	7,918,622	7,684,455	33,646,979
CGIAR	920,615	1,086,236	1,280,061	1,566,887	1,549,320	6,403,119
Non CGIAR	3,947,087	4,778,550	5,538,624	6,624,073	6,522,935	27,411,269
Indirect Cost	3,083,233	3,615,834	4,187,398	4,945,070	4,858,972	20,690,327
Total Budgets	**24,870,745**	**28,778,290**	**33,196,059**	**39,006,583**	**38,430,251**	**164,281,928**
Core Partner						
ICRISAT	17,358,641	21,025,208	25,328,965	31,767,009	31,121,620	126,601,442
IITA	3,794,413	3,379,947	3,638,728	3,037,022	3,294,155	17,144,264
ICARDA	1,608,147	1,657,131	1,710,658	1,765,158	1,853,965	8,595,059
Bioversity International	751,327	1,374,089	1,189,897	1,124,456	839,401	5,279,170
CIRAD/IRD	1,358,217	1,341,915	1,327,812	1,312,938	1,321,110	6,661,992
Total Budgets	**24,870,745**	**28,778,290**	**33,196,059**	**39,006,583**	**38,430,251**	**164,281,928**

FLAGSHIP PROGRAM 5 (FP5): PRE-BREEDING AND TRAIT DISCOVERY

FP5.1 Rationale and scope

In general, the realized genetic gain in GLDC crops in target agro-ecologies has been historically low. For example, in the last five decades, sub-Saharan Africa has recorded only ~25% increase in cereal yield compared to over 300% in developed countries[265]. The major reasons are low investments in research; slow adoption of modern technologies; narrow genetic base of current varieties; and lack of appropriate varieties with market-preferred traits[266]. Hence, FP5 focuses on exploiting the untapped genetic resources of wild relatives and landraces by developing and using cutting-edge tools and techniques for trait discovery and accelerating the rate of realized genetic gains in GLDC crops under mixed cereal-legume-tree-livestock systems of semi-arid and sub-humid regions of SSA and SA. Recent technological advances in genomics, breeding, and rapid achievement of homozygosity in major cereal crops provide excellent opportunities for accelerating genetic gains in GLDC crops[267]. Therefore, FP5 focuses on trait discovery, functional validation of traits and pre-breeding by exploiting natural and/or systematically induced variations for prioritized traits in combination with modern genomics, transgenics, phenomics, and breeding tools for accelerated, precise, cost-effective and efficient breeding of new varieties, targeted to achieve higher productivity and quality produce in farmers' field.

Increased agricultural productivity can contribute to improved food and nutritional security and reduced poverty in smallholder farming communities. Breeding for improved productivity, increased nutritional value and/or closing the yield gap varies with the location and prevailing conditions. Since systematic breeding has had only a brief history in GLDC crops, much of the natural diversity conserved in the genebanks remains underutilized[268]. Due to limited attention to the development of modern genomics and breeding tools for these crops, the knowledge of genetic and molecular controls or the nature of genetic diversity for key traits is lacking. While the major biotic and abiotic constraints to enhancing genetic gains in GLDC crops are specific to either legumes or cereals, many of the techniques, platforms and breeding tools targeted in FP5 are applicable to both legumes and cereals and these facilities located in the target regions can be shared.

FP5 will build on past successes and lessons towards enhancing and stabilizing yield in GLDC crops. These include the availability of reference genome sequences for the majority of target crops, ability for interspecific crossing, fast and precise trait mapping and candidate gene discovery, DNA markers for many desirable traits, efficient transformation protocols and proof-of-concepts for several intractable traits for most crops, modern tools and technologies and their applications, and public and private sector partners and networks. The target traits have been prioritized based on needs of the smallholder farmers and end-use preferences in existing or emerging local, regional, and global markets. Improved productivity, tolerance to drought and heat, nutritional qualities and consumer-preferred characteristics of the target crops will be of primary focus that will continuously be updated based on feedback from FP1, FP2, FP3 and FP4. A list of region-wise and crop-wise prioritized traits is provided in Table FP4.2 with 'no-regret' traits that will be the prime focus, especially during initial phase of this CRP until a systematic prioritization exercise is completed by FP1.

Identifying promising germplasm, developing and deploying traits in breeding for climate-resilient and nutrient-dense varieties/hybrids of GLDC crops are the prime foci of FP5 and FP4. FP5 constitutes the first half of the product delivery pipeline for varieties and hybrids, working in close association with FP4 for seamless continuity for product development and delivery through FP2 and FP3. FP5 will also develop enabling technologies for modernization of crop improvement programs through high throughput sequencing and genotyping, digitalization of data capture and its management in association with the EiB and BigData Platforms.

Research on productivity gains in nutrient-rich and/or climate-resilient GLDC crops directly addresses grand challenges of, (1) competition for land, (2) climate change, (3) nutrition and diet diversity, and (4) maximizing whole-farm production (food/feed/fodder/fuel) from limited resources (water/nutrient/labor). Continuing utilization of novel genetic diversity, including natural diversity conserved in genebanks, systematically-induced, and transgenic variability for the enhancement and stability of yield under stresses are essential components of genetic enhancement and crop improvement research. Hence, FP5 also addresses a fifth grand challenge: diminishing genetic resources.

FP5.2 Objectives and targets

GLDC agro-ecologies are highly prone to negative impacts of climate variability and changes such as extreme drought and rising temperatures, and changing or new emerging pests and diseases. Enhanced resilience to climate change and improved crop performance under biotic and abiotic stresses are high priorities for the GLDC discovery and breeding programs. Significant potential exists for improving yields and yield stability in GLDC crops even under low-input conditions through systematic breeding, tapping the available natural diversity conserved in genebanks or induced variability, and modern tools and technologies. The dryland cereal and food legume crops of GLDC complement well by providing sources for energy, proteins and essential micronutrients and vitamins, thereby providing holistic and balanced diets in GLDC agro-ecologies. In addition, modern tools and technology platforms such as high-throughput sequencing and genotyping, SNP markers, transgenics, genome editing, and leveraging genomic information, etc., are common between legumes and cereals, thereby providing unique opportunities for their applications in CRP-GLDC in facilities that are in the regions where these crops are grown together.

The objectives of FP5 are, 1) to widen the genetic base of GLDC crops under biotic and abiotic stresses by providing strategic pre-breeding lines to FP4 for new variety development and enhancing resilient dryland farming systems, and 2) to provide an extensive tool kit of modern genomics, genetic enhancement, breeding tools, and high precision phenotyping for efficient breeding of GLDC crops. FP5 will focus on, (1) understanding the genetic, molecular, biochemical and physiological bases of crop- and region-specific target traits, (2) deploying this knowledge through the development of tools and technologies for germplasm screening and selection of the mini core collections representing entire collection and (3) with FP4, utilizing these tools and technologies for the development of varieties and hybrids for local adaptation, end-use orientation, and tolerance or resistance to prevailing abiotic and biotic stresses.

Key outputs from FP5 include: 1) Identifying and utilizing superior and/or novel sources of target traits from evaluation of germplasm mini core collections and mutant populations; 2) Understanding genetical, physiological and/or biochemical mechanisms of target traits; 3) Providing diagnostic molecular markers/candidate genes for desired traits, and transgenics with novel traits for intractable constraints; 4) Establishing platforms and technologies for high-throughput genotyping, precision phenotyping, genome modification, genomic selection, and rapid homozygosity/generation turnover; 5) Developing breeding informatics tools and databases for improving efficiency of discovery and breeding programs; 6) Developing and enhancing capacity of NARES partners in integrated crop breeding; and 7) Expanding the network of partners and collaborators for efficient implementation of FP5 outcomes.

FP5.3 Impact pathway and Theory of Change

In close collaboration with FP4, FP5 focuses on achieving genetic gains (sub-IDO 1.4.3) by (1) increasing genetic variation in the base germplasm through exploitation of genetic resources and induced mutant populations, (2) increasing the accuracy of selection through precision phenotyping and genomics-assisted breeding, and (3) achieving improved breeding efficiency by deploying modern tools and technologies such as high-throughput genotyping, use of molecular markers in breeding, rapid homozygosity or rapid generation turnover, and genome engineering technologies. Through science of exploration, it focuses on achieving traits which cannot be obtained by traditional breeding (FP4) (Figure FP 5.1).

The three CoAs of FP5 are closely interlinked. CoA 5.1 will exploit the genetic variability available in the germplasm of GLDC crops and enhance the genetic base for breeding populations. This CoA will ensure the use of genetic resources (sub-IDO 1.4.4) and leverage the CGIAR Platform on Genebanks (including ICRISAT Regional Genebanks) by identifying and utilizing superior and/or novel traits from the vast germplasm collections available in the CGIAR gene banks. In addition, induced diversity through mutant populations or transgenic approaches will provide an alternative approach for novel trait and allele creation in cases where natural variation is unavailable in cultivated gene pools. CoA 5.2 on trait discovery and CoA 5.3 on enabling technologies are closely interlinked for providing inputs and will also work closely with the CGIAR EiB Platform to provide novel breeding tools and technologies to the breeding programs, which will improve the precision and efficiency of breeding programs in combining desirable alleles and accurately selecting desired combinations.

Priority target traits addressed by FP5 include drought and heat tolerance, early maturity, high yields, grain nutritional value (maintaining or improving naturally dense micronutrient and protein levels) and prospects for mechanization. Most of these are required to develop climate-smart varieties and hybrids for contribution to sub-IDO 1.4.1 (reduce pre- and post-harvest losses, including those caused by climate change) and cross-cutting sub-IDO A1.4 (enhanced capacity to deal with climatic risks and extremes). The discovery efforts in FP5 will include these traits and as the program progresses, they will rely more on updated consumer demands and constraints identified by FP1, from feedback information on value chains from FP2, and important traits for system-level agronomy from FP3.

In synergy with FP2 to FP4, the availability of superior varieties and hybrids of GLDC crops will improve nutritional security of farmers and their families (sub-IDO 2.1.1; increased availability of diverse nutrient-rich foods). Among other initiatives, the work on quality improvement of grain and straw, primarily supported by collaborations with HarvestPlus (part of CRP A4NH) and by bilateral projects, is likely to address the issue of hidden hunger (deficiency of micronutrients Fe and Zn) and the need for higher fodder value. FP5 will also contribute to cross-cutting sub-IDO D1.2 through capacity building of researchers (including NARES partners) by conducting trainings, workshops, seminars, exchange visits, etc., in addition to developing and deploying modern genomics/genetics/breeding tools and technologies. This will enable researchers to replicate FP5 outputs in the future. Finally, FP5 outputs and outcomes will feed into global breeding programs through collaborations and publications.

Key assumptions linked to FP5:

- The evaluation of mini core/reference set and trait-specific germplasm leads to identification of desired alleles that can be introgressed in breeding materials bypassing barriers and linkage to negative traits.
- Marker-trait associations are detected for the traits prioritized under this CRP.
- Required level of funding is available through public-private partnerships to develop these platforms and technologies.
- Crop breeders use trait-specific genetically diverse and agronomically desirable germplasm lines and the breeding materials developed from pre-breeding.
- The crop improvement programs integrate genomics-assisted breeding approaches for introgressing and combining desired traits.
- The platforms and technologies developed under FP5 are used by crop breeders for accelerating genetic gains for targeted traits.
- The crop breeding programs use the information, technologies and breeding materials from FP5 to develop locally-adapted and farmer-and market-preferred cultivars.

Given these assumptions, in order to successfully reach outcomes, continuous collaboration with FP4 is needed in order for FP5 outputs to be used effectively in breeding programs. To strengthen linkages between pre-breeding, trait identification and breeding programs, capacity development (e.g. in integrated breeding) of NARES partners across hubs and countries will be essential. Right from the beginning of the program, FP5 will engage with private sector partners, and where applicable, with universities for capacity development purposes. Additionally to existing bilateral projects, FP5 management will make efforts to mobilize supplementary resources in order to guarantee an adequate level of funding.

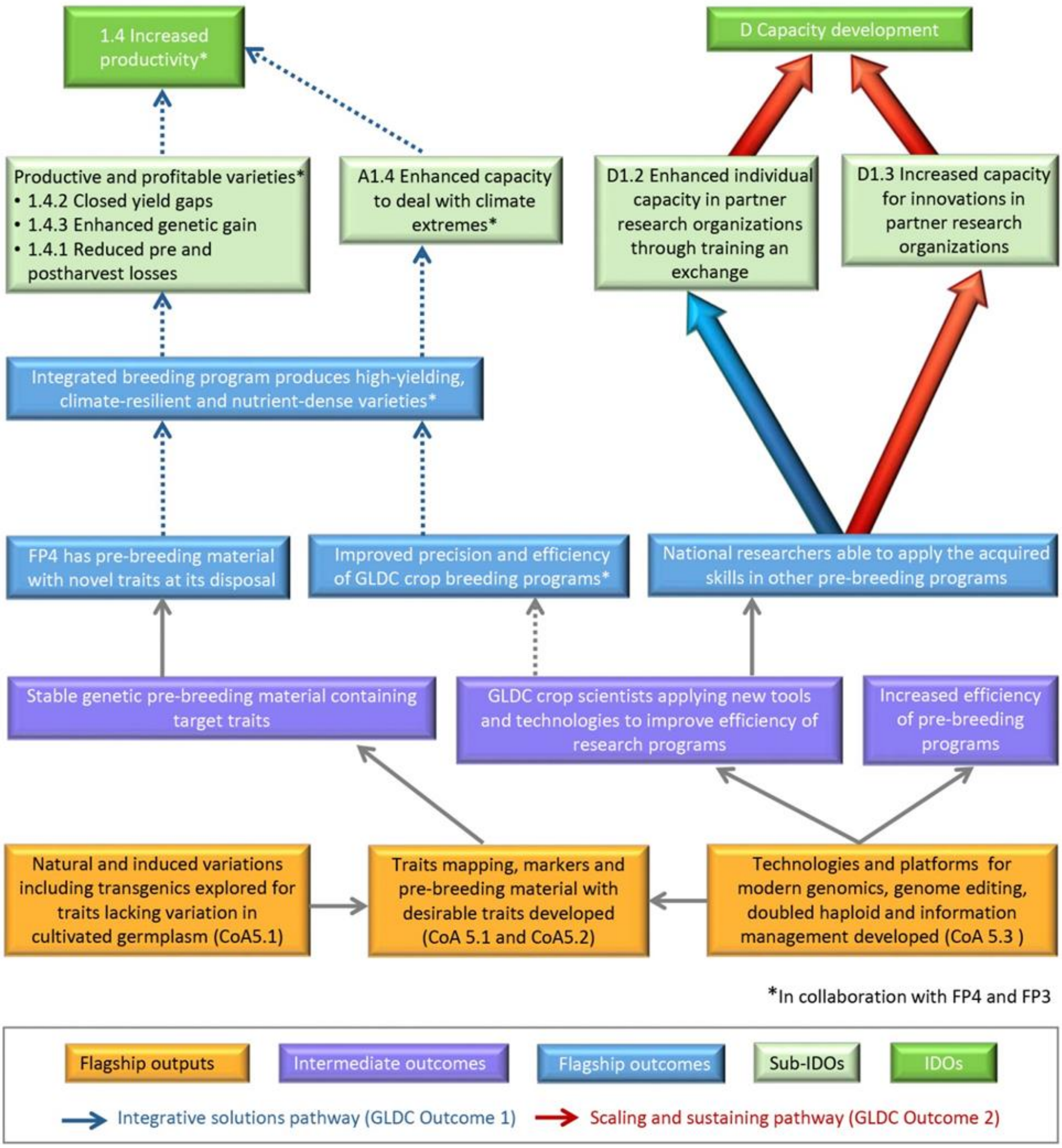


Figure FP5.1. FP5 Impact pathway

FP5.4 Science quality

FP5 relies on the assumption that considerable natural diversity in the genebanks and/or systematically induced variation for the desired traits can be exploited through modern tools and technologies. Within the overarching agri-food systems context of GLDC, FP5 and FP4 are organized along a variety/hybrid development pipeline with specific acknowledgement and incorporation of line-breeding (as opposed to trait breeding) processes where required. Guided by the successes and challenges of Phase I of the component programs of GLDC, the innovative concepts in Phase II for FP5 are:

- Organization of CoAs of FP5 and FP4 along four different stages with data-driven and informed decisions for germplasm and project advancement from one stage to the next.
- Emphasis on widespread implementation of genomics-assisted breeding, enhancing efficiency of traditional breeding, leveraging breeding evaluation and information management tools and databases such as the BMS and Genomic and Open Breeding Information Initiative (GOBII) supported by the Bill & Melinda Gates Foundation.

- FP5 in close linkages with the EiB Platform is fully devoted to enabling technologies that address (a) molecular, genetic, biochemical or physiological methodologies for high-throughput trait screening in the laboratory, controlled environment and fields, and (b) molecular, tissue-culture and transgenic tools including functional gene validation platforms for reverse genetics to establish gene-to-phenotype relationships.

Research on crop improvement in FP5 and FP4 is organized along four stages from A to D on trait basis to address and track delivery of region-specific trait needs for different crops (Figure FP5.2).

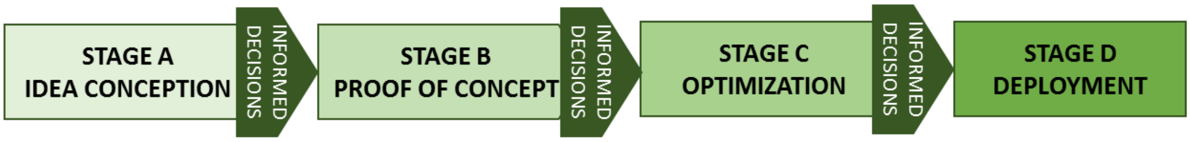


Figure FP5.2: Stages and Flowchart of Discovery Pipeline

Stage A constitutes the development of concepts and ideas with other FPs, and includes activities such as crop simulation modelling to look at trait scenarios (in FP3), the search of literature and patents for novel methodologies, and collaboration with the Genebank Platform. Stage B establishes proof-of-concept through laboratory, controlled-environment and field research to validate superior performance of varieties and hybrids. It includes pre-breeding activities such as germplasm development – multi-parental populations, backcrossing and management of allele frequencies, expanding the germplasm pool through wide crosses and transgenics – germplasm characterization by modern tools like resequencing, trait phenotyping, and deconvolution of the associated genetics. Field performance of superior germplasm lines, varieties and hybrids is established through two seasons of testing in multiple testing locations in stage C, prior to advancement to Stage D for deployment of breeding products.

In addition to the initial validation of germplasm performance, FP5 also includes the development of a prioritized set of enabling technologies and platforms that are critical to the establishment of proof-of-concept, expediting and enhancing efficiency of the breeding cycle which are lacking or underdeveloped in GLDC crops relative to major crops, maize, rice and wheat. The EiB Platform will be extremely useful to leverage experiences in more advanced crops. Tapping of the existing potential for genetic gain in these crops for either low-input or high-input agriculture requires the assembly of critical tools of marker-assisted breeding, forward and reverse genetics (including TILLING), doubled haploid, rapid generation advancement, high-throughput genotyping/phenotyping, genome editing and genomic selection. Clearly, the sustained growth of agricultural biotechnology needs science-based decision-making, especially approaches that are based on science-driven globally-harmonized regulatory systems to evaluate and ensure safe use and deployment of transgenic technologies.

Trait-specific rather than crop-specific organization of CoAs as in FP5 and FP4 facilitate cross-utilization of fundamental expertise (entomology, pathology, genomics, physiology, precise phenotyping, bioinformatics, and cell and molecular biology), especially under limitations of human resources, especially for the application of emerging information across crops with similarities on gene-to-phenotype associations. The establishment of common technology platforms for both legumes and cereals that incorporate or utilize crop-specific platform ingredients like molecular markers, cell and molecular biology and phenotyping can contribute to economies of scale.

FP5.5 Lessons learned and unintended consequences

The reference genome of several GLDC crops was sequenced recently[269] and could be leveraged for genomics-assisted breeding. Adoption of modern tools and technologies, which has been low in the past for GLDC crops, is crucial for the improvement of GLDC targeted crops and agroecologies. Recently it has become possible to undertake sequencing of large-scale germplasm collection[270]. The core breeding programs must operate in the “global integrating systems” to assure effective and appropriate orientation and efficiency by providing varieties with location-specific adaptation which will be captured in defining the PCNs and target population environments (TPEs) for multi-location trials (more details in FP4). More emphasis needs to be given to consumer- and market-preferred traits. Results with interspecific crosses provide confidence that broad allelic variation exists for some traits in the wild species which can be tapped for GLDC crops. The regeneration of synthetic interspecific hybrids of the cultivated groundnut (*Arachis hypogaea*) offers a spectrum for accessing totally new genetic variability. Wild species of lentil have been identified as a good source of resistance to biotic stresses, micronutrient content and earliness. The recent development of guinea sorghum hybrids in West Africa, and the adaptation of hybrid pearl millet from India introduced in Tanzania demonstrated up to 30% improved yield over local checks under low-input agriculture. Hybrids of pigeonpea have also been developed for the first time for release in India[271] that have demonstrated significant yield advantage. Hence, the hybrid technology should be expanded and refined further in GLDC crops and target agro-ecologies to make a significant impact.

Breeding programs deal with target areas over long periods as a part of testing and release procedures. Hence, the system in place is designed to avoid "surprises" at the end of the product delivery process. However, occasionally there may be possible trade-offs between the markets and household nutrition as farmers may be tempted to sell more nutritious, high-value products and consume cheaper (carbohydrate-rich) foods. The development of commercially viable varieties of GLDC crops will change their standing from home-produced foods of high nutritional value to commodities with a cash rather than nutritional return. This has potential negative consequences for gender-sensitive changes in the distribution of benefits, particularly considering folate, iron and protein in the diet. The enabling technologies may not be applicable for all the traits in all the crops, e. g., use of diagnostic markers in forward breeding. Hence, such unintended consequences of FP5 and FP4 research will be monitored along with FP1, FP2 and FP3.

FP5.6 Cluster of Activities (CoA)

To achieve the set outputs and targets, FP5 activities are assigned to three clusters focusing on priority traits in target GLDC crops as follows:

CoA 5.1 Pre-breeding

Pre-breeding refers to activities designed to utilize un-adapted germplasm, which includes wild species as well as "exotic" landraces which are not suited for use directly in breeding programs[272]. Wild species are valuable sources of new genes and alleles, particularly for resistance to biotic and abiotic stresses. While these have largely remained under-utilized due to crossability barriers and linkage drags due to negative alleles in regions flanking the desirable alleles, successful introgression of genes from wild species into their cultivated counterparts have been demonstrated, particularly from primary or secondary gene pools. ICRISAT, ICARDA and other CGIAR Genebanks facilitate access to regional and global germplasm diversity to scientists and NARES partners through global and the Regional Genebanks established in Africa. To enhance greater utilization of germplasm, core (10% of entire collection), mini core (10% of core or 1% of entire collection), and FIGS (Focused Identification of Germplasm Strategy) and Generation Challenge Program (GCP) reference sets provide entry points for capturing the diversity conserved in global genebanks. The regional genebanks are extremely important in providing easy access of germplasm to scientists especially in cases where export of certain germplasm is restricted in some countries.

Pre-breeding will develop intermediate breeding materials for developing new varieties. Some examples of the priority target traits for GLDC crops in this CoA include – chickpea (*Helicoverpa*, dry root rot), cowpea (flower thrips, *Striga*), groundnut (late leaf spot, *Spodoptera*), pigeonpea (*Phytopthora* blight, *Helicoverpa*), pearl millet (Blast, *Striga*) Sorghum (Shootfly, stem borer), and lentil (Stemphylium blight, collar rots). Traits where sufficient variation or sources of resistance are not available in the cultivated target crops, wild species and systematically-induced variations offer attractive options for identification and utilization of novel traits for germplasm enhancement, besides the use of transgenic technology for intractable traits/genes bypassing the species barriers.

The key activities in this CoA will include: 1) Resequencing, evaluation and characterization and identification of germplasm with superior and/or novel traits or wild introgressions in the background of elite cultivars; 2) use of wide hybridization to transfer desired traits from wild species into the breeding materials, or synthetically from the progenitors; 3) Development of new sources of cytoplasmic male sterility in crops like pearl millet, sorghum and pigeonpea; 4) Development of intermediate breeding materials with broad genetic base and desired traits for the development of farmer- and market-preferred varieties/hybrids (linked to

FP4); and 5) Development of transgenics of GLDC crops for intractable traits, and their translation through FP4. Outputs from CoA5.1 will include the availability of novel and diverse germplasm, intermediate breeding materials with a broad genetic base and desired traits, and enhanced human capacity.

CoA 5.2 Trait discovery

Breeders from partner Centers have consolidated their expert opinion and published reports by crop/country or the major productivity traits and quality traits required to address farmer and consumer demands. This CoA will emphasize on traits prioritized (Table FP4.2) from surveys and focus group discussions in the Phase I programs, DC and GL, and on newer priorities identified through FP1, and feedback from FP2. CoA5.2 will focus on understanding the genetic, physiological and biochemical mechanisms of traits; identification of diagnostic molecular markers and functional validations of candidate genes associated with these traits; and development of novel breeding approaches for enhancing yield potential for GLDC crops. Some of the research areas (e.g., exploitation of the germplasm of cultivated species for pod borer resistance, resistance to aflatoxin contamination and low P tolerance in legumes; cold tolerance in sorghum) have been deprioritized in CoA5.2 because of limited or lack of genetic variability in the existing germplasm and/or due to change in priorities (refs). The focus will be on key traits such as nutrient-use efficiency for ESA, WCA, or by using alternative approaches through genetic engineering, host-induced gene silencing (HIGS) and genome editing under CoAs 5.1 and 5.3. In the initial phase of GLDC, research will continue on 'no regret' or key important traits, while a systematic trait prioritization exercise will be undertaken by FP1 which will enable FP5 to focus on specific traits based on future market demands. The summary of prioritized traits (including 'no regret traits'), besides yield enhancement as a common trait for crops/regions are presented in Table FP4.2.

While at the plant level, agronomic traits include grain yield, nutrient-use efficiency, nitrogen fixation, and phenology, at the crop and system level, traits such as plant architecture (for intercropping), residue quantity and quality (for livestock; contribution to soil cover and organic matter), and ability to establish in harsh environments (creating a good plant stand) are equally important. Yield enhancement will remain an important trait as long as the untapped genetic potential of these crops offer opportunities, especially for yield gains in low input situations. Research will also focus on early maturity and plant stature that allow possibilities for machine harvesting, especially in chickpea and lentil. While nitrogen fixation traits will be important for the legumes, nutrient-use efficiency and herbicide tolerance will be important for all GLDC crops. Further evaluations will explore the potential of legume germplasm for capacities to fix N symbiotically, especially under conditions of water limitation or low soil P availability.

Key abiotic stresses that adversely affect production of GLDC crops like drought and heat will be closely linked to the use of crop simulation analysis (FP4 CoA4.1) to guide the search for genetic alterations potentially contributing to increased crop performance under water limitation, besides potential trade-offs with some of these traits. The physiological mechanisms of drought tolerance in relation to water economy will be addressed by high-throughput phenotyping and well-characterized mapping populations[273]. Testing and identifying of germplasm and using molecular markers for drought and/or heat tolerance will be explored especially for chickpea, cowpea, lentil, groundnut, pearl millet and sorghum.

Disease resistance research in the target countries is prioritized based on the severity of yield losses, extent of disease prevalence, resistance sources available and regional demands. This CoA aims for better understanding of host plant resistance and diversity in resistance sources and the pathogens where the identification of diverse sources of resistance to diseases will be organized through evaluation of mini core collections as well as sampling procedures like "Focused Identification of Germplasm Strategy" (FIGS). Linked to CoA5.1, technologies like transgenics and host-induced gene silencing (HIGS) are being used for complex diseases in addition to phyto-sanitary and food safety issues such as pre-harvest *A. flavus* infection and resulting aflatoxin contamination. Supported by CRP and bilateral funding, efforts will be made to enhance understanding of new and emerging diseases, genetics and resistance mechanisms and molecular markers/candidate genes associated with disease resistance.

Insect pests of the target cereal crops include aphids, shoot fly, stem-borer and midges, while pod-borers (*Helicoverpa armigera* and *Maruca vitrata*), leaf miners, aphids and stored grain pests are the major insect-pests of legumes. Due to low or non-existence of resistance to pod borers in cultivated chickpea, cowpea and pigeonpea, screening of germplasm mini core collections and introgression of insect resistance from wild relatives will be undertaken as part of CoA5.1 and complemented by transgenic approaches where applicable. Yield losses from parasitic (*Striga*, *Orobanche*) and non-parasitic weeds are severe in both legumes and cereals. While breeding for resistance to *Striga* has been successful for sorghum and cowpea to some extent, efforts on the identification of molecular mechanisms of host-pathogen resistance are currently ongoing for identifying sustainable resistance to *Striga* through CoA5.3. For countries and regions where high-input agriculture is practiced, the combination of herbicides and herbicide-tolerant crop varieties will be explored through mutation breeding, as well as transgenic technologies in GLDC target crops amongst both CGIAR and non-CGIAR partners, and as guided by the ISPC's strategy on biotechnology (ISPC 2014).

GLDC crops are highly valued for their nutrient-dense nature, and FP5 endeavors to ensure that their nutritional qualities are further enhanced in new varieties/hybrids. Key quality traits include protein content in legumes (oil quality in groundnut) and micronutrients (iron, zinc, calcium) in most crops. Existing collaborations with HarvestPlus in A4NH (for micronutrients on lentil, pearl millet and sorghum), the USAID Feed the Future Innovation Lab (for Peanut Productivity and Mycotoxin Control) and the University of Georgia and USDA Southern Regional Research Station, Louisiana (for research on aflatoxin in groundnut) will be further strengthened for testing of promising germplasm and identification of nutrient-dense germplasm lines. Fodder quality will be enhanced in collaboration with CRP-LIVESTOCK under "Full-purpose crops" through joint resource mobilization. While the initiatives have been taken towards identification of molecular markers for these quality traits, further understanding will be developed using targeted analysis of specific pathways and regulatory genes. Collaboration with ILRI and CRP-LIVESTOCK will provide access to grain and fodder-quality screening facilities such as Near-Infrared Spectroscopy (NIRS) and the X-Ray Fluorescence analyzer. The possibility of developing and using field-based NIRS for high-throughput fodder-quality analysis will be explored and extended to grain quality. In addition, certain consumer-preferred and market-pull traits such as longer shelf-life of pearl millet flour (affected by rancidity), high oil and aflatoxin-free groundnut will be addressed through various discovery approaches (Table FP4.2).

CoA 5.3 Enabling technologies

Deployment of modern tools and technology platforms is the main objective of this CoA. Most of these tools and technologies being common between legumes and cereals, provide an excellent leverage for applications to these two groups, especially when facilities are located in the regions where these crops grow[274]. A Community of Practice (CoP) for these enabling technologies and platforms is proposed. The CoP will provide an effective mechanism for information- and experience-sharing, mutual learning and problem-solving that will map existing knowledge, identify gaps for proactive interventions, promote innovations by creating new knowledge, and develop new capabilities. The CoP will connect with other CoPs and experts with similar interests to facilitate the development and efficient use of enabling technologies and platforms for trait discovery in GLDC crops. The current status and targets for some of these tools/technologies for achieving the proposed outputs of FPs 5 and FP4 are summarized in Table FP5.1. This CoA will also have close association with the EiB and BigData Platforms.

These include genome sequencing, resequencing, and high-throughput marker platforms for facilitating the application of genomic tools in FP5 and FP4 based on ongoing efforts in the HTPG and GOBII projects. Identification, validation and deployment of available diagnostic markers for priority traits are also being addressed and will be further expanded in forward breeding of GLDC crops.

These platforms will enable the development or validation of functional gene-to-phenotype associations through medium-throughput model systems or target crop transformation, and/or through reverse/forward breeding with systematically-induced mutant or activation-tagged populations. The genetic transformation platforms will be based on 'gain of function' or 'loss of function' approaches including genome editing through new technologies like CRISPR/Cas9[275] to generate events for screening and functional validation of traits. The importance of genetic engineering and genome editing technologies is important for the genetic improvement of GLDC crops. While using genetic engineering as the technology of last resort, some of the key constraints that are otherwise difficult to address, due to low or non-existent natural genetic variability, will be tackled through transgenic interventions. However, transgenic work is only targeted to countries that have biosafety legislation and guidelines in place. The intent is to transfer transgenics that are well characterized under pre-field and/or field conditions with the NARES partners in compliance with the respective regulatory regimes. Hence, it is imperative that efforts will be on the capacity building of NARES scientists on the technology, biosafety and stewardship for its effective deployment. ICRISAT's policy on genetically engineered crops will be followed. In addition, induced mutation breeding approach will include development and use of systematic mutant population(s) such as TILLING[276] and other mutant populations.

Table FP5.1. Current status and targets for enabling technologies for GLDC crops

Group of Tools & Technologies	Examples of Enabling Tools and Technologies	Current status	Targets 2022
Structural genomics	High-throughput SNP markers for genotyping	Not available in most of GLDC crops	HTP markers platform in 2 cereals and 2 legumes
	Genomic selection (GS)	Not available in most of GLDC crops	GS implemented at least in 1 cereal and 1 legume
	Forward breeding (FB)	Not available in most of GLDC crops	FB a routine in at least 3 cereal and 3 legumes
Functional genomics	TILLING or other systematic mutant populations	Not available for most GLDC crops	TILLING population in at least 1 cereal and 1 legume available and used
	Gain or loss of functional transgenic platforms	Transgenic platforms available in groundnut, pigeonpea, and chickpea, sorghum, *Arabidopsis* and tobacco	High-throughput functional validation platform established and/or used in at least 4 GLDC crops or model plants.
	Genome editing platform	Not available in most of GLDC crops	This platform will be established for at least 2 GLDC crops.
Biochemical platform	Nutritional quality research lab	Available in SA at ICRISAT-HQ in India	Functionally established and made available at one center each in ESA and WCA
Precision phenotyping in controlled environments	Leasyscan for precision screening for abiotic stress (for WUE) and biotic stresses (glasshouse screens for diseases and pests); high-throughput screening assays for components of resistance to *Striga* spp.	A lysimeter facility and a LeasyScan Phenotyping Platform & biotic stress screening facilities are available at ICRISAT-HQ	These platforms will be standardized for use in at least five GLDC crops. Such platforms will be developed for screening against other target key traits in GLDC crops such as diseases.
Rapid achievement of homozygosity	Doubled haploid (DH) technology	Not available in most GLDC crops	Will be made available in at least 2 GLDC crops.
	Increase number of generations per year or shuttle breeding	Not available in most GLDC crops	Will be made available in at least 2 cereals and 2 legumes

Four nutritional research labs, one each at ICRISAT HQ, ICRISAT Zimbabwe, ICARDA Rabat, and IITA will be utilized. These will allow the study and screening for grain (digestibility and rancidity) and stover for nutritional quality for human food, and animal feed and fodder quality. The food science and nutrition expertise available at ICRISAT and IITA will be leveraged to develop and calibrate quality analyses that can be scaled for throughput and efficiency.

Precision phenotyping for trait discovery and characterization housed in this CoA, is structured under different connected layers (trait-based, controlled environment based at different levels of "data-intensity") and provides trait-based phenotyping activities to FP5. These facilities enable high-throughput screening of germplasm and other breeding materials in the lab, controlled environments, or fields for desired traits. During the initial stages, capacities of the existing screening facilities will be leveraged for abiotic stress (drought) and biotic-stress screening facilities (insects, fungal pathogens and aflatoxin).

Rapid achievement of homozygosity is one of the most effective approaches for efficient breeding programs through accelerated breeding cycle for quick generation of lines with fixed traits. The technologies to be developed or refined for rapid achievement of homozygosity will include, (1) doubled haploid (DH)[277] and (2) rapid generation turnover (RGT). While the DH technology is already being utilized for several important crops, it is currently not available for GLDC crops. This is a high priority area under the uplift budget scenario for FP5, where in addition to anther culture, kinetochore protein (CENH3) modifications will be explored for production of DH[278]. Recent advances in CENH3 research in combination with genome editing technologies could allow the generation of haploid inducer lines with single point mutations[279]. RGT techniques (*in vitro* culture, photoperiod alterations, SSD, off-season planting/shuttle breeding, etc.) will be standardized for prioritized GLDC crops for obtaining multiple generations per year.

These activities funded by the on-going bilateral grants are aimed at taking breeding informatics to the next level by making available modern bioinformatics tools and databases to breeders and biotechnologists. With the advent of BMS, CGIAR plant breeders can centrally handle the nursery and research trials. A recent multi-institutional (Cornell University, ICRISAT, IRRI, CMMYT) project funded by the Bill & Melinda Gates Foundation, GOBII, will develop a high performance Genotypic Data Management System which will be helpful to breeders and genomics experts in handling high-throughput molecular marker data, besides performing basic and advanced bioinformatics analysis such as Linkage Disequilibrium (LD), Genomic Selection (GS), and Population Stratification (PCA, MDS, etc.). These informatics tools will be available to physiologists, breeders, genomics scientists and other scientists from CGIAR and NARES partners through a high-performance computing infrastructure.

FP5.7 Partnerships

Close links will be established with AFS CRPs (maize, rice wheat), A4NH on bio-fortification, and global platforms (Genebanks, EiB) to expedite the work on GLDC crops. These linkages will ensure that their learnings and experiences can be readily translated, besides being extremely important for the development and deployment of various activities in FP5, especially in the CoA5.3 (Enabling Technologies).

Non-CGIAR Partners: ARI-Egypt, ARI-Sudan, BARI, BGI-Shenzhen, CIRAD, Cambridge University, Cornell University, DARI (Iran), EIAR, EMBRAPA, FAO, GCDT, GDAR Turkey, GRDC Australia, IAEA, IAR (Nigeria), ICAR (India), IER, INRAN, ISRA/CERAAS, INRA (Morocco), IIAM (Mozambique), IRD, KALRO (Kenya), DRD (Tanzania), NIAB UK, NARO (Uganda), NARC-Nepal, NARES in various regions, NIPGR, India; various SAUs (India); SMIL, USA, SLU Cambridge, UC Davis, UGA (University of Georgia), UC Riverside, University of Saskatchewan, Global Institute for Food Security (GIFS, Saskatoon), University of Queensland, University of Western Australia, USDA, WACCI, World Vegetable Center and WSU-Pullman.

Various private companies in HPRC (Hybrid Parent Research Consortium) at ICRISAT, provide successful public-private partnerships in pearl millet, sorghum, and pigeonpea in India. In FP5 partnerships with private companies such as DuPont Pioneer, will be further developed and enhanced, especially to develop and deploy enabling technologies such as high-throughput markers, doubled haploids, genome editing, etc.

Partners are of two types: Upstream partners who can deliver knowledge and expertise for the deployment of genetic resources in breeding (e.g. UC Davis or CIRAD) and those that can assist in the development and delivery of outputs to useful outcomes (NARES such as ICAR, BARI, INRA or EIAR). While partnerships with several NARES already exists, strategic partnerships will also be developed to support ongoing research and future fund raising/resource mobilization.

FP5.8 Climate Change

The agro-ecologies of GLDC are more prone to negative impacts of the ensuing climate change and variability. While the GLDC crops, in general have relatively high tolerance to harsh weather conditions, there will still be dramatic effects both directly and indirectly due to variabilities in temperature, drought, insect pests and pathogens, etc. Climate change in combination with more frequent and unpredictable extreme weather events will result in 'shocks' in agricultural production that directly impacts food availability and prices, and thereby contributing to poverty and food and nutritional insecurity, especially for smallholder farmers in GLDC agro-ecologies. The focus of FP5 will be on traits that are directly or indirectly related to climate change, especially tolerance to periodic drought, waterlogging, pest and disease resistance, and tolerance to higher temperatures. FP5 along with other FPs in GLDC and AFS CRPs will also facilitate diversified production systems that will enhance the resilience of vulnerable producers to climate and price shocks, and reduce seasonal food and income fluctuations. Techniques for identifying specific traits that will be needed in climate-resilient varieties by users of the germplasm, will also be addressed.

FP5.9 Gender

A gender lens is critical at the initiation of a trait development/breeding pipeline to ensure that traits of interest and new opportunities for women and youth are included. Research on these traits will be supported by GLDC and/or bilateral funding. Building on achievements under Phase I of CRPs, FP5 will continue to address issues affecting women and youth as follows:

- Participatory research: Continuously receive feedback from FP1 on traits that are important to women and children and prioritize these traits in specific research activities.
- Capacity building: Enhance equal participation of women and youth during trait discovery through training of women and youth within the ongoing pre-breeding activities.
- Product utilization: Continue to focus on discovery of traits that enhance the utilization of research products by women including the reduction of rancidity in pearl millet flour and enhancing the quality of processed flour in cowpea for utilization, and entrepreneurship development through FP 2.2.
- Nutrition quality: Target the discovery of traits that will result in improved nutritional value of all focus crops, and continue to pyramid traits that enhance protein content (legumes), and high Fe and Zn (pearl millet), besides other micronutrients and vitamins to counter malnutrition.
- Reduce drudgery: In collaboration with FP3, prioritize the discovery of traits that will reduce drudgery such as enhanced herbicide tolerance, machine harvesting, etc.
- Market traits: Using recommendations from FP1, FP2 and FP3, identify traits of relevance to local and export markets to increase incomes and overall well-being of the rural populations, majority being women and children.

FP5.10 Capacity development

FP5 will focus on both human and infrastructure capacity development to train future scientists who can support research on these important crops. The recently-funded project from the Bill & Melinda Gates Foundation will help achieve a low-cost and high-throughput genotyping platform to ensure that marker-assisted breeding is routinely used for GLDC crops. The platforms for use of diagnostic markers for key traits in forward breeding of at least six GLDC crops will be achieved and made available to NARES partners. High-throughput phenotyping platforms such as Leasyscan will be further enhanced for screening for drought tolerance and other key prioritized traits. Precision and controlled environment facilities will be strengthened for screening against key diseases. The three labs for nutritional quality analysis (in IITA, ICRISAT-Zimbabwe, ICRISAT HQ) will be strengthened to provide analytical and R&D support.

ICRISAT maintains three Regional Genebanks at Niamey, Nairobi and Bulawayo in Africa to enrich its global collections for diversity by exploring and filling the identified gaps, and to meet demand for mandate crops germplasm in Africa. During 2015 and 2016, ICRISAT Regional Genebanks and partners collected over 3800 accessions from eight countries in Africa.

ICARDA has recently established a modern state-of-the-art quality lab at Rabat, Morocco. The food science and nutrition expertise available at IITA and ICRISAT will be leveraged to develop and calibrate quality analyses that can be scaled-up for high-throughput and efficiency. HPRC, a public-private partnership that has successfully operated in India for pearl millet, pigeonpea and sorghum parent line development will be extended to other crops and regions. Future scientists will be trained in various areas at the participating CGIAR and private partner facilities. A strong collaboration with private partners, including DuPont Pioneer will be established to enhance capacity for enabling technologies in CoA5.3. Short exchange visits and trainings for specific technologies will be conducted with partners. Scientific workshops, short training courses, studentships, scholarships, seminars, exchange visits, networking with NARES, etc., will be a high priority to train future agri-technocrats. At least 100 high quality publications, 10 courses/workshops and 25 trained students are expected during the proposed phase of GLDC.

FP5.11 Intellectual asset and open access management

Since many modern technologies, breeding products and inventions may be under proprietary regimes, patent and proprietary issues, hence related freedom to operate (FTO) issues will be considered to ensuring that institutions can access and use technologies under appropriate conditions. The Lead Centre, ICRISAT, maintains all its data products using state-of-the-art data platforms/applications such as Dataverse, BMS, Grin-Global, aWhere, ESRI webGIS platform etc. Dataverse is the primary repository to share diverse data sets whereas BMS is being used as the primary database solution for managing crop databases and other breeding-related activities. BMS will be linked to other public databases to ensure smooth data sharing with appropriate metadata. ICRISAT's Genebank uses Grin-Global data management system which will be continued under GLDC. All these data platforms and repositories are compliant with the CGIAR's standard interoperability protocols and standards.

FP5.12 FP Management

FP5 is led by Dr Rajeev Gupta, Principal Scientist and Theme Leader-Genomics and Trait Discovery, ICRISAT. Dr Gupta is an experienced biotechnologist, molecular biologist, biochemist and successful leader with over two decades of global experience in public and private sectors. He is supported by a team of experienced plant scientists, including Drs Ousmane Boukar, Fouad Maalouf, Rajeev Varshney, Enghwa NG, HD Upadhyaya, Kiran K Sharma, Pooja Bhatnagar, Shivali Sharma, Jean Francois Rami and Laurent Laplaze.

FP5.13 Budget summary

Flagship Program 5 : Pre-breeding and Trait Discovery						
Funding Needed	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
W1 + W2	1,242,113	1,304,250	1,369,350	1,437,900	1,509,750	6,863,363
W3	3,368,850	1,424,450	654,900	42,500	42,500	5,533,200
Bilateral	5,940,373	8,204,755	5,973,587	5,978,859	5,972,416	32,069,990
Other Sources	-	-	-	-	-	-
Total Needed	**10,551,336**	**10,933,455**	**7,997,837**	**7,459,259**	**7,524,666**	**44,466,553**
Funding Secured						
W1 + W2	1,242,113	1,304,250	1,369,350	1,437,900	1,509,750	6,863,363
W3	3,368,850	1,424,450	654,900	42,500	42,500	5,533,200
Bilateral	2,555,997	1,234,264	242,682	198,400	174,400	4,405,743
Other Sources	-	-	-	-	-	-
Total Secured	**7,166,960**	**3,962,964**	**2,266,932**	**1,678,800**	**1,726,650**	**16,802,306**
Funding Gap						
W1 + W2	-	-	-	-	-	-
W3	-	-	-	-	-	-
Bilateral	(3,384,376)	(6,970,491)	(5,730,905)	(5,780,459)	(5,798,016)	(27,664,247)
Other Sources	-	-	-	-	-	-
Total Gap	**(3,384,376)**	**(6,970,491)**	**(5,730,905)**	**(5,780,459)**	**(5,798,016)**	**(27,664,247)**
Line Item						
Personnel	4,706,770	4,870,616	3,939,039	3,797,464	3,826,372	21,140,261
Travel	577,067	604,626	390,080	345,744	341,647	2,259,164
Capital Equipment	341,551	343,756	301,965	296,012	302,138	1,585,422
Other Supplies and Services	1,865,883	1,975,951	1,291,785	1,158,254	1,149,849	7,441,722
CGIAR	404,839	409,253	278,951	254,007	253,913	1,600,963
Non CGIAR	1,460,752	1,485,419	946,677	834,072	870,716	5,597,636
Indirect Cost	1,194,474	1,243,834	849,340	773,706	780,031	4,841,385
Total Budgets	**10,551,336**	**10,933,455**	**7,997,837**	**7,459,259**	**7,524,666**	**44,466,553**
Core Partner						
ICRISAT	7,995,646	8,379,732	5,263,267	4,601,511	4,524,313	30,764,469
IITA	138,563	90,566	70,602	72,490	134,549	506,770
ICARDA	1,057,079	1,100,627	1,216,042	1,298,621	1,364,508	6,036,876
CIRAD/IRD	1,360,048	1,362,531	1,447,925	1,486,638	1,501,296	7,158,438
Total Budgets	**10,551,336**	**10,933,455**	**7,997,837**	**7,459,259**	**7,524,666**	**44,466,553**

Annex 3.1 Participating Partner Budgets

The overall budget was prepared after consolidating the budget submissions from the participating Centers and partners (CSIRO, CIRAD, IRD). GLDC has a total of seven participating Centers, of which four are Tier-I (including the Lead Center) and three are Tier-II. W3 and bilateral budgets of the participating Centers and partners have been mapped to GLDC based on their relevance and contribution to GLDC objectives. A total of US$413 million has been budgeted for this CRP for a period of five years (2018-2022), consisting of approx. 15% from W1/2 and 85% from W3 and bilateral sources. A total of US$8.9 million has been budgeted towards GLDC Management.

GLDC will follow a transparent process of governance and financial management. The allocation of W1/W2 resources to the participating Centers and partners will be decided by the ISC based on recommendations from the RMC following a consultative process. Considerations will include strategic use of W1/W2 funds to leverage W3 and bilateral funding, contributions by partners in FPs, performance of the partners in achieving the stated goals of GLDC, ability to generate W3 and bilateral resources to support the CRP and other considerations that the ISC may deem appropriate to maximize the contributions of GLDC to the SLOs.

Details of the participating Centers' budgets are in the submitted budget tables.

Annex 3.2 Partnership Strategy

GLDC argues is that the lives and livelihoods of dryland populations will be enhanced by increasing the productivity, resilience, profitability and quality of the most important cereals and grain legumes in the semi-arid and sub-humid agroecologies of SSA and SA. Improved capacities of the agri-food systems of key cereal and legume crops will enable coherent production, market and policy innovations that deliver resilience, inclusion, poverty reduction, nutritional security and economic growth.

Table 1: Forms of partnership with the CRP

Role	Resourcing	Responsibilities
Leader, Flagship Program, Cluster of Activities	10-40% time funded by CRP	Formally lead a Flagship Program or Cluster of Activities to plan, budget and report on annual workplans. Involves engagement with CRP participants, partners and stakeholders. CoA Leaders report to their respective FP Leaders. Co-leadership is possible.
Member of Independent Advisory Committee (ISC)	Time allocation is in-kind; travel and operating funded by CRP	IAC reports directly to the ICRISAT Governing Board on the performance of the program. The ISC consists of a majority of non-CGIAR partners, with CGIAR members being *ex officio*. It includes the ICRISAT Director General and the CRP Director.
Member of Research Management Committee (RMC)	Time allocation is in-kind; travel and operating funded by CRP	RMC has responsibility for implementation of the CRP. It includes the Flagship Leaders and non-CGIAR representatives.
Partner in core CRP R4D activities	Funded with W1/W2 funds	The CRP has limited W1/W2 funds to be allocated to critical CRP initiatives that are not supported with bilateral grants. The majority of W1/W2 funds are allocated to Tier 1 CRP partners.
Partner in approved allocations from the CRP Innovation Fund	Access to Innovation Fund resources	The CRP Innovation Fund provides a mechanism to seize emerging opportunities that will catalyze scale-out and market-led development. Initiatives will require co-investment leveraged from private, NGO or public sector partners. The CRP Innovation Fund is drawn from W1/W2 funds.
Partner in W3/bilateral projects mapped to the CRP	W3/bilateral project resources	The predominant form of partnership within the CRP. Funded projects led by CGIAR or partner organizations involving collaborating organizations and mapped to deliver against the CRP agenda.
Stakeholder aligned to and active in R4D in the domain of the CRP	Self-funded	Stakeholders (research, development, agribusiness, public sector, NGOs, donors) of the CRP who wish to be connected to the CRP R4D and its network.

The GLDC agenda demands broad research partnerships and alignment with Country and Regional priorities and capacities in the target regions of SSA and SA. GLDC can only deliver on its R4D agenda through strong, broad and active partnerships and network of connections that provide the opportunities to identify and enact R4D that delivers promised impacts for beneficiaries. The Table below presents the forms of partnership on how individuals or organizations can connect with GLDC.

Annex 3.3 Capacity Development Strategy

The participating centers of GLDC have a long history of capacity development interventions that enhanced capacities of partners and national agricultural research systems, extension, agribusiness and farmers. The program will build on this experience, while integrating the support of a GLDC Capacity Development Taskforce and key stakeholders.

By uniting and coordinating the efforts of the Centers involved, GLDC will cohere interventions into a comprehensive, holistic, integrated and all-inclusive systems approach which ensures that interventions are demand-driven and at the same time support the achievement of the IDOs.

GLDC aims at developing the capacity of female and male individuals, institutions, organizations and systems to enable them to perform certain tasks leading to the achievement of research and development goals. All GLDC team members are in one way or the other contributing to these different dimensions. GLDC will support the team in a demand-driven way through internal training and support through the Taskforce.

In congruence with donor expressed priorities, the main focus will be on National Innovation Systems, specifically NARES, national and regional development agents and private sector entrepreneurs who wish to invest in GLDC agri-food systems. GLDC commits to contributing to developing these actors' capacity and each Flagship Program has articulated its contribution. CGIAR and NARES teams are already partners in many R4D projects, often on equal footing, but also with evident gaps in skills and facilities. While all GLDC participants take responsibility for capacity development of partners, a GLDC Taskforce, consisting of experienced facilitators of transdisciplinary research processes, will support the GLDC team in being more efficient in their efforts. The Taskforce will focus on the development of the CRP teams' capacity to conduct capacity development training. Concrete activities in this sense will be coordinated during the implementation of the program. They are likely to include stakeholder analyses, capacity development needs assessments of partners, specific skill trainings for NARES scientists (e.g. leadership or science writing trainings), financial support partner inclusion into flagship activities, fund raising for capacity development activities, trainings for partners in capacity development approaches and techniques and support in embedding cutting-edge expertise into the curricula of National tertiary education programs.

The vision is that main stakeholders, partners and teams will have in place human resources, institutions and systems capable of working collaboratively while successfully carrying out their defined roles in GLDC, leading to the achievement of IDOs in the target regions. The mission is to ensure the development and successful implementation of capacity development that is fully integrated into the impact pathways and leads to the development of capacities of participating actors and innovation systems as a means to support them in effectively achieving the targeted development outcomes. GLDC will ensure a special emphasis on the development of NARES partners and the uptake of research as part of a broader innovation system and follow an integrated approach. This involves a move towards multi-stakeholder, interdisciplinary and client-driven strategies which ensure that critical actors will be involved from the beginning and will endorse the decisions taken.

Capacity Development is the key pathway that drives impact for GLDC and one of the key performance indicators for the program's success, especially within the framework of ensuring that agricultural research outputs will be transferred to the other stakeholders involved in the value chain thus enabling development outcomes.

GLDC will support capacity development to improve performance within a wider system, rather than as an end in itself. Therefore, there is generally an underlying theory of change that presumes that capacity development components will strengthen certain actors and modify attitudes and practices, in turn changing the performance of a wider system. Since, capacity development is a complex interplay between individual, organizational and institutional levels, the focus, is on the processes rather than just on the acquisition of skills and knowledge to perform a defined task.

GLDC's starting point is careful priority-setting based on a needs assessment of critical capacity gaps. Especially CoA1.1: Foresight, Climate Change Analysis and Priority Setting, will contribute to this task in collaboration with the GLDC Taskforce. The latter will conduct a comprehensive stakeholder analysis and the identification of the stakeholders who are most critical for achieving GLDC goals.

GLDC will invest in building the organizational capacity of NARES and public and private sector partners. In particular, FP3: Integrated Farm and Household Management, FP2: Transforming Agri-food Systems and CoA4.4: Science of Scaling Seed Technologies will contribute to this task. The Taskforce will, with backstopping from the CGIAR Capacity Development Community of Practice, support these activities in a demand-driven way.

During the first Phase of the CRPs it was identified that critical capacity gaps for achieving ambitious impact objectives are related to institutional strengthening. In particular, CoA1.2: Value Chains, Markets and Drivers of Adoption and CoA1.4: Enabling Environments and Scaling to Accelerate Impact, as well as all clusters of FP 2, will develop this capacity of various agri-food system players with special emphasis on governance actors. Also, gender-sensitive approaches will be especially developed in CoA1.3: Enhancing Gender Integration and Social Inclusion in the Drylands. The GLDC Taskforce will support these activities by facilitating multi-stakeholder platforms and feeding the results into large-scale policy processes (e.g., international conventions).

The Taskforce will be strongly involved in the management of the GLDC Innovation Fund. One critical purpose of the fund is to test approaches to develop capacity in fields which are critical for ensuring impact and which are identified in the process of program implementation. Special emphasis will be put on innovations which have the potential to change paradigms.

GLDC acknowledges that coordinated efforts increase cost efficiency and effectiveness in achieving impact, reduce transaction costs, enable synergies and avoid duplications. Based on the CGIAR Country Coordination strategy, the Taskforce will facilitate investments to be coordinated at the sites where different CRPs and CGIAR Centers plan their interventions. Site selection priorities will be decided based on a consultation process with the other CRPs and their respective capacity development taskforces, in coordination with the CGIAR Capacity Development Community of Practice.

Annex 3.4: Enhancing gender integration and social inclusion in the drylands

Under CRP GL, a gender analysis implementation framework was designed to map to the crops (legumes) research cycle, with five key stages: i) End-user profiling, trait discovery and breeding, ii) Phenotyping and seed systems, iii) End-user technology testing and adoption, iv) Value chain and market development, and v) livelihoods and impacts. A cross-cutting category was included on social norms, youth and nutrition issues. A strategic decision, based on gender capacity that was available in the CRP, was to focus on three key areas: a) the cross-cutting category on social norms (GENNOVATE: cross-CRP study on social norms and innovations in agriculture and NRM) b) end user profiling, trait discovery and breeding (from a review of methods used to integrate gender in breeding) c) Phenotyping and seed systems (gender gaps in legume/cereals production systems). Strategic input on gender disaggregation of data in adoption, impact and livelihood studies would be provided by the economics team.

The GENNOVATE study is a global qualitative study, implemented by 11-CRPs, that was designed, with a shared methodology, to provide empirical evidence on the relationship between gender norms, agency and agricultural innovations. The study investigated whether gender norms and agency advance/impede the capacity to innovate/adopt technologies or whether agricultural technologies affect gender norms and agency across different contexts. Data from 20 case studies among 20 communities in dryland areas in six countries of SSA where in-depth focus group discussions, life histories and key informant interviews were collected. The key messages drawn from the study are: i) in the dryland areas, adoption of crop varieties is considered when complimented by innovations that support crop production in water shortage situations;

ii) as women assess innovations, a key driver is labor saving opportunities offered, iii) Women, especially the young, cite 'support of men or senior women - in getting around constraining social norms' to be able to innovate; and iv) The social norms applied to young women are most constraining, in terms of mobility and public participation, compared to the young men and the adults. Learning from the current experiences helps us focus on – replicable methodologies of understanding the gender/social norms, building evidence and designing behavior change interventions – to support GLDC in transforming gender relations in the drylands to enhance innovation and productivity.

The FAO and the World Bank, have documented the importance of being aware of the gender yield gap in agriculture. GL and DC prioritized understanding the magnitude of 'gender gaps' in the legume and cereals systems production systems and invested in a postdoctoral fellowship to generate evidence in this area. Data has been collected in the groundnut systems of Malawi, among the matrilineal and patrilineal cultures, and considering the male-headed, female-headed and female-managed households in each. The Oaxaca blinder econometric methodology has been chosen as the method to analyze the data; primarily because it decomposes the gender gap into an explained component – linked to the endowment effects (differences between the men and women observed variables) and an un-explained component – the structural effects. The structural effects describe the share of the gap that is sourced in unequal returns to the endowments. This effect is usually divided into the male advantage and female disadvantage, which are calculated based on the deviation of the respective group coefficients from pooled estimates[280]. Data analysis from the Malawi data is currently ongoing. Learning from this, GLDC will invest in generating evidence of gender gaps in other crops, in different countries and designing interventions that close the gender gaps.

The CRP GL and DC prioritized integrating gender analysis to the 'trait discovery, developing of varieties and hybrids'. An investment was made into a postdoctoral fellowship focused on reviewing literature on the methods invested in the past in the breeding processes that included gender analysis. In theory, participatory research is a process of inquiry between scientists and communities that aims to resolve problems through an interactive process of discovery, empowerment, knowledge sharing, and action. Inherent in the theoretical Participatory Research (PR) approach is the inclusion of marginalized voices to ensure that everyone's inputs and needs are met. In the 1970s and 1980s, PR was adapted to agricultural research and development (R&D) and until now, participatory processes are often considered a panacea for acquiring context-specific and gender-sensitive stakeholder input; information that is essential to improve technology development and uptake. However, critiques of PR in R&D note that these processes are often applied in a topical manner that fails to give voice to marginalized stakeholders and neglects the PR objectives of empowerment and knowledge sharing. Likewise, gender researchers lament the failure of programs to thoughtfully engage in gender-sensitive design and analysis of R&D projects. One of the principal goals of Participatory Plant Breeding (PPB) and PVS is to increase the adoption of varieties that can improve the agricultural productivity of farmers, and a mainstay of the approach is developing varieties to meet end-user needs. Using grounded theory to assess how inclusion of 'gender voice' has progressed in PBS practice over the past two decades, since an analysis and publication in '2002 CGIAR Gender and Participatory Plant Breeding, a systematic review of the literature', 102 research articles, that include gender analysis and PVS or PPB is underway. Lessons gained from this process will guide GLDC's methodology and guide on integrating gender analysis in plant breeding.

Prioritizing gender-preferred traits. The bean breeding program has provided a unique example of prioritizing gender-preferred traits. The social economics team investigated farmers ranking of production and post-harvest bean traits under varying production conditions in Kenya. The study identified a very strong correlation between the weight attached to cooking time of a bean and a variety's acceptability[281], information that was looped back to the program scientist. Cooking time[C], is a women-preferred trait. It relates to the labor [time] and firewood [cost] resources needed for household food preparations; and having a significant reduction in these resources made the reduced cooking time emerge as a key driver of selection of varieties by both women and men. The bean program has initiated a gender-responsive breeding program, to identify the markers for 'cooking time trait' with the possibility that cooking time trait could be transferred to various bean varieties, taking advantage of the accelerated breeding tools and genomics.

[C] Other traits that have been mentioned in PVS include the snapping trait [in finger millet, that saves labor in harvesting], the wood thickness in pigeonpea plants [for use as firewood]

Researchers working in TL II, under chickpea research and development program in Ethiopia, informed that there was very low participation of women in training events organized by the program, compared to men. This was, despite the program instituting a policy that every male farmer would be required to attend the training with his wife. Even then, a training of about 70 participants would have only 5-6 women; and yet the scientists would 'see' the women working on the chickpea fields[282] (Ojiewo 2015, personal communication). Women's attendance in scientific meetings, even in the CRP, is always low. There is a possibility that the pool of women in the CRPs is small. As shown in DS research, this could also be related to social norms in the farming communities as well as in the scientific communities. Once social norms are addressed, women can be integrated in research in very gender-differentiated societies[283]. Social norms are difficult topics for even well-designed household surveys to explore effectively. Social norms of gender are in constant dialogue with women agencies and may determine women's capacity to act, participate and get involved in the agricultural continuum from farmers to scientists. GLDC will prioritize supporting women's gainful participation as well as capacity development along the cereals and legumes value chains – from farmers' to scientists' continuum.

CRP GL and DC in phase 1 did not initiate activities that focused on gender and seed systems for legumes and dryland cereals. CRP DS had several successful projects[284], where farmers learnt to supplement their income through seed production and sale of local crop varieties. Tanzania has a policy supporting the quality declared seed processes. This has been identified as an area the needs prioritization and investment in GLDC phase 2.

Building on earlier work of CRP DS, GLDC gender research prioritizes a socio-ecological systems approach to understand the social power web and its interaction with ecological elements of the system, as well as the impact of agricultural development interventions, in shaping rural food security and agricultural livelihoods. The systems approach is used to identify agriculture related socio-economic factors and mechanisms, needed to be managed for improving food and livelihood outcomes. This socio-ecological systems approach, acknowledges the coherent interrelationships between biophysical and socio-economic systems that controls the functions and performance of agricultural livelihood systems, in terms of total productivity, profitability, ecosystem services integrity and social equity. Change to ensure that women, men and youth in farming communities can benefit from research will happen through an understanding of what impact upscaling of research products (technologies) have on the ground, on the socio-economic fabric and ecological situation of the targeted agricultural livelihood system on all stakeholders. The understanding of these effects and of the dynamics and feedback loops triggered by research interventions will allow stakeholders to see opportunities and adapt their behavior.

The Gender M&E Strategy will be nested within the overall GLDC M&E strategy and will also draw on and be consistent with CGIAR's indicators listed in the reporting requirements for the CRP Annual Reports. A participatory gender-explicit monitoring and evaluation framework will be designed and implemented which integrates local and gender-specific indicators for monitoring outcomes. Monitoring focuses not only on equal treatment for women and men, equity in participation of young women and men but also ensuring that the intervention outcomes provide benefits for both women and men in an equitable way. To ensure this, all data from intervention activities and M&E processes are disaggregated by gender and analyzed, feedback provided for better integration of gender analysis into activities, programming and implementation process of the CRP, as well as informing policy makers.

Output indicators include:

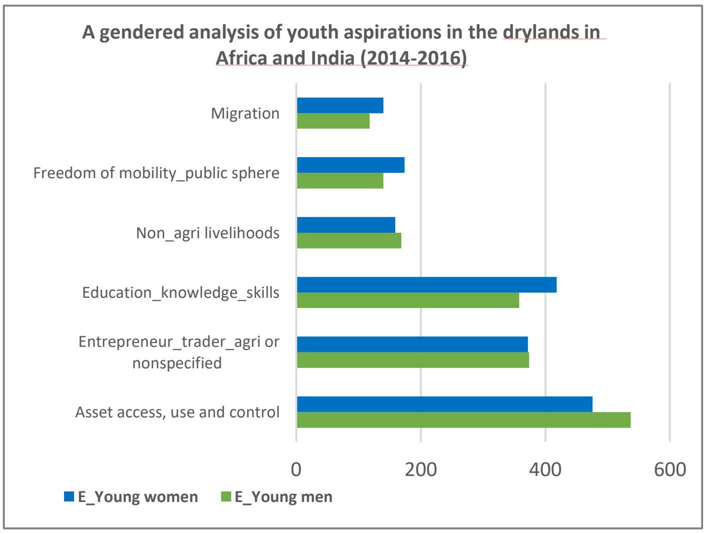
- Sex-disaggregated and gender-relevant data collected.
- Gender and social analysis conducted, and used to inform program and intervention design.
- Gender-sensitive and women-targeted technologies identified/ developed and disseminated.
- Paper, reports, policy briefs and other science products that are gender sensitive and gender focused are produced and disseminated.
- Capacity-building strategy on gender developed and implemented for program staff and partners.

Annex 3.5: Youth Strategy: Youth Sensitive Transformation of the drylands

Youth employment in SSA and SA, as well as other regions, is one of the main policy debates currently ongoing among the global research and development community. About 90% of the world's young people live in Africa, Asia, and Latin America and the Caribbean. Up to 70% of youth in SSA and SA live in rural areas[285], and 47% of rural youth in Africa work in agriculture[286]. The combined challenges of continued population growth, declining agricultural productivity growth and environmental depletion put pressure on agricultural research and development to work on all fronts to further enhance agricultural productivity and food security.

Defining the youth as a social category. 'Youth' is a term that is used to refer to young men and women in a community. However, youth definition differs from community to community. Even the legal definition of youth may differ from country to country[D]. Being youth is not a uniformly experienced transitional phase in life between childhood and adulthood, but a highly gendered one, that intersects with other identities such as marital status, ethnic affiliation, class, education or employment status[287,288]. Young people's embeddedness in families, social networks and communities, as well as norms and expectations related to age and gender, influence the exercise of agency[289] as well as livelihood decisions and outcomes[290]. Defining the 'youth in the drylands' as a target group is not straightforward or easy, but calls for a process of evidence gathering and targeting.

Integrating youth in the Research Agenda. The degree to which agriculture and the agri-food sector might provide decent work opportunities for young men and women in the drylands of SSA and SA, and the contribution that GLDC can make is a priority area of investment in phase 2. Through the GENNOVATE study, qualitative research has been carried out on aspirations of the youth; 40 focus group discussions were done between the year 2014 and 2016 in six countries[E] by social scientists affiliated to the CRPs GL, DC and DS. Findings revealed that majority of the youth aspire to exploit non-agricultural livelihood pathways. However, a number of young men and women were already engaged in agricultural production activities already.



Agricultural commercialization and engagement with value chains has the potential to deliver livelihood benefits, income, to rural people including young men and women. The argument is that commercialization should be looked at from a local economy perspective (as opposed, e.g. to an individual, farm, crop or commodity perspective). A local economy perspective starts with economic and employment opportunities associated with the commercialization of production itself. But it also encompasses the activities that support (e.g. seed and fertilizer sales) and/or add value (e.g. marketing processing and transportation) to this production, and all the other economic activities that are enabled by or linked to commercialization (e.g. business offering goods or services that are purchased with income derived directly or indirectly from it). Commercialization as an economic and rural development phenomenon is about much more than producing and selling products. This maps well to the formulation of FP2 where a transformation of the agri-food system is proposed 'past on-farm production'

[D] The UN system defines youth as persons between the ages of 15 to 24, and children as persons below the age of 14 years; Ethiopia's national youth policy (2004) defines youth as those aged between 15-29, while the National Youth Policy of Nepal (2010) defines youth as "women, men and third gender" persons aged 16-40 years old.

[E] India-12, Mali -10, Burkina Faso -2, Niger- 6, Ethiopia-4 and Tanzania -6 and where we see potential of strategically engaging youth in the 'rural commercial economy'. FP3 agenda will focus on:

1. Understanding who are the dryland youth, men and women, what are their aspirations and values: understand the 'youth typologies" to deal with the heterogeneity of their social embeddedness and to characterize different types aiming for a more targeted research.
2. Understanding which young men and/or women are able to take advantage of different opportunities, and how they take the initial steps to engage with a commercialized local/rural economy as producers, workers, business operators, or suppliers of products to the system.
3. Understanding the 'opportunity structures' available to the youth and the unique challenges they have; assessing/testing the agricultural value chains (incl. their support systems) that have the highest potential for the youth to engage and benefit in different regions.
4. Designing metrics for monitoring progress, learning, impact, and empowerment of the young men and women in different areas; impact on on-farm adoption and productivity – through backward linkages.
5. Test ways of scaling out the best options for youth engagement, especially application of ICT within digital agriculture initiatives such as the ihub[F] facility at ICRISAT.

Annex 3.6 Results-Based Management (RBM) and Monitoring, Evaluation, Impact Assessment and Learning (MEIAL)

The CGIAR SRF and SLOs represent the RBM Framework adopted by all CRPs and embedded in the 15 Centers of the Consortium. The GLDC management structure is aligned to the RBM framework and supported by a Performance Indicator Matrix. It will also use Monitoring, Evaluation, Impact Assessment and Learning (MEIAL) processes to (1) communicate the impact of research in contributing to solving development challenges, (2) implement agile learning about effective ways to design and deliver research impact at scale through strategic partnerships, (3) demonstrate accountability, benefits and value for money of investment in research, and (4) allow evidence based decisions to be made about how and where best to target public spending.

Given legacy uploads and use by Phase 1 CRPs (DS, DC, GL), the on-line MEL Platform software[291] will form the basis of GLDC RBM practice. Accordingly, GLDC will budget circa 10% for RBM and MEIAL, strategically allocated to: 1) undertaking essential monitoring and targeted evaluations; 2) undertaking impact assessment studies not covered by bilateral funding; 3) defining common M&E standards through reflection and learning interventions with non-CGIAR Partners; 4) publishing meta-analyses that triangulate learning theory and publish cases studies with GLDC implementation data to extract R4D lessons relevant to poverty alleviation in dryland agroecologies; and 5) further development and implementation of the MEL Platform (in collaboration with CRP-RTB). Management of cross-GLDC investment in and return from MEIAL will be through FP1-CoA1.4: Enabling environments and scaling to accelerate impact.

MEIAL processes are an integral part of the broad conceptual, implementation and delivery cycle of GLDC. The overarching goal of the strategy is to ensure a robust CRP governance framework. The following factors will be critical to the success of the strategy:

1. Based on the ToC and Impact Pathway, identify and agree with partners, key indicators to evaluate progress along value chains and within an agri-food system.
2. Integrate participatory research feedback loops to provide real-time feedback on technologies and gain a deeper understanding of gender-based and youth barriers to adoption in light of emerging national priorities, farmer and market-demands, partnership evolution and the enabling environment for each priority country.

[F] http://www.icrisat.org/innovation-hub-opens-for-agri-tech-entrepreneurs/

3. Outward-looking approach that recognizes delivery of outcomes requires successful collaboration and coordination with other organizations and actors within the agri-food system and integrating activities on-site whilst contributing to country strategies.
4. Promotion of a strong culture that incentivizes CRP staff and partners to proactively engage in the process of generating high quality evidence, evaluated and adapted based on aggregated data and knowledge.

In alignment with the CGIAR MEL Community of Proactive Companion document[292] and the RBM framework/integrated framework for performance management system[293], this strategy sets out three objectives:

1 Ensure a robust governance framework for all activities through clear processes in order to generate learning and feeding into management decision-making in service of achieving contributions to the SLO;

2 Establish a cost-effective approach, and processes to inform conceptualization and successful delivery of all CRP activities at the level of SRF and within the broader framework of country strategies to ultimately achieve the SDGs;

3 Foster and promote a strong culture with CRP staff and partners.

The Strategy developed in Phase I by CRP-GL, DC and DS together with CRP-RTB within the CGIAR RBM framework will be adapted for GLDC.

The GLDC Performance Indicator Matrix operationalizes RBM at the FP/CoA levels, country and cross-cutting themes. These dimensions generate nested ToCs where all actors find their position in terms of accountability, learning and contribution to adaptive management. ToCs outline how the research effort and supporting processes will lead to key developmental changes measured through quantitative and qualitative indicators to support adaptive management and learning against annual targets established with partners for each priority country and crop production system. This will provide a unique context-specific knowledge repository as the basis of the rigorous impact assessment design in order to understand what works, what doesn't and why. Risks and assumptions are defined at each TOC step. Risks are treated according to the Risk Management Plan[294].

While the CGIAR reform promotes better integration, mapping bilateral projects[295] remains a challenge in terms of value for money (V4M) analyses. GLDC will continue to investigate different approaches for V4M together with other institutions[296].

The strategy and the implementation plan are defined along four building blocks: 1) Monitoring; 2) Evaluation; 3) Impact Assessment; and 4) Adaptive Learning.

Monitoring is the responsibility of the CRP Director, and FP/CoA managers. It implies regular observation of program implementation, data collection and analyses for informing management decision, evaluations and impact assessments. Adaptive and agile management is one of the first key results of the strategy allowing smart learning, resulting in program adjustment, efficient supervision and feedback loops. Reporting requires Scientists to submit their activity reports annually or on a mid-term basis. However, the system allows real-time tracking of activity implementation through time-based activity management.

Evaluation is the responsibility of the CRP Governing Bodies and Partners. Evaluation is informed by triangulating multiple sources of evidence, commissioned externally and reported to oversight committees free of conflict of interest. Results are fed back into the program cycle and learning. In addition, indicators will serve program evaluations. Indicators may change as how best to track progress under the GLDC ToC emerges.

Impact Assessment, managed within FP1-CoA1.4, will facilitate the option development process through designing and carrying out rigorous impact studies of various promising research innovations in partnership with other CRPs. These studies will require high internal validity for the research process, as well as lower external (development) validity due to their localized nature. To address this challenge in the scaling process, the performance of devised options, across the program, will be tested at larger scales and across heterogeneous conditions. GLDC will pursue more conventional impact assessment and cost effectiveness/benefit studies, as part of a concerted effort to rigorously identify what works, where, for whom, how, and at what cost. Theory-based evaluation approaches and mixed methods will maximize learning.

Adaptive Learning is the process to achieve its ambitious strategy using the results produced by the other elements and pursue behavioral change internally and externally to the system. Both the research-in-development and impact assessment will generate important evidence relevant to improving conditions in such systems, which will support the learning and scaling agenda. Work will take place with partners to influence key decision-makers to both uptake and promote options developed/tested, and create policy and institutional conditions conducive for facilitating such uptake. The overall impact will be critically assessed in how it has influenced wider policy and practice and by monitoring the wider uptake of proven options and extrapolating the corresponding impact.

High quality MEIAL needs to be balanced against other priorities to ensure that effectiveness and V4M is delivered for donor investments. The following principles establish a systematic but proportionate cost-effective MEIAL approach to identify priorities:

1. The scale of investment/potential impact;
2. Strategic imperative;
3. Delivering legal obligations;
4. Degree of risk; and,
5. Contribution to the evidence-base.

Priorities will be set out and made publicly available on the GLDC Website. The initial MEIAL Strategy and activities will be launched in the first quarter in accordance with funding confirmation and it will be developed with a participatory approach and updated annually.

GLDC will use the customizable open access MEL platform that enables the transparent documentation of implementation processes and results, and where information is easily available to stakeholders.

An important aspect of ensuring a robust and results-oriented governance and management framework is to establish an enabling environment, which incentivizes the collection and use of high quality evidence to inform decision-making during the entire cycle of research planning and implementation. A Steering Committee will have overall responsibility for monitoring the MEIAL Strategy and activities and for ensuring that lessons generated are shared, fed back and appropriately incorporated into improved decision-making. The GLDC MEIAL officer will oversight the quality assurance of plans and deliverables together with wider analytical processes undertaken across the partners.

At the heart of the Strategy is the need to enhance the overall organizational culture to proactively embrace, share and apply learning about what works and why, or why not, and use this knowledge to advance understanding, improve decision-making and increase efficiency and V4M during implementation. Capacity Development (Annex 3.3) will focus on providing people with appropriate knowledge and skills required to design and deliver new and quality approaches, but also to draw lessons and insights from the existing evidence base more effectively. A good support system is essential to building these capacities. By reinforcing the connections between MEIAL, good governance and project management, GLDC will continually seek ways to develop appropriate tools, guidance and support in a cost effective fashion. Technical support and advice will be provided by the MEIAL officer and this will be augmented by the development of a network of MEIAL champions identified across the CRP. Best practices and insights from external experts and partner organizations will be sought.

Annex 3.7 Linkages with other CRPs and site integration

CGIAR Country Coordination efforts will support cross-CRP support of national R4D strategies, including prioritization, strategic partnerships along value chains for coordinated investment and large-scale implementation in service of realizing the goals of the SRF and SDGs by 2030.

Linkages to other CRPs are critical – GLDC crops are often companions to the enterprises supported by the other AFS CRPs and so there are two-way impacts and interactions that must be considered (Table 1). Beyond cropping systems diversification and sustainable intensification, enhanced linkages between GLDC and AFS

CRPs are possible on: i) sharing of learning on cross-commodity pre-breeding and breeding tools, models and methods (through EiB); and ii) development and sharing of methods, tools and data in relation to foresight, impact assessment, gender, value chain/market analysis.

The four Global Integrating Programs offer critical inputs into GLDC, especially taking responsibility for high-level systems research on the agroecologies in which GLDC crops are grown. Likewise, GLDC will benefit from CGIAR-wide investments in the cross-cutting themes of gender and youth and capacity building and from the Coordinating Platforms on EiB and BigData.

Table 1: GLDC Combined Inter-CRP Collaboration of Benefits (Provide and Receive)

CRP	Provided Benefits	Received Benefits
LIVESTOCK	- GLDC grain and fodder for use as plant protein sources to support the movement towards reducing the reliance of aquaculture on marine ingredients. -Information on feed supply and demand scenarios. - Mitigation options for livestock-related environmental impacts at the farm scale.	-Knowledge and information related to the needs and priorities of the fish feed industry. - Access to research sites in dryland areas to assess integrated approaches to livelihood improvement - Varieties/hybrids of 'full-purpose' crops (food, feed, fodder) for testing of feed/fodder quality in animal feed trials. Genomics and genetics of genetic traits.
FTA	- Varieties/hybrids for tree-based systems. - Modelling impacts of tree-based options on livelihood outcomes and implications for scaling across landscapes.	- Tree-based options for land restoration and intensification
MAIZE	-Smallholder preferences to improve the match of technologies of intercropping systems (also receives) -socioeconomic data to parameterize crop and socio-economic models (also receives)	- foresight analysis of improved maize and legume for maximum positive impact on food security and poverty under climate change - Varietal testing and fertility management of bean and pigeonpea in maize-based systems in humid tropics.
RICE, RTB, *WHEAT*	- Innovation platforms for livelihood options Mixed flour and processing options (also receives) - Varieties/Hybrids of rotation and inter/companion crops (Also provides)	-Management practices for crops in rotations or mixed cropping in GLDC target and spillover countries. (Also provides)
A4NH	- High-yielding, varieties of pearl millet for screening for improved micronutrient content. - Characterized food systems for household typologies; nutrition perspective on diet diversification (also receives)	- Micronutrient information on/dissemination of high-yielding, adapted varieties and hybrids of pearl millet. - Expert nutrition analysis and appropriate measurement tools
CCAFS	- Farm characterization: collation of datasets; Rapid survey tools and M&E purposes; Modelling tools and analyses across scales (e.g. GLOBIOM); specific climate-related analyses. - Technologies to enhance adaptation, reduce GHGs; Data on crop-livestock production - Climate-smart crop varieties and hybrids in early development for evaluating benefits through a CSA lens.	- Priority setting for CSA: downscaled climate projections, regional climate outlook, prioritization frameworks; Support to breeding programs with relevant climate information. - Global analyses of opportunities for climate services and associated safety nets; Insurance Learning Platform. - Metrics, methods and participatory platforms (e.g. Climate Smart Villages) to evaluate emerging technologies and practices; evidence and business cases for promoting scaling out.

PIM	- Dryland-cereal and legume-related input for foresight modeling; adoption of technology and seed systems; suggested topics for political economy analysis. - Case studies of value chain analysis; findings on post-harvest loss (PHL) - Past studies on seed-sector constraints and countries; testing of novel approaches to seed delivery. - Results of work on insurance. (and receives)	- Foresight modeling tools and results; analysis of technology adoption; policies for seed performance; country-level political economy analysis. - Tools for value chain analysis, intervention testing and scaling up; methodology for measurement of PHL. - Address of cross-cutting regulatory issues inhibiting seed sector, novel approaches to seed delivery with cross-commodity relevance.
WLE	- Impact assessment to achieve sustainable intensification beyond the farm system; Socio-demographic drivers of change at scale (and receives) - Water-smart agricultural and livelihood systems; the role of agriculture water management innovations to build resilient livelihoods, nutritious food supplies and to transform poverty affected farming (and receives)	- Current status on water resources variability/accessibility to current and future scenario, decision analysis tools for trans-disciplinary impact assessment. - Enhancing water management, soil moisture and irrigation alongside agronomy and mechanization change; sustainable intensification–livestock systems, groundwater management; water flows management through modelling and existing monitoring for access and value chains. (and Provides)
Genebank Platform	- Phenotyping platforms and results; SOPs for nursery research and seed health maintenance. - Collections of novel diversity of GLDC crops; use of existing and new GLDC germplasm collections; phenotypic characterization	- Maintenance of germplasm reserves, receipt of high-quality seeds for use in breeding programs. - Maintenance of germplasm reserves and high-quality seeds for use in pre-breeding.
EiB Platform	- Feed-back on phenotyping capacities/needs and current developments; High Throughput phenotyping tools/ approaches (e.g., LeasyScan) from GLDC to enrich the GG module. - Genomics data for use in analyses pipelines such as Genomic Open Source Breeding Informatics Initiative (GOBII)	- New phenotyping tools/technologies. - Customization of tools for data analysis pipeline, and SOP for effective use of genotypic /sequencing/marker information; in knowledge on breeding design simulation, cross prediction, use of high-density genomics data for genomic selection, gene-to-phenotype models etc. (and provides)
BigData Platform	-Regional characterization of GLDC-based farming systems; current yield trends/gaps, region-specific portfolio of genetic, environmental, and management constraints - Sustainable livelihood options for GLDC-based systems - Regionally explicit options on land & water management (LWM) for enhancing the performance at farm/village-level. - Regionally explicit GLDC varieties and phenotyping platforms; characterization of GLDC seed systems (seed production units, seed quality maintenance and distribution network). - Regionally explicit collections of GLDC crops (including existing and new germplasms) and their phenotypic characterization (including potential and current phenotypic gains)	- Regional data of environmental drivers of yield (e.g. varying climate, soil and water condition); socio-economic data (e.g. market's demands and accesses, technological availability, access to financial services, extension services). Data and results generated by CRP-DS's global socio-ecological GIS research. - Data on the multi-dimensional contexts that influence farmers' adoptions, ingenious decisions, and effectiveness of management options for target and spillover countries. CRP-DS's global socio-ecological geo-informatics research. - Contexts that influence effectiveness and niches of sustainable LWM options, drivers of land degradation. - Past, current and future environmental data from regions which GLDC reports data on pre-breeding and discovered traits.

Table 2: Plans for cross CRP site integration in CGIAR target countries		
	Joint Activity	**Target Country for Collaboration**
Livestock	- Jointly develop and implement projects that have multiple commodities and disciplines. An example to emulate is that of AFRICA RISING project which although is led by IITA, it has other implementing centers which include-ICRAF, CIAT, ICRISAT, IITA, ILRI, World Vegetable Center and CIMMYT respectively. These together with various national R4D partners in the country, are demonstrating a good example of collaboration and integration. - Co-location and co-investment of research on environmental impacts and mitigation at farm scale	Ethiopia, Tanzania, India, Nigeria
FTA	- Develop a common theory of change aligned to the strategy for accelerated growth and sustainable development of Burkina Faso (SCADD), particularly the national program for the rural sector (PNSR).	Burkina Faso, Ethiopia
Maize	- Systems efforts that include soybean in maize-based systems.	Ethiopia, Tanzania, Nigeria
Rice, RTB, Wheat	- Address opportunities for sustainable intensification of the rice-based cropping systems in the country with the inclusion of a second or a third crop of pulses. This adds value both in terms of income and for nutrition. - Crop rotations involving pulses - Intensification of rice-pulse systems and hence the collaborations will be mostly with RICE.	Ethiopia, Mali, India, Uganda,
A4NH	- Characterized food systems for household typologies; nutrition perspective on diet diversification	India
CCAFS	-To examine the ending PNSR in the context of multiple socio-economic and climatic scenarios, to improve its robustness, flexibility and feasibility in the face of possible diverse futures. -- Scaling up of climate-smart technologies and practices through CSV approach in rain-fed systems of West Africa. -- Location-specific varieties with package of practices that are recognized as CSA and are incorporated into global, regional and national policies and investment packages.	Burkina Faso, Ethiopia, Mali, India, Ghana, Niger
PIM	- Contributing to the SLO targets. - Value for decisions on investment in research, value for regional and national planning for climate-preparedness - Reduced systemic barriers to seed production and delivery systems that foster quality increases and are sustainable	Ethiopia, Tanzania, India
WLE	- Contributing to the SLO targets. - Improved decision making tools for the use of water and its allocation at various scales; restoration of degraded land	Burkina Faso, Ethiopia, Tanzania, Nigeria, India

Annex 3.8 - Staffing of Management Team and Flagship Projects

Please refer to online document.

References

Please refer to online document.