

Critical Interim Research Initiative: Draft note for consideration at CGIAR SC 4

Purpose

This note provides information regarding an important interim dryland cereal and legume research opportunity to be discussed in conjunction with the SC 4's consideration of future Grain Legumes and Drylands Cereals (GLDC) CRP.

Action Requested

Three possible options are presented for the System Council to consider and discuss the best way forward.

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There is no restriction on the circulation of this document

Prepared by: Group of interested donors

Part A - Background

1. **Background:** This note provides information regarding an important interim dryland cereal and legume research opportunity to be discussed in conjunction with the SC 4's consideration of future Grain Legumes and Drylands Cereals (GLDC) CRP. At CGIAR SC 2, the System Management Board decided not to advance the GLDC CRP to the System Council. At that time, several donors expressed concern about the impacts of no funding for on-going, well-reviewed crop improvement efforts. Points raised included the inability to stop/start breeding programs, their long-term nature, and their roles as sources of international public goods that the CGIAR alone provides to developing world agriculture. Moreover, the affected crops are essential elements of food security in vulnerable regions, where they also are critical contributors to resilient production systems. The SC Chair agreed that interested donors should consult and explore the potential for an interim, gap-year support via bilateral arrangements that would ensure continuity in support of these essential CGIAR activities. An update of the progress to generate interim proposals from affected centers was provided by USAID in the SC 3 virtual meeting, and in several subsequent emails.
2. **Issues:** During the course of discussions over the last several months, the following matters have emerged that can contribute context to upcoming System Council deliberations.
 - a. **Scope:** The proposals received are considerably larger than the amounts that would have been requested in the GLDC CRP, which only requested \$2.7 million for breeding and trait identification across 8 crops. The difference reflected the fact that the centers were urged to provide proposals that realistically met the critical needs of the breeding program and some essential related activities in agronomy, entomology, pathology and IPM.
 - b. **Separation:** Initial discussions among donors indicated that several could consider some, but not all, of the various pieces that would have been included in the CRP. Differential donor preference reflected, for example, varying priorities among regions or target environments. Thus, four separate proposals were prepared: Semi-Arid Tropics Crops (ICRISAT); Beans (CIAT); African legumes (IITA); and Barley (ICARDA). In soliciting four separate proposals, no assumption was made regarding future arrangements of CGIAR support. The program and budget documents (attached) are for one-year, interim activities.
 - c. **Funding vehicle:** As noted above, the SC Chair indicated that bilateral arrangements could be used when the interim approach was initially discussed in Mexico City. During the course of discussions since then with potential donors, it has become clear that some cannot consider funding via Window 3 or another bilateral mechanism, while other donors relied on the approval of a CRP in order to commit aligned funding in a bilateral arrangement. Still other donors indicated that the issue was one that the System had created and thus a System-led solution was needed, in other words a response that was somehow sanctioned by the System.
3. A possible solution that would permit more funders to join an interim collective effort on legumes and drylands cereals could be a one-time, special case earmarking of Window 1 contributions. There is some precedent for earmarking when approved by the Fund Council

during the earlier phase of the reform. For example, in order to respond to urgent needs using atypical means, the FC had previously agreed that donors could earmark Window 1 funds for impact assessment, gender programming and possibly other non-CRP activities. These were clearly labeled as one-off opportunities associated with a specific program objectives, not a wholesale invitation to label Window 1 contributions.

Part B – Options for Consideration

4. **Options for Consideration:** What was clear from recent consultations with Donors to the CGIAR was that the research on these crops is critically important and simply leaving a gap in funding was not a desired outcome. What was less clear was the way this need could be met in a temporary way, but one that also promoted collective action. Key aspects of the above analysis were shared with the office of the Chair of the CGIAR as well as the leadership team in the System Management Office. Based on initial, informal feedback, USAID attempted to capture both potential benefits but also concerns under various approaches. Three possible options are presented below for the System Council to consider and discuss the best way forward. For each one there are both benefits and weaknesses that we have tried to identify; you may see additional issues when reviewing them.

- I. Expanded interim proposals (4 proposals as Annexes) funded with a combination of earmarked, *additional* Window 1 funding from interested donors, possibly in combination with other donors via Window 3 or bilateral (non-CGIAR Fund) arrangements.

Pros:

- System-level solution to a system created problem sends positive signal regarding support of critical, on-going CGIAR programs.
- More fully funds realistic costs of research programs.
- Allows the largest number of donors to support a critical part of the portfolio that is currently missing.
- Allows for development of joint reporting.
- Provides an opportunity to grow shared funding via Window 1 that fully responds to donor demand/prioritization.

Cons:

- Transitional aspects relating to forward planning around an eventual replacement CRP program and budget are not clear.
- Rules and regulations regarding Window 1 donors may not be fully reflected.
- Proposals have not had a full review by ISPC review, and no commentary is available.

- Role of the SMB with respect to proposing and monitoring a special initiative is not clear.

II. Potential contributions through additional, earmarked Window 1 contributions would be limited to the scope and budgets associated with flagship 4 and 5 from GLDC, which were highly rated by the ISPC in the earlier proposal.

Pros:

- System-level solution to a system created problem sends positive signal regarding support of critical, on-going CGIAR programs.
- Already reviewed by ISPC, albeit as part of a previous draft CRP.
- Allows some Window 1 donors to designate additional fund for support of a shared effort to support the Critical Interim Research Initiative.
- Allows for the development of joint reporting, although may need to encompass Window 3 or bilateral contributions not able to fit under \$2.7 million cap.

Cons:

- Window 1/2 budget in GLDC proposal is inadequate to fully fund basic functions of breeding on crops in question.
- Limits the ability for donors to provide additional support beyond \$2.7 million through Window 1.

III. No earmarking of additional, Window 1 funding; any action taken informally and solely among interested donors using bilateral arrangements (possibly including Window 3).

Pros:

- No action needed by System Council.
- Adheres more closely to established norms.

Cons:

- Lack of visibility: does not support collective action or a coordinated approach in response to a problem.
- Limits the ability of some donors to participate due to their policies regarding Windows 1, 2 and 3.
- Result in less funding overall in the shared CGIAR research agenda (W1/2).
- Opportunities for shared reporting less.

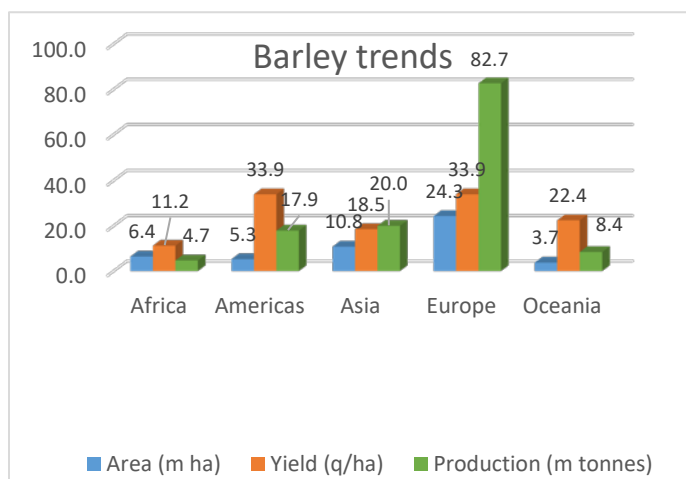
Proposal

Barley germplasm enhancement for dry regions with special emphasis on Africa and Asia

Rationale

Barley is a key climate change crop in West Asia and North Africa (WANA), East Africa (EA) and South Asia (SA) due to its drought, heat and cold tolerance. Its ability to grow under marginal agronomic conditions (limited water and fertilizer), provide nutritious food to communities along with feed and forage for livestock that inhabit these ecosystems clearly demonstrates its importance in ensuring food and nutritional security in drylands. In addition, the crop provides an opportunity for income generation through the production of malting barley.

Barley production in **Ethiopia** (EA) has increased from 1.0 m tons (2005) to 1.9 m tons (2014) registering a 10.0 % annual increase predominantly driven by increased demand for malting types, which is still far short of demand (Kifle, 2016). Similarly, barley imports by **Morocco** are expected to be 0.7 million tons in 2016 (USDA 2016), mainly for food and feed. **Tunisia's** barley consumption is estimated at about 850,000 tons per year and the barley imports are estimated to rise to 0.70 million tons (2016-17) over 0.28 million tons (2011-12) (USDA 2016). Similarly, in **Egypt** the estimated barley imports are about 100,000 tons (2016) over 21,000 tons in 2011 (USDA 2016). This indicates that imports of barley is increasing significantly in most of the barley growing countries in Africa. Demand for the grain has increased by approximately 4% p.a. in **China** (brewing) and **Saudi Arabia** (livestock feed) over the past five years and is set to continue this trend. The grain and dry straw is fed to livestock, while grazing of the crop is common in WANA and other regions. The barley breeding program of ICARDA focuses on producing lines that meet a diversity of uses on more than 16 million ha predominantly in the non-tropical drylands. Further, improved germplasm as well as wild relatives and landraces from ICARDA are used for varietal release in several developed countries that include Europe, Australia, South America, Canada, and Mexico for utilization in breeding programs for specific traits. The development and release of this germplasm by the national systems is critical in improving yields and ensuring resilience to biotic and abiotic stress, thereby contributing to IPGs. The overall objective of the ICARDA barley breeding program is to ensure the continuous development and supply of improved germplasm with enhanced grain/biomass yield and quality attributes that meet market requirements and introgression of resistance genes to major abiotic and biotic constraints.



Problem statement

In general barley productivity is low as it is predominantly a rainfed crop in these regions with zero to low inputs and is produced predominantly by resource poor smallholder farmers. Yields are often less than 1.5 t ha⁻¹ in major barley growing countries. A further major constraint is the prevalence of a number of diseases and pests that attack the crop. **Barley grain is used in the production of barley bread, couscous, and local homemade beverages and soups within these communities.** Recent food trends and malting uses in selected countries indicate an increase in demand for barley grain. Countries that include Morocco, Tunisia, Egypt, Algeria and Ethiopia cannot meet local demand and have resorted to importing barley for human consumption, feed and malting purposes. The high biomass production and rapid regeneration after

grazing are unique attributes of the crop that make it well adapted as a dual purpose crop. The grain is high in beta glucan content, which is known for its hypo-cholestromic effect, and therefore can be promoted as a **health food**. Further, the grain is high in micronutrients (Fe and Zn), and barley is an important component in the diets of women and children in Africa.

As we move into an era of greater climate variability and change, barley is unique amongst cereal crops. It can be cultivated over a wide range of altitudes from sea level to over 3,000 m and is produced under extremely low rainfall (<150 mm) regimes. The crop can best be described as **'climate resilient'** and will be a critical component of crop production systems in adapting to climate change. There is a need to build resilience into current elite material that is well adapted to extreme **drought and cold during the vegetative and reproductive growth stages**; and resistance to diseases and pests through the ingress of genes from wild progenitors that are held in trust by ICARDA.

Project Objectives

The interim funding and support will enable ICARDA and NARS partners the opportunity to continue strengthening their barley breeding programs to ensure the continuous supply of improved genetic material. This initiative will complement on-going W3/bilateral projects that cover the full spectrum of the agri-food system associated with barley based cropping systems (Annex 1)

The overarching goal is to generate enhanced multi-purpose barley germplasm to meet feed, food, fodder and malting demands in the dry regions of Africa and Asia. This will enhance the resilience of communities in the region to current and future climate change impacts, improve their livelihoods, and help them adapt to reduced rainfall patterns while producing food for human and animal consumption. The specific objectives are:

1. Trait discovery in barley genetic resources with use of precision phenotyping and hot spot screening at ICARDA's regional platforms and the NARS networks for **biotic and abiotic stresses**.
2. Pre-breeding using **landraces and wild progenitors** for abiotic and biotic stresses.
3. Combined **classical and molecular breeding** tools to allow rapid identification and promotion of germplasm (better adapted, highly productive and with enhanced quality) that would ensure continuous development of varieties by NARS in respective countries/regions.
4. Germplasm enhancement for **dual purposes in barley** with an emphasis on **straw/forage quality**.
5. Integration of faster breeding approaches that include **shuttle breeding** and **doubled haploid (DH) technologies/speed breeding** for advancing genetic gain.
6. **Markers identification and validation** through genome wide association mapping studies for biotic stresses and quality traits of interest.
7. Integrate within breeding programs the notion of **integrated disease and pest management (IPM)** for host resistance with use of biotechnology tools.
8. **Strengthen capacity of national collaborators/young scientists** in germplasm enhancement and evaluation programs for the establishment of widely adapted germplasm with specific traits.

Project Implementation

A: Pre-breeding and Trait discovery

Pre-breeding with wild relatives through crossing (*H. spontaneum*) or embryo rescue (*H. bulbosum*) for introgression of adaptation to heat, drought and cold tolerance is still underutilized. Landraces with diverse resistance sources to rusts, net and spot blotches, scald and powdery mildew will be utilized in pre-breeding and breeding initiatives. Advanced technologies that include embryo rescue, doubled haploid technology, and marker assisted selection (MAS) have an important role to play, although these technologies have been demonstrated but not applied to a large extent in public breeding programs.

B: Breeding

Utilizing products of pre-breeding and trait discovery of desirable traits in combination with modern genomics and breeding tools to improve breeding efficiency and genetic gain is envisaged. There exists significant potential for improving genetic gains in barley even under challenging environments with low-input conditions through the implementation of systematic breeding, tapping into available natural diversity and the use of modern tools and technologies. Shuttle and speed breeding are becoming common practice in some advanced breeding programs. However, the majority of NARS still do not have facilities/capabilities to benefit from these advances, which will be a high priority for ICARDA to establish the system for rapid seed movement and the use of its platforms.

Targets traits

1. Enhanced resilience to climate change is one of the top priorities of barley breeding programs as target regions are highly exposed to the negative impacts of climate change such as drought and rising temperatures, with devastating effects on food, feed and fodder production.
2. Micronutrient dense cultivars development as two thirds of the world's population is at risk of deficiency in iron (Fe) and zinc (Zn). Large genetic variations have been identified for **Fe** and **Zn** as well as **beta glucan** contents in the germplasm of barley, which offer opportunities for the development of varieties with substantially higher contents of these traits.
3. Identify and introgress novel sources of abiotic (drought and heat tolerance) and biotic (foliar blights, rusts, scald, powdery mildew, BYDV) from the evaluation of germplasm, landraces and wild progenitors.
4. Identify molecular markers/candidate genes associated with desired traits utilizing high throughput genotyping, precise phenotyping, genomic selection, and rapid homozygosity through a network of partners and collaborators. ICARDA has developed association mapping (AM) populations with detailed phenotyping in progress. The genotyping with 50K SNPs chips is proposed for 2017 with the assistance of USDA Fargo, while for other populations this is planned to be done with JH Institute, Scotland and Traits Genetics, Germany.
5. Build capacity of the NARS partners in integrated crop breeding and germplasm selection as well as genotyping data analysis.

We will establish close connections and benefit from the Genetic Gains platform, which is fully devoted to enabling technologies that address (a) (molecular) genetic, biochemical or physiological methodologies for high-throughput trait screening in the laboratory, controlled environments and the field, and (b) molecular and tissue-culture tools for accelerated genetic gain including a functional genomics platform for reverse genetics to establish gene-to-phenotype relationships.

C: Disease/ pests resistance:

Diseases have been prioritized based on their impact on yield, extent of disease prevalence, resistance sources available and regional demands. “Focused Identification of Germplasm Strategy” (FIGS) will be used for the identification of the diverse sources of resistance. Pathogen diversity studies will be organized through surveys and surveillance activities and pathogenicity tests will be conducted to establish a base for diverse trait/resistance discovery studies in target regions as well as to continuously monitor change or evolution of the new virulence(s). Molecular markers/candidate genes will be identified that are associated with disease resistance. Insect pests of barley include the aphid and midge. The aphids are the major insect-pests of barley, which also spread the viral disease like BYDV. Screening of land races and wild relatives will be undertaken for effective resistance.

D: Quality traits:

Barley is highly valued for its nutrient-dense nature as well as malting quality for industrial use. The key nutritional quality traits to be addressed under this program will include **protein and micronutrient**

contents (iron, zinc) and beta glucan in grain. Micro malting analysis will be undertaken at ICARDA's laboratory for major grain and malt quality traits for acceptance by industry.

E: Addressing Climate Change:

The focus will be on traits that are directly or indirectly related to climate change, in particular tolerance to periodic drought, pest and disease resistance, and tolerance to higher temperatures. Significant genetic diversity for stress tolerance remains yet to be tapped that will enhance the resilience of vulnerable producers to climate and price shocks, and reduce seasonal food and income fluctuations. Evaluation of the newly developed germplasm will be undertaken in diverse conditions at ICARDA/NARS locations in Morocco, Lebanon, Algeria, Tunisia, Ethiopia, and India for extreme environments.

F: Gender

A gender lens is critical at the initiation of a trait development and breeding pipeline, to ensure that traits that are of interest to women or that represent opportunities for youth, are included from the start. This will be fostered by:

1. Feedback from work in Phase-I Dryland Cereals on traits that are important to women and children will be used to prioritize these traits in specific research activities.
2. Traits that include protein, beta glucan content, and high Fe and Zn that will result in improved nutritional value of barley, will be prioritized.

G: Capacity Development

ICARDA barley program will focus on both human and infrastructure capacity development to train future scientists, who can support research on barley in the NARS networks. The proposed project will help to achieve the precise phenotyping with the trained staff. A low-cost and high-throughput genotyping with ARIs collaboration will ensure that marker assisted breeding is available for barley.

We plan to strengthen the barley quality analyses in the ICARDA laboratory in Morocco. The food science and nutrition expertise will be created with training from ARIs to develop and calibrate quality analyses that can be scaled up for high throughput and efficiency. Similarly, it will also address the malting quality needs for sub Saharan Africa and South Asia in addition to Morocco. Workshops, short training courses, studentships, exchange visits, and net-working with NARS will be set at a high priority to train future agri-technocrats.

Project Outputs and outcome:

1. The proposed research on barley at ICARDA will ensure an increase in the number of pre-breeding lines which are currently in short supply at ICARDA as well as in NARS breeding programs. Useful genetic diversity emanating from the project will lead to further genetic gain in barley. The enhanced germplasm resulting from ICARDA barley breeding efforts will pave the way for the development/ release of cultivars by NARS with enhanced resistance to abiotic and biotic stresses, nutritional and industrial traits in addition to higher yield. The novel and durable resistance to biotic stresses will contribute to an increased life span of cultivars in the regions where chemical control is negligible.
2. The work on quality improvement of grain and straw is likely to satisfy the **hidden hunger of micronutrients** (Fe and Zn) and **beta glucan for humans and higher feed value for livestock**. Grazing options with better quality forage with higher biomass will be key for small ruminants in the drylands of WANA, Sub-Saharan Africa and South Asia.
3. Emphasis on the enhancement of breeding to accelerate the rate of genetic gains, through MAS and genomics-assisted breeding, and the use of technologies that include **DH** and **shuttle/speed breeding** will further help in the improvement of ICARDA capacity as well as NARS for barley improvement.

4. In dryland environments sources of carbon are limited and competition exists between soil improvement and animal/human nutrition. An increase in biomass production of barley will benefit both livestock and human food demand as well as provide crop cover for soil improvement.
5. Capacity development of young scientists in the region shall enable them to take up/ implement a collaborative barley research program with ICARDA for regional benefits. This ensures effective networking for barley germplasm evaluation/ phenotyping for abiotic/ biotic traits of regional or global importance and harnessing the progress made at NARS level. This will contribute to the increased availability, improved nutrition and increased incomes of smallholders in Africa and Asia.

Activity Milestones & Indicators

The activities, milestones and their success indicators for the proposed research plan in the barley improvement program at ICARDA for 2107 are indicated below. Note that ICARDA sees this a long-term Program that needs to be supported beyond 2018.

Activities	Milestones 2017	Indicators
A: Pre-breeding and Trait discovery	<ul style="list-style-type: none"> • Identification of sources for abiotic and biotic stresses. • Incorporation of the identified traits through hybridization in elite genotypes for use as parental lines in breeding program. 	<ul style="list-style-type: none"> • More than 1000 of accessions of land races, advanced lines and wild relatives screened under multi environment evaluation. • More than 100 new crosses made with the identified sources. • Four DH populations developed through non-conventional approach.
B: Breeding	<ul style="list-style-type: none"> • Identification of enhanced germplasm for low input rainfed and optimum management in spring and winter barley. • Phenotyping and genotyping of the association mapping panel. • Identification and use of molecular markers for important traits. 	<ul style="list-style-type: none"> • More than 500 elite spring and winter barley genotypes provided for distribution to more than 50 NARS partners through eight ICARDA International Nurseries with approximately 400 sets globally. • Need based germplasm sharing for specific traits of regional importance. • Generation and evaluation of more than 20,000 barley genotypes at ICARDA platforms and NARS stations in Morocco, Lebanon, Turkey, India and Ethiopia. • Phenotyping of the mapping population at multi-locations and screening for abiotic (drought, and salinity) and biotic (stripe and leaf rust, net blotch, Powdery mildew and BYDV) traits completed. • Genotyping with 50 K SNP array completed for AM17 (320 accessions).
C: Disease/ pests resistance:	<ul style="list-style-type: none"> • Screening for barley diseases and pests at hot spot locations; artificial inoculations. • Seedling screening under controlled environments for important diseases. 	<ul style="list-style-type: none"> • More than 1000 accessions screened for diseases from breeding material generated by the breeding program. • Focused Identification of Germplasm Strategy (FIGS) subsets screened for net blotch, powdery mildew and leaf rust and new sources of resistance identified from landraces and wild relatives. • Identified sources from the aforementioned established in field screening assessment to verify under controlled seedling/ adult stage screening.
D: Quality traits:	<ul style="list-style-type: none"> • Evaluation of germplasm for grain, and malting quality traits. • Evaluation of forage quality. 	<ul style="list-style-type: none"> • More than 500 grain samples analyzed for physical attributes and more than 200 for micro malting. These include quality attributes include malt extract value, amylases activity, wort viscosity, Kolbach index, filtration rate, FAN and beta glucan content. • 600 genotypes analyzed for forage quality.
E: Addressing Climate Change:	<ul style="list-style-type: none"> • Evaluation of germplasm from different sources at a number of locations (Climbar & Arimnet projects) • Conduct drought and heat trials with ICARDA material in India, Morocco, Turkey and Lebanon 	<ul style="list-style-type: none"> • Generation of the agronomic and disease data/ information from Morocco environments placed in an open access data repository on the ICARDA MEL and shared with respective projects leaders. • New sources of wide adaption under dry and/or hot environments identified and communicated to collaborating NARS.
F: Gender	<ul style="list-style-type: none"> • Identification of gender specific traits in barley genotypes. 	<ul style="list-style-type: none"> • Genotypes with possible nutritional (higher Fe, Zn and beta glucan) and plant (non-ear breaking) traits identified.
G: Capacity Development	<ul style="list-style-type: none"> • NARS scientists participation in ICARDA training/ seminars/ on field interactions arranged. 	<ul style="list-style-type: none"> • At least one short training course in barley improvement organized / trainees involved.

Proposed budget

The tentative budget estimates to undertake the project for one-year (2017) at ICARDA is presented below. The exact budget details have been worked out based on approximate rates applicable at ICARDA for staff, overheads and other charges as applicable.

Budget Items	Man days	Rate (US\$)	2017
1. Personnel <i>(please provide details and justifications in the budget notes)</i>			
Barley Breeder	220	700	154,000
Associate Barley Breeder	220	500	110,000
Associate Pathologist	220	500	110,000
Post Doc (Breeding/ Biotechnology)	220	280	61,600
Science Quality Assurance charges	880	150	132,000
Hosting charges	880	30	26,400
IT charges	880	18	15,840
Sub Total (1)			609,840
2. Supplies & Services <i>(please provide details and justifications in the budget notes)</i>			
Operational	NA	NA	250,000
Contractual staff/Research Assistants (3)			90,000
Sub Total (2)			340,000
3. Equipment			
Need based equipment/ chemicals			75,000
4. Travel & Meetings			
Travel	NA	NA	50,000
5. Other Expenses <i>(Specify below)</i>			
land charges (Morocco, Lebanon, and other places) (20 ha @ 5000/ha)			100,000
6. Capacity development (short term training 15 candidates for 10 days)			50,000
TOTAL Direct Costs (1to 5)			1,224,840
Overhead charges @12.16%			148,941
Subtotal			1,373,781
CSP 2 %			27,476
Grand Total			1,401,256

Annex 1: On-going projects and projects in the past funded through USAID related to barley.

Table 1 presents all on-going W3/bilateral projects where the focus is entirely on barley. In addition, Table 2 presents on-going W3/bilateral projects where barley is a component of a project with other crops/livestock, production system and seed delivery are key aspects of the research for development.

Table 1: On-going W3/bilateral projects focusing on barley only.

Description	Donor	Donor short name	USD Amount
Development of improved varieties of malting barley	Impulsora Agricola, S.A. de C.V.	IASA	1,800,000.00
Barley Improvement for High Yielding Quality Malt, Food and Feed for Various Agro-ecologies.	Indian Council for Agricultural Research	ICAR	1,831,534.00
Mining the ICARDA Barley Germplasm Collection for Biotic and Abiotic Priority Traits.	Grain Research and Development Corporation	GRDC	628,490.00
Collaborative Program for barley component and coordination.	Agricultural Research Center - Egypt	ARC	382,013.00
ICARDA-CAAS barley improvement for China	Government of China	China	364,401.00
Genetics of Heat Tolerance in Barley	King Abdullah University of Science and Technology	KAUST	13,836.00
CRP 3.6-DC "Fe, Zn, and β -Glucan dense barley for women and children"	International Crops Research Institute for the Semi-Arid Tropics	ICRISAT	4,962,000.00

Table 2: On-going W3/bilateral projects that cover a range of crops that include barley.

Description	Donor	Donor short name	USD Amount
Identify new improved varieties of cereals (wheat, barley, maize and rice), vegetables, legumes (chickpea, lentil, mungbean, soybean), oil-seed (sunflower, sesame, safflower) and fodder (alfalfa, esparsit) and other non-traditional crop	Government of Russia	Russia	2,280,000.00
Malt Barley and Faba Bean Ethiopia	United States Agency for International Development	USAID	2,000,000.00
In vitro culture and genomics-assisted fast track improvement of local landraces of wheat and barley in Morocco, Tunisia and Algeria for enhancing food security and adaptation to climate change	Food and Agriculture Organization of the United Nations	FAO	496,502.00
Trait discovery and deployment through mainstreaming the wild gene pool in barley and grass pea breeding programs to adapt to climate change.	Global Crop Diversity Trust	GCDT	787,322.00
Sustainability and Operation of the Regional Research Centers in a Number of Arab Countries	Arab Fund for Economic and Social Development	AFESD	3,363,135.00
Increasing the Productivity of Cereal-based Systems to Enhance Food Security in Iran	Government of Iran	Iran	10,486,183.00

Proposal

Sustaining modern crop improvement programs for priority semi-arid grain legume and dryland cereal crops

1. Rationale and objectives

In 2017, key cereal and grain legume crops – groundnut, pigeonpea, lentil, chickpea, sorghum, pearl and finger millets – are not part of the CGIAR Research Programs. These crops are critical in the semi-arid, dryland ecologies of developing countries as they are resilient and nutritious. They are used for local consumption and as traded commodities, or as feed and fodder for livestock. Further, several of these crops benefit soil fertility and are considered to be ‘climate smart’. These regions, and the women, men and youth who depend on the local agriculture, are a significant target for the CGIAR and its partners to deliver on the Strategic Result Framework (SRF) objectives of poverty reduction, food and nutritional security and resilient farming systems.

This proposal is for interim support for sustaining critical research not included in the 2017 CRP portfolio. The investment will ensure ongoing generation of farmer- and consumer-preferred varieties that provide solutions for (i) improving productivity and profitability in high-risk dryland agriculture, (ii) unlocking value (nutrition, income and employment) of these dryland cereals and legumes for the growing rural and urban populations; and (iii) secure farming systems against endemic and emergent challenges such as the climate-change effects of drought, heat, and associated biotic stresses, while underpinning the strategic positioning of production systems to secure livelihoods and economic development.

Interim funding is requested to support priority CGIAR research programs delivering International Public Goods (IPGs) through modern crop improvement research for the aforementioned cereal and grain legume crops. It leverages Phase I CRP and bilateral investments, especially focusing on gap areas and strategic crop improvement activities that need to continue in the interim period. The key objectives for this funding are to:

- 1) Advance the modernization of CGIAR and NARS breeding programs to improve efficiency and performance;
- 2) Sustain the trait discovery and validation pipeline comprised of modern genomic tools and genetic stocks offering biotic and abiotic stress tolerance for priority cereal and grain legume crops;
- 3) Build the network and capacity of crop improvement programs in Sub-Saharan Africa, Central and West Asia and North Africa and South Asia to ensure complementarity between CGIAR and NARS programs; and
- 4) Form the basis of a successful proposal for a grain legume and dryland cereal CRP to be included in the 2018 CGIAR Research Portfolio.

This proposal is led by ICRISAT, with partners involving ICARDA and key NARS collaborators.

2. Investment priorities based on value of production of target crops

Seven crops are targeted for investment priorities based on their relative economic importance in 2014 in 14 priority countries in different regions of production (Table 1). These crops have also been included in food nutrition and income security programs of many target countries and are supported by among others, CAADP country investment plans, country-led development partner, and Country Development/Assistance Cooperation strategies.

An analysis was conducted by Dr Tom Walker as part of a prioritization process for the GLDC proposal for value of production from 14 priority countries. This indicated the annual value of production for the seven crops of US\$42B. A further US\$6.4B production value annually was identified from GLDC spill-over countries. As a reference, the value of production of common bean, cowpea and soybean combined in the priority countries was only US\$7.2B (US\$3.7B, US\$3.0B and US\$0.6B respectively). The priority countries are Burkina Faso, Ethiopia, Kenya, Malawi, Mali, Morocco, Mozambique, Niger, Nigeria, Senegal, Sudan, Tanzania, Uganda and India.

Table1	Value of Production (Million USD)				
Crops	CWANA¹	ESA	SA	WCA	Grand Total
Chickpea	367	453	7,293	0	8,112
Finger Millet	3	580	768	0	1,350
Groundnut	4	2,320	4,734	4,039	11,097
Lentil	297	110	1,048	0	1,455
Pearl Millet	0	609	3,403	3,225	7,237
Pigeonpea	0	720	2,903	0	3,624
Sorghum	2	3,982	1,833	3,427	9,245
Grand Total	673	8,774	21,982	10,691	42,120
<i>In comparison</i>					
Cowpea	-	230	-	2,762	2,992
Soybean	-	190	-	368	558
Common bean	-	3,585	-	88	3,673

¹ CWANA: Central & West Asia, North Africa; ESA = East & Southern Africa; SA = South Asia; WCA = West & Central Africa

3. Strategies

Interim funding will enable ICRISAT, ICARDA and NARS partners to support and strengthen breeding pipelines through the modernization of crop improvement programs covering breeding, pathology, entomology, physiology, genomics and data science disciplines. The 16 ICRISAT and 2 ICARDA breeding programs will be managed under the Breeding Management System (BMS) and, based on recent Breeding Program Analysis Tool (BPAT) recommendations, it is proposed to

1. Accelerate modernization of CGIAR breeding programs through experimental field management, cloud computing based data analysis, mechanization, precision irrigation and better experimental design.
2. Integrate High-Throughput Genotyping (HTPG) facilities to support integration of multiple traits into new varieties and increase the selection intensity to accelerate our progress in realized genetic gains.
3. Conduct domain prescription for the set of target locations and future production environments where new varieties and hybrids developed will be grown (target population environments) by clarifying the genetics, agronomic practices, or their combination to improve system productivity and resilience in the face of changing climate and farming systems.
4. Complete validation of markers from past investments (GCP, TL1&2 and HOPE and several bilateral projects) and discovery of markers for key traits for climate smart trait production in forward breeding programs.
5. Coordinate and standardize multi-national trial networks to ensure consistency and help foster and strengthen communities of practice.
6. Expand options for discovery of new traits including transgenic and superior trait-alleles for selected crops. Emphasis will be placed on groundnut (aflatoxin, drought), chickpea (Bt) and pigeonpea (Bt).
7. Build capacity of NARS partners to design, manage and use modern breeding approaches to improve breeding program efficiency. Selected areas include: use of standardized trait ontologies, tablet data capture, optimal experimental designs and modern statistical (data) analysis tools, field management to increase heritability and selection for stress environments.

4. Proposed activities

Two Flagship Programs (FPs) within the submitted CRP-GLDC proposal were highly rated in the donor review of the CRP – ‘Pre-breeding and Trait Discovery’ (FP5) and ‘Variety and Hybrid Development’ (FP4). Hence, this proposal for interim funding is aligned with these two Flagships, their goals and Cluster of Activities (CoAs). While FP activities covered the full CRP funding program, this interim proposal will support those essential activities that require additional support beyond available W3/bilateral funding. The tables below specify these activities within the context of the full research programs.

4.1 Capacity strengthening through BPAT

Breeding Program Analysis Tool (BPAT) reviews of crop improvement programs in India and Africa confirm a set of priority recommendations for CGIAR breeding in support of national programs. These recommendations

must form the basis for future investment in crop improvement programs servicing semi-arid crop improvement programs. These recommendations are:

- i. Migration of Breeding Management System (BMS) to manage, analyze and apply data across locations to inform breeding decisions and support germplasm exchange. ICRISAT is aggressively migrating all its breeding programs to this platform to be complete by mid-2017. While ICARDA has, to date, migrated its lentil breeding program to BMS, the migration of the chickpea program to BMS will be completed in 2017.
- ii. Automation of data capture processes through hand-held field recorders, mechanization and Laboratory Information Management Systems (LIMS). ICRISAT will use these funds for breeding programs to support this migration and that of key site national partners.
- iii. Application of HTPG to integrate the use of diagnostic markers for validated markers to support trait integration into crop improvement programs within and outside the CGIAR as an IPG. This activity is partly supported by BMGF.
- iv. Increase the number of crosses and population per cross significantly; and speed up the generation advance process to enhance genetic gain.
- v. Increase multi-location testing for both early generation testing at key sites across African and South Asia. Capital investments will be required for improving field capacity through other bilateral sources.

These recommendations underpin capacity strengthening for breeding program activity management with the goal of improving efficiency in program strategy and throughput and are integral of the under-listed clusters of activities.

4.2 Pre-breeding

Pre-breeding will develop intermediate breeding materials that breeders can use further in developing new varieties. The key activities include:

Full set of activities GLDC CoA 5.1	Specific interim funding and outputs in 2017	Current Bilateral Funding (\$M)	2017 Gap Funding (\$M)
Evaluation & characterization of germplasm or wild introgression in the background of elite cultivated lines, and identification of germplasm with superior and/or novel traits.	<p>Expand genepools for resilient breeding</p> <ul style="list-style-type: none"> Identify new sources, including transgenics of resistance to <i>Helicoverpa</i> in chickpea and pigeonpea; development of IPM methods including bio-pesticides/biocontrol agents and their production to delivery. Pre-breeding for <i>striga</i> in sorghum and millets. Continue the development of BCNAM population using superior donors for drought in sorghum, into the elite background varieties of SA, ESA & WCA. Pre-breeding for earliness, <i>Stemphylium</i> blight and rust resistance, micro-nutrient contents and <i>Orobanche</i> tolerance in lentil Pre-breeding for <i>Ascochyta</i> blight, <i>Fusarium</i> wilt resistance; salinity, cold, drought and herbicide tolerance in chickpea Advancing of the NAM, TILLING and MAGIC populations developed in Kabuli chickpea Converting of new SNP markers recently identified in chickpea and lentil to marker-assisted selection <p>Trait Physiology</p> <ul style="list-style-type: none"> Complete studies on mechanisms of tolerance in chickpea and lentil to heat. Complete studies on root hyper-nodulation in chickpea <p>Exploring heterosis</p> <ul style="list-style-type: none"> Identify new sources and candidate genes for Cytoplasmic Male Sterility in pigeonpea, pearl millet and sorghum <p>Outputs: 1) Cereals (sorghum, pearl millet, finger millet): >600 accessions and breeding lines characterized for tolerance to drought, <i>Striga</i>, disease & nutrient use efficiency in Africa and Asia. 2) legumes (chickpea, groundnut, pigeonpea, lentil): >700 accessions and breeding lines characterized for resistance and tolerance to drought, heat, low aflatoxin, <i>Fusarium</i> wilt, rust, <i>Ascochyta</i>, <i>Stemphylium</i> blight,</p>	2.21	ICRISAT 0.50 ICARDA 0.10

	<i>Orobanche</i> , <i>Botrytis</i> grey mould, pod borers; 3) Leasyscan method standardized for heat and drought tolerance screens in 1 legume and 1 cereal; 4) Knowledge on mechanism of heat tolerance and its dissection from drought tolerance understood.		
Use of hybridization schemes to transfer desired traits from unadapted germplasm into the breeding materials, such as the reconstitution of the <i>Arachis hypogea</i> genome from its putative wild ancestors, and use of existing synthetic amphidiploids to develop backcross populations in the background of elite cultivars for Africa and Asia.	New breeding line development <ul style="list-style-type: none"> • Nutrient dense legumes and cereal breeding lines • Hybrid parent development • New population development for biotic stresses from wide hybridization & introgression lines for cereals & legumes • Increase the number of inter-specific crosses in chickpea Outputs: 1) Over 10 hybrid parents (restorer, maintainer) lines developed for each crop (pearl millet, sorghum & pigeonpea) based on early generation lines under testing; 2) pre-breeding lines with novel genes (earliness, tolerance to <i>Stemphylium</i> blight, rust, herbicide, <i>Orobanche</i> and heat) available for mainstream breeding.	1.10	ICRISAT 0.10 ICARDA 0.10
Development of intermediate breeding materials with a broad genetic base and desired traits and making these available to breeders of CGIAR centres and NARS globally for the development of farmer- and market-preferred varieties/hybrids.	New population development <ul style="list-style-type: none"> • Develop new populations with native and/or induced variations with prioritized traits for national, regional and global testing by breeders CGIAR and NARS • Development of new populations by using the new sources of resistance / tolerance recently identified in chickpea Outputs: 1) NAM, MAGIC, BCNAM and other populations advanced in sorghum, pearl millet, chickpea, groundnut and pigeonpea; 2) marker-based introgression of priority traits in elite lines of chickpea (drought), groundnut (high oleic), lentil (wilt), sorghum (shoot fly, drought) & pearl millet (DM, high Fe/Zn).	2.20	ICRISAT 0.35 ICARDA 0.10

4.3 Trait discovery & Enabling Technologies

Trait discovery will focus on traits prioritized, on top of yield enhancement, as common traits for crops and regions specified as:

Full set of activities GLDC CoA 5.2	Specific interim funding and outputs in 2017	Current Bilateral Funding (\$M)	2017 Gap Funding (\$M)
Chickpea			
Global: Drought and heat tolerance, <i>Helicoverpa</i> resistance (transgenic), protein and micronutrient (Fe and Zn) content Regional: <i>Ascochyta</i> blight resistance (ESA, CWANA), dry root rot resistance (SA), herbicide tolerance (SA, CWANA); leaf miner tolerance (CWANA), fusarium wilt tolerance (CWANA); salinity tolerance (CWANA)	New markers, their validation and new sources <ul style="list-style-type: none"> • Develop and validate the markers for drought, salinity, heat tolerance, biotic stress and nutritional traits (IPG) • Converting the markers already published in 2015-2016 for MAS application in chickpea breeding program • Fine mapping and QTL analysis for <i>Ascochyta</i> blight using SNP markers • Fine mapping of the <i>Fusarium</i> wilt resistant gene • Association mapping of the FIGS sub-sets using DArT and DArTseq for salinity tolerance • Establishment of protocol for applying of CRISPR/Cas9 in chickpea • Mapping of five RIL populations for drought, cold, salinity tolerance AB and FW resistance • Characterize & validate Bt transgenic events for efficacy (Regional) • Initiate activities for rapid achievement of homozygosity Outputs: 1) Validated markers for drought tolerance, heat tolerance; 2) three or more generations of chickpea per year achieved using MAS; 3) clone and characterize CENH3 homolog; 4) molecular characterization and controlled environment testing completed for stacked Bt events of chickpea; 5) protocol for CRISPR/Cas9 in chickpea developed; 6) maps for <i>Ascochyta</i> blight, <i>Fusarium</i> wilt resistant gene, and FIGS sub-sets for salinity tolerance.	1.20	ICRISAT 0.29 ICARDA 0.10

Groundnut			
Global: Drought tolerance, stem rot resistance, oil content, kernel micronutrient (Fe and Zn) content, Aflatoxin resistance Regional: Resistance to rosette (WCA, ESA), early leaf spot (ELS) resistance (WCA, SA), fresh seed dormancy (SA)	<ul style="list-style-type: none"> Develop and validate genes/markers for drought, rosette resistance and low aflatoxin contamination (IPG) Explore genomics and transgenics for low aflatoxin contamination (IPG) Evaluate germplasm for new sources of resistance to biotic stresses Deploy MABC for oil content and foliar disease resistance for improving elite lines for developing superior lines with higher yield under target environments (Regional). Outputs: 1) Validated markers for drought tolerance and rosette resistance traits; 2) aflatoxin resistant lines validated & characterized using RNAi & other molecular tools; 3) introgression elite lines advanced with high oleic trait.	1.12	ICRISAT 0.25
Pigeonpea			
Global: Drought tolerance, <i>Helicoverpa</i> resistance (transgenics), protein and micronutrient (Fe and Zn) content, high milling recovery Regional: Resistance to sterility mosaic disease (SA)	<ul style="list-style-type: none"> Develop and validate markers for resistance to <i>Fusarium</i> wilt and SMD and protein content (IPG) Characterize and validate Bt events for <i>Helicoverpa</i> resistance (Regional) Evaluate germplasm for new sources of resistance to emerging biotic & abiotic stresses (<i>Maruca</i>, phytophthora) Initiate activities for functional validation platforms (e.g. CRISPR/Cas9) for reverse genetics Outputs: 1) Validated markers available for <i>fusarium</i> wilt and sterility mosaic disease; 2) molecular characterization and controlled environment testing completed of Bt events; 3) breeding lines with multiple disease resistance identified.	0.85	ICRISAT 0.17
Pearl Millet			
Global: Drought tolerance, downy mildew resistance, Rancidity (flour shelf-life), nutritional quality (Fe, Zn) Regional: Blast resistance (SA), <i>striga</i> resistance (WCA)	<ul style="list-style-type: none"> Develop and validate markers for drought, DM and high Fe/Zn (IPG) Discovery and mapping <i>striga</i> resistance (IPG) Initiate MABC for introgression of multiple traits (drought and DM) in elite line Evaluate germplasm for new sources of resistance to emerging biotic stresses (blast) Outputs: 1) Validated markers available for drought, DM and high Fe/Zn traits for forward breeding; 2) mapped new QTLs for downy mildew, blast, terminal drought, salinity, heat, high grain Fe, Zn density, low flour rancidity and forage-related traits.	0.87	ICRISAT 0.16
Sorghum			
Global: Drought tolerance and nutritional quality (Fe, Zn). Regional: <i>Striga</i> resistance (WCA)	<ul style="list-style-type: none"> Develop and validate markers for drought tolerance and nutritional quality traits Deploy MABC for drought and <i>striga</i> tolerance for improving elite lines Evaluate breeding material for stover quality Pursue the development of BCNAM populations with drought tolerance donor sources Initiate activities for rapid achievement of homozygosity Initiate activities for functional validation platforms (e.g. CRISPR/Cas9) for reverse genetics Outputs: 1) Validated markers for drought/stay green & shoot fly tolerance to be deployed in forward breeding; 2) mapped new QTLs for drought, stem rot and stover quality-related traits; 3) clone and characterized CENH3 homolog.	0.92	ICRISAT 0.19
Finger Millet			
Heat tolerance and blast resistance (IPG)	<ul style="list-style-type: none"> Discovery, mapping and development for heat and blast tolerance traits Marker identification and initiate validation of blast & heat tolerance Evaluate germplasm for new sources of resistance to biotic and abiotic stresses (blast, heat tolerance) 	0.55	ICRISAT 0.11

	Outputs: 1) Germplasm identified with elevated levels of heat & blast tolerance; 2) associated QTLs documented.		
Lentil			
Heat tolerance, extra short duration varieties and agronomic traits	<ul style="list-style-type: none"> Phenotype germplasm for new sources of resistance to biotic & abiotic stresses, machine harvestability, herbicide tolerance & nutritional (Fe and Zn) quality traits. Develop & validate markers for heat tolerance, earliness, and iron and zinc contents Evaluate breeding material for priority traits Development of genomic and genetic resources (mapping population; MAGIC and TILLING populations) Genome wide association mapping for priority traits Outputs: 1) markers for heat tolerance, earliness, and iron and zinc contents; 2) genome wide association maps undertaken and published; 3) donors with novel genes/traits (machine harvestability, herbicide tolerance and <i>Orobanche</i> tolerance) identified.	0.50	ICARDA 0.20

4.4 Environmental Classification and Target Population of Environments (TPEs)

Mechanistic crop models will be used to prescribe the set of target locations and future production environments (TPE) where varieties and hybrids developed by ICRISAT and NARS will be grown. Prediction of genotype performance in a TPE informs selection by predicting future performance, averaged over several farms and seasons. This improves targeting of varieties especially for rainfed and low resource-use agriculture, where weather variability, soil quality and depth, and management differences abound. Activities will initially focus on groundnut to gain experience before expanding to other prioritized crops and include:

Full set of activities GLDC CoA 4.1	Specific interim funding and outputs in 2017	Current Bilateral Funding (\$M)	2017 Gap Funding (\$M)
Systematic cataloguing and public data repository of existing soil and weather information, and crop agronomic practices, for major crop production environments of West, Central and Eastern Africa).	Data base development <ul style="list-style-type: none"> Development of data repository systems for meteorological, production and soil data for West and Eastern Africa Outputs: 1) Database consisting of existing soil & weather information, crop agronomic practices for major crop production environments of West and Central, Africa and North Africa.	0.50	ICRISAT 0.13
Characterization and classification of all production environments, identifying and defining separate or overlapping TPEs for the target crops.	TPE characterization <ul style="list-style-type: none"> Identification of genetic traits, or agronomic management alterations that enhance crop/system productivity/resilience/cash return and/or reduce risk, and design target plant ideotypes or crop agronomic packages, or cropping systems. Outputs: 1) TPEs of sorghum, pearl millet & groundnut characterized in major production environments; 2) overlapping TPEs for the target crops identified.	0.60	ICRISAT 0.10
Integration of modelling tools in decision-making by geneticists/breeders, agronomists and social scientists as integrals of their work.	Deployment of modelling by scientists <ul style="list-style-type: none"> Integrate use of modelling by breeders - crop simulation modelling to inform trait prioritization and deployment; social scientists, forecast modelling (global futures) Capacity building for modelling Outputs: 1) Models confirmed by physiologists & breeders as suitable to inform trait prioritization and deployment; 2) global future models available to inform trait prioritization and breeding program strategies.	0.55	ICRISAT 0.10

4.5 Phenotyping

Together with the use of simulation to increase selection efficiency, improving the quality of phenotyping is critical for increasing genetic gains. Three priorities include: (i) Focusing on traits of importance for crop productivity; (ii) Designing testing locations that are common across dryland crops and programs; (iii) Focusing testing of breeding / integrated crop management packages for specific TPEs. The major activities will be:

Full set of activities GLDC CoA 4.2	Specific interim funding and outputs in 2017	Current Bilateral Funding (\$M)	2017 Gap Funding (\$M)
Establish at least one pilot managed-stress testing site for managed drought stress in a representative testing location of a major TPE; pilot the feasibility of using spectral imaging for phenotyping disease and pest reactions, and of using remote-sensing for field phenotyping.	Establish regional phenotyping facilities <ul style="list-style-type: none"> Construct an inventory that shows capacity, gaps and opportunity of existing phenotyping capacity in the main production environments Initiate development of a pilot stress testing site for drought and multi-spectral imaging in West Africa. Outputs: 1) An inventory of existing phenotyping capacities in the main production environments of semi-arid environments of WCA and ESA & identified capacity, gaps and opportunities; 2) one pilot managed-stress testing site for managed drought stress in a representative testing location of a major TPE of WCA and ESA.	0.70	ICRISAT 0.13
Systematically deploy optimal statistical designs, metadata standards and new precise statistical methods that combine design information with phenotyping nodes and spatial adjustment within and between trials.	Deploy precise phenotyping <ul style="list-style-type: none"> Pilot trait-based phenotyping using traits identified through modelling; Conduct field-based phenotyping in selected well-equipped stations Advanced data analytics & management <ul style="list-style-type: none"> Deploy optimal statistical design, metadata standards and precise statistical methods Connect phenotyping nodes to cloud-based data warehousing and computing based on BMS. Outputs: 1) Feasibility studies on using spectral imaging & remote-sensing for phenotyping; 2) BMS training of NARS and CGIAR breeders; 3) network for connecting phenotyping nodes to cloud-based data warehousing and computing using BMS piloted.	0.40	ICRISAT 0.05

4.6 Variety and Hybrid Development

Three mutually reinforcing components namely: Variety/hybrid development, nursery management and variety/hybrid characterization will be implemented:

Full set of activities GLDC CoA 4.3	Specific interim funding and outputs in 2017	Current Bilateral Funding (\$M)	2017 Gap Funding (\$M)
Breeding process and program improvement – working NARS will develop a new generation of farmer-preferred varieties and hybrids, using conventional, molecular, and participatory plant breeding methods.	Program strengthening <ul style="list-style-type: none"> Undertake BPAT analysis for selected NARS to inform planning intervention capacity strengthening (2 in ESA, 2 in WCA, 2 In SA) Capacity building <ul style="list-style-type: none"> Skills enhancement for NARS the focus being BMS, smart tools for data collection, forward breeding, population development and management and infrastructure upgrade. Accelerating genetic gains <ul style="list-style-type: none"> Increase the number of new populations from crossing programs & speed up generation advance process Enhance selection intensity and precision using forward breeding (starting with legumes) Deploy MABC and GS for drought tolerance, <i>Ascochyta</i> blight, oil content, drought, <i>striga</i> & midge. Confined tests of transgenic material for low aflatoxin, and other stresses Advancement and evaluation of breeding lines for productivity (abiotic and biotic), value added and process traits. Outputs: 1) Two NARS in each of WCA, ESA & SA complete BPAT analysis and strategy development of their breeding programs; 2) at least 100 additional crosses made for each new trait by CGIAR; 3) shuttle breeding between Africa and Asia involving at least 200+ lines for all target crops; 4) regional phenotyping of key biotic stresses (at least one	2.37	ICRISAT 0.98 ICARDA 0.10

	disease and one pest) conducted per target crop; 5) major parental and released materials genotyped and markers validated for particular traits for groundnut, pigeonpea, sorghum & chickpea; 6) forward breeding initiated in one groundnut program in both Asia and Africa focusing on one market-validated trait; 7) marker trait validation completed for selected diseases of legumes and cereals; 8) MABC used for validated traits in groundnut and chickpea; 9) confined field trials conducted for candidate transformation events to confirm efficacy and subsequently used in pre breeding; 10) at least 7 populations per target cereal and legume (>40 populations) for various input and output traits advanced in Africa and Asia.		
Multi-environment adaptation testing for yield, fodder handling to assess spatial and temporal adaptation to different agro-ecological conditions across multiple seasons, identifying the most adapted material for advancement.	Variety development <ul style="list-style-type: none"> Multi-location and participatory testing of early generation populations to identify the most adapted material for advancing and distribution Outputs: 1) At least 2 regional nurseries per target crop (20 entries / nursery) shared with NARS partners; 2) over 5 new partnerships formed in Africa and Asia; 3) NARS partners trained and supported to conduct participatory variety selection by farmers and other value chain actors for material in national performance trials.	1.23	ICRISAT 0.40 ICARDA 0.10
Improved nursery research and management to support pre-variety and variety release processes, as well as production of breeder seed and doubled haploids for selected crops.	Pre-release testing and entry <ul style="list-style-type: none"> Selected entry of candidate crop varieties (legumes and cereals), with improved stress tolerance and other traits into variety release processes. Strategic production of early generations of new varieties and candidate lines Outputs: 1) NARS partners trained & support/equipped in early generation seed & nursery management using BMS.	0.77	ICRISAT 0.11 ICARDA 0.05

5. Budget

The current bilateral funding for ICRISAT and ICARDA crop improvement programs for groundnut, pigeonpea, lentil, chickpea, sorghum, pearl and finger millets in 2017 represents a total of US\$18.7M as indicated in the above tables. In response to the request to present a proposal and budget for interim support in 2017 for sustaining CGIAR crop improvement for these crops, **gap funding of US\$5.15M is requested**, as per the breakdown below. This gap funding represents the current shortfall in W1, W2 and W3/bilateral funding of the identified crop improvement programs that would have been supported in the GLDC CRP.

ICRISAT	2017 Interim funding
Research staffing (Appendix A)	\$2.27
Support staff	\$0.54
Operating	\$0.60
Overheads	\$0.71
ICRISAT total	\$4.12
ICARDA	
Research staffing (Appendix A)	\$0.62
Support staff	\$0.06
Operating	\$0.22
Overheads	\$0.13
ICARDA total	\$1.03
GRAND TOTAL	\$5.15

6. Collaboration and integration

This initiative will work with other W3/bilateral projects (e.g. TL III, HOPE 2) that cover the full agrifood systems research agenda for these targeted crops – i.e. the relevant seed system, value chain and socio-economic research.

While eight CGIAR Centers were stakeholders in the GLDC CRP (ICRISAT, Bioversity, CIAT, ICARDA, ICRAF, IITA, ILRI, IWMI), this initiative cannot cover their full aspirations. Objective 4 here will work on developing a successful proposal for a grain legume and dryland cereal CRP that will be included in the 2018 CGIAR Research Portfolio. These CGIAR partners will be invited to contribute to this task.

Non-CGIAR partners, especially the NARS in the target countries, apex and sub-regional agricultural organizations and the private sector are key stakeholders in this proposal and its future agenda. In supporting crop improvement programs for these priority crops, partnerships with stakeholders in the private and public sectors is essential. The proposal will invest in engagement and consultation strategies, especially in the co-development of Country Strategies for targeted countries and through alignment with the CGIAR Site Integration processes.

Appendix A: List of supported staff

Researcher	Interim funding %	Focal area
ICRISAT		
Vincent Vadez	50%	Global physiology; phenotyping
Rajeev Varshney	30%	Global genomics, trait identification
Pooran M Gaur	40%	Chickpea breeding - Asia
Kiran K Sharma	50%	Transgenics, molecular biology
Abhishek Rathore	65%	Bioinformatics; BMS
Hailemichael Shewayrga Desmae	10%	Groundnut breeding - Mali
Samuel M C Njoroge	95%	Plant pathologist - ESA
Moses Siambi	20%	Legume improvement - ESA
Henry Fred Ojulong	35%	Finger Millet breeding - ESA
N V P R Ganga Rao	45%	Pigeonpea breeding - ESA
Damaris A Odeny	65%	Genomics, trait identification - ESA
H D Upadhyaya	50%	Genebank, trait discovery
Eric Okuku Manyasa	10%	Sorghum breeding - ESA
Malick Niango Ba	90%	Entomology - WCA
Babu Nagabhushan Motagi	75%	Groundnut breeding - Nigeria
Ijantiku Ignatius Angarawai	65%	Sorghum breeding - Nigeria
Rajeev Gupta	50%	Global genomics, trait identification
Pooja Bhatnagar-Mathur	50%	Transgenics, molecular biology
Baloua Nebie	65%	Sorghum breeding - Mali
Toure Aboubacar	90%	Sorghum breeding - Mali
Prakash Gangashetty	50%	Pearl millet breeding - Niger
Jana Kholova	30%	Global physiology; phenotyping
Falalou Hamidou	52%	Genebank, physiology - WCA
Anupama J Hingane	60%	Pigeonpea breeding - Asia
S Gopalakrishnan	50%	Microbiology - Asia
Mamta Sharma	50%	Plant pathology - Asia
Rakesh K Srivastava	50%	Millet genomics
Hari Kishan Sudini	65%	Plant pathology - Asia

S Srinivasan	85%	Chickpea breeding - Asia
Rachit Kumar Saxena	50%	Pigeonpea genomics
C V Sameer Kumar	50%	Pigeonpea breeding - Asia
P Janila	60%	Groundnut breeding - Asia
Shivali Sharma	50%	Pre-breeding
Santosh P Deshpande	10%	Sorghum genomics
Mahendar Thudi	58%	Chickpea genomics
S K Gupta	40%	Pearl millet breeding - Asia
Rajan Sharma	30%	Plant pathology - Asia
Ashok Kumar	70%	Sorghum breeding - Asia
Postdoctoral Fellows	100%	Three PDFs to support breeding programs in Asia, WCA, ESA (100,000 USD/PDF)
ICARDA		
Shiv Kumar Agrawal	60%	Lentil breeding
Aladdin Hamwiah	40%	Chickpea genomics, trait discovery
Moez Amri	50%	Chickpea Breeding
Michel Ghanem	30%	Legume Physiology
Mustapha El-Buhassini	20%	Legumes – Entomology
Seid Ahmed Kamel	50%	Legumes – Pathology
Abdoul Aziz Niane	30%	Legumes – International Nurseries
Postdoctoral fellow	100%	Support breeding in Asia (200,000 USD/PDF)



African Cowpea and Soybean Program

Cowpea and soybean play important roles in nutritional and food security and income generation for men and women farmers as well as small to large-scale enterprises in sub-Saharan Africa (SSA). Through their abilities to fix atmospheric nitrogen these crops contribute to soil fertility, making them very important in farming systems in the sub-region e.g. as rotational or inter-crops in cereal dominated cropping systems. In addition to their protein-rich grains, cowpea biomass (haulms) provides important nutritious fodder for ruminants in the Sahel regions of West and Central Africa and soybean is a major component of livestock feed, making the crops excellent sources of income for growers.

With high and increasing consumer demand, and the negative impact of climate change on agricultural production, there is considerable need and scope to develop new varieties of cowpea and soybean to meet the needs of farmers and industry. This can be achieved using a combination of conventional and fast-track genomic breeding tools. However the breeding programs for the two crops are under-resourced at both the CGIAR and NARS levels and they are particularly vulnerable at the moment owing to uncertainty of funding.

Activities of the African Cowpea and Soybean Program target selected priority countries in SSA. Nigeria, Ghana, Mozambique, and Tanzania are high priority countries for both crops. Additional countries specific for soybean improvement are Zambia, Malawi, DRC, and Kenya. The additional countries for cowpea are Burkina Faso, Cameroon, Mali, Niger, and Senegal. For cowpea we propose IPM efforts in addition to breeding because there are key insect pests (legume pod borer and pod sucking bugs) for which good sources of host plant resistance have not been identified for use in breeding. Strategic IPM research will be done at the IITA station in Benin but implementation, particularly releases of natural enemies, will be carried out in Nigeria, Ghana, Burkina Faso and Niger.

A network for cowpea and soybean breeders and scientists in key disciplines allied to breeding in SSA will be established to enhance collaboration within the region and with ARIs. This will contribute to efficiency in the use of resources available for research in the region and lead to increased availability and use of appropriate new varieties and pest management practices that will increase and sustain genetic gains on farmers' fields for soybean and cowpea in the face of increasing challenges in crop production environments.

This concept note presents the objectives for the Program with a 5-year timeframe and the outputs expected from activities that will be conducted during the interim year 2017.

1. Scope of Work

1.1. Soybean Breeding

Objectives:

- i. Developing field based abiotic stress tolerance (drought, low P, high biological nitrogen fixation) and disease resistance (rust, frog-eye, leaf blight) phenotyping platforms to identify appropriate genotypes for use as source parents
- ii. Trait pipeline, which includes identification, characterization, genetic analysis of quantitative trait loci (QTLs), and development of diagnostic markers for priority traits. Diagnostic markers will facilitate forward breeding and increase efficiency of varietal delivery to the farmers
- iii. Variety pipeline aimed at developing new genetic diversity of soybean varieties for improved grain yield under multiple stress conditions. The new varieties will have an annual genetic gain of 1-2%

increase in yield over the current varieties and are expected to perform at least 5% better in that trait year to year than the current best checks

- iv. Product dissemination, portfolio management and varietal succession strategies that will result in at least one variety released per year in each of the 8 participating countries.

Expected Outputs from activities of the interim year 2017:

- i. Top performing 5% of experimental lines in advanced variety trials outperforming the best check by at least 105% (minimum of 5% yield advantage over best check) identified and advanced to participatory variety selection.
- ii. Preliminary soybean variety evaluation and selection centers in Southern Africa that will leverage unique environments to test and select for specific attributes in breeding lines based on heritability and genetic correlations among environments
- iii. Lines with potential to contribute to increased genetic diversity of rust resistance in released IITA varieties identified as potential parents for breeding
- iv. Pedigree breeding population started and advancement of segregating breeding lines with relevant market traits established sustainable continuity of the soybean breeding pipeline for Africa
- v. Mechanization within soybean testing locations increased for trial planting to 10% on average and harvesting to 40% on average to improve consistency, data quality and speed.
- vi. Improved breeder seed of at least two released varieties made available to seed companies in participating countries
- vii. Complete IITA soybean database in BMS for open access by the collaborators

Linkages with existing projects: Currently the IITA soybean breeding program is a partner under the Soybean Innovation Laboratory with funding from the USAID's Feed-the-Future program. The proposed activities for the 2017 will avoid gaps in the soybean breeding pipeline and will ensure that elite experimental lines are continuously disseminated to farmers through scaling-out projects such as N2Africa (BMGF), AfricaRISING (USAID), and the imminent project on Technologies for African Agricultural Transformation (TAAT) funded by the African Development Bank (AfDB). Continual release of new varieties to these development projects will ensure that both the farmers and processors meet their needs in the soybean value chain. Some of the improved facilities that will be established for phenotyping (e.g. for drought tolerance) will benefit both soybean and cowpea in this program as well as other related projects.

1.2. Cowpea Breeding

Objectives:

- i. Trait discovery pipeline which will include support to the establishment of high-throughput, cost-effective genotyping and phenotyping platforms, and the use of the breeding support tools such as the BMS
- ii. Use appropriate phenotyping platforms to identify genotypes for use as source parents for priority target traits e.g. tolerance to abiotic stresses (drought, heat and low P) and host plant resistance to insects (aphids and thrips) and disease (bacterial blight)
- iii. Line development pipeline aiming to develop a new generation of farmer-preferred varieties using conventional and molecular approaches; improve nursery management to support multi-environment testing of advanced lines, pre-variety and variety release processes; and promote adaptation testing and release trials through the cowpea regional trials.

Expected outputs from activities of the interim year 2017:

- i. Equipment for mechanized planting, harvesting, and threshing introduced and the existing screenhouses and irrigation facilities upgraded to double the sizes of segregating populations to at least 5,000 plants and the number of breeding cycles to 3 per year
- ii. At least 2 superior and/or novel sources of target traits (aphids, thrips, drought, striga and bacterial blight) identified in germplasm accessions and segregating populations for each trait generated for marker-trait association studies.
- iii. BMS implemented for efficient data management by IITA and programs in Nigeria, Ghana, Burkina Faso, Niger, and Mali
- iv. At least 20 advanced breeding lines made available to NARS partners for testing in their environments
- v. At least two improved varieties identified for release in 2018 from breeding programs of NARS partners in 4 countries

Linkages with existing projects: Our cowpea breeding program focuses on key traits identified over the last 5 years. Game changers identified for cowpea breeding in the first phase of the Grain Legume CRP included drought and P tolerance and insect resistance. The Tropical Legume III (TLIII) focuses on improving cowpea productivity and production through breeding lines tolerant to drought and resistant to aphid, bacterial blight and striga. The proposed program will complement TLIII in addressing these traits through the provision of additional resources to expand the size of the program and make it more efficient and effective. We will have the resources to adopt and implement better breeding practices introduced through collaboration with Monsanto with support from BMGF. We will also make more effective use of the genomic resources being generated through our collaboration with the University of California-Riverside under the USAID's FtF Climate Resilient Cowpea project. The varieties that have been released and those in the pipeline will reach the next-users and ultimate beneficiaries through our collaboration with the USAID FtF Cowpea Outscaling project (focused on seed systems) and the imminent AfDB TAAT program. Success of, and sustainability of outcomes from, these outscaling and development oriented projects in turn depend on our ability to maintain a pipeline of better performing and farmer or market-preferred varieties. This inter-dependence is facilitated by the overlap in target countries for the ongoing projects and the proposed program. The 5 target countries for the cowpea value chain in the TAAT program (Nigeria, Niger, Mali, Burkina Faso, and Senegal) are priority countries for the proposed program. Nigeria, Mali, and Senegal are focus countries for the Cowpea Outscaling project while Nigeria, Burkina Faso, and Mali are key countries for both TLIII and the IITA-Monsanto projects.

1.3. IPM of cowpea pests**Objectives:**

- i. Develop novel approaches to increase parasitoid host finding efficiency and to determine establishment rates and parasitism efficiency
- ii. Investigate semio-chemicals for use as insect pest attractants or repellents, or to enhance efficiency of biocontrol agents
- iii. Validate and disseminate smartphone-based decision support tools giving farmers customized IPM information and recommendations in real time and in their own languages
- iv. Use interconnected data capture devices to collect high-throughput and real-time information about plant health status in relation to climatic and environmental factors
- v. Design an integrated resistance management (IRM) strategy for resistant varieties (including transgenic cowpea) and assess non-target impacts of host plant resistance on natural enemies

Expected outputs from activities of the interim year 2017:

- i. Data about establishment of the cowpea pod borer parasitoids released in 2016 in Benin and Burkina Faso are collected and analyzed.
- ii. At least 50 000 parasitoids of the pod borer are released with farming communities both in Nigeria and Niger, in conjunction with biocontrol sensitization campaigns.
- iii. Host finding behavior of at least one of the pod borer parasitoids is investigated
- iv. Data about the nature and attractiveness of male aggregation pheromones of the brown pod bug to egg parasitoids are collected and analyzed.
- v. A prototype farmer application running on Android smartphone is validated with farming communities at pilot sites in Benin

Linkages with existing projects: The IPM team is involved in the USAID FtF Legume Innovation Lab IPM-omics project and the BMGF funded precision-IPM project, both ending in 2017.

1.4. Network**Objective:**

Establish and manage a network of researchers in genetic improvement and IPM of cowpea and soybean in sub-Saharan Africa that will raise and sustain research efficiency and quality through increased opportunities for capacity strengthening, peer review, links with ARIs, regular exchange of relevant information, as well as discussions on technical parameters, common indicators and methods.

Expected Outputs from activities of the interim year 2017:

- i. A community of practice for researchers in genetic improvement and IPM of cowpea and soybean in priority countries of sub-Saharan Africa (Burkina Faso, Ghana, Mali, Mozambique, Niger, Nigeria, Senegal, Tanzania, Zambia, Malawi, Kenya, and DRC)
- ii. Information on the network's activities, cowpea and soybean projects in SSA, and relevant opportunities for capacity strengthening accessible through a dedicated web portal and other tools including Whatsapp and twitter
- iii. At least 10 cowpea and soybean breeders sponsored for training events e.g. in advanced quantitative genetics and statistical analyses using R
- iv. At least 40 technicians from collaborating breeding programs sponsored for training in new tools for, and approaches to, phenotyping
- v. Regional field trials planned with program partners, and conducted using harmonized approaches in at least 2 locations in 6 countries for cowpea (Nigeria, Niger, Ghana, Mali, Burkina Faso, Senegal) and 4 for soybean (Mozambique, Malawi, Zambia and Nigeria) based on germplasm from IITA and key partners. The trials will be jointly monitored in tours. Partners will include seed companies e.g. SeedCo, MRI-Syngenta and Zamseed for soybean and SeedCo for cowpea
- vi. One workshop organized to exchange information on progress and challenges in genetic improvement and IPM of cowpea and soybean

2. Budget

A summary of the overall budget (\$4,613,887) for implementation of the interim year (2017) of the African Cowpea and Soybean program is shown immediately below.

Summary of Budget for 2017

Category	Budget for 2017 per project component (in USD)				
TOTAL BUDGET	Soybean Breeding	Cowpea Breeding	Cowpea IPM	Network	TOTAL
Personnel*	700,591	611,902	404,902	50,000	1,767,395
Training	20,000	144,500	16,000	30,000	210,500
Travel	55,000	35,000	60,000	50,000	200,000
General and Administrative Cost	15,000	20,000	12,000	11,576	58,576
Materials & Supplies	118,000	115,000	189,000	15,000	437,000
Capital/Equipment	250,000	570,000	55,000	0	875,000
Bank & Other Charges	21,000	2,000	2,000	0	25,000
Sub-grants to Partners	80,000	360,000	0	0	440,000
Subtotal	1,259,591	1,858,402	738,902	156,576	4,013,471
Indirect costs	188,435	278,017	110,540	23,424	600,416
TOTAL	1,448,026	2,136,419	849,442	180,000	4,613,887

*SOYBEAN: Soybean Breeder (100% FTE, Zambia); Postdoctoral Scientist (Breeding-West Africa, 100% FTE, Nigeria); Pathologist (50% FTE, Zambia); Molecular Geneticist (25% FTE, Ibadan, Nigeria); Technicians and field labor (sites in Nigeria, Zambia, Malawi, and Mozambique)

COWPEA: Cowpea Breeder (80% FTE Senior Scientist, Kano, Nigeria); Cowpea Breeder (Consultant, 100% FTE Ibadan, Nigeria); Molecular Geneticist (25% FTE Senior Scientist, Ibadan, Nigeria); Technicians and field workers

COWPEA IPM: Insect ecologist (100% FTE Senior Scientist, Cotonou, Benin); National Visiting Scientist (100% FTE, Cotonou, Benin); Biological control specialist (50% FTE Senior Scientist, Cotonou, Benin); and Research assistants

NETWORK: An international trials manager to assist in coordination of the network by a senior scientist



The role of common beans in Global Food Security and Food Systems

Our vision,
a sustainable food future

Mission Statement: To contribute to food and nutrition security and the alleviation of poverty in Africa and Latin America through bean-based technology that exploits the genetic diversity of the *Phaseolus* genus.

As the world's most widely consumed food legume, common bean (*Phaseolus vulgaris* L.) plays multiple roles in Global Food Security and Food Systems that serve both the poor and a growing middle class, as...

- A source of protein, complex carbohydrates, minerals and folate
- A source of dietary fiber
- A potent prebiotic for enhanced gut health, and preventative measure for cardiovascular disease, colon and breast cancers, and type 2 diabetes

As with most other pulses, bean yields have not increased sufficiently to meet demand. For example, a study of consumption in Uganda and Tanzania indicates that the poor are unable to purchase beans to meet their needs, and can only consume about a third of the beans that higher economic strata eat. Bean prices in Central America similarly limit consumption. As crop programs in the CGIAR define themselves as Agri-Food System CRPs, the first priority of a bean research program must be to make beans available and accessible within the local food system, for both rural and urban consumers, through enhanced productivity that reduces prices. Technology that meets this goal must be cost effective for producers, ideally reducing production costs such that profitability is maintained when prices drop. A cornerstone of this goal is the development of germplasm resources and varieties that respond to needs and opportunities of bean users. SDGs are addressed by varieties with characteristics that in turn respond to sub-DOs as formulated in the SRF.

SDG 1: End poverty in all its forms everywhere, is addressed by varieties that:

- Enjoy ready market potential and meet consumer demands
 - **Sub-DO 1.3.2:** Increased livelihood opportunities
 - Milestone: At least 5 improved lines that optimize quality for a budding “precooked” bean industry in East Africa. (2018)
- Maximize the return on investment of inputs, especially through fertilizer efficient varieties
 - **Sub-DO 1.3.4:** More efficient use of inputs.
 - Milestone: Evaluation of root hair length for low soil fertility tolerance standardized in breeding program. (2017)
 - Milestone: At least 10 lines that produce $\geq 1 \text{ T ha}^{-1}$ at 8 ppm P analysis. (2019)
 - Milestone: Better understanding of target areas, major soil types determined and trial sites established

SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture, is addressed by varieties that:

- Display greater yield potential and yield stability under smallholder farming conditions
 - **Sub-DO 1.4.3:** Enhanced genetic gain
 - Milestone: At least 10 climbing bean lines with adaptation to mid-altitudes of East Africa and yielding $\geq 2.5 \text{ T ha}^{-1}$ (2018)

- Milestone: Genetic differences in translocation of photosynthate to grain are characterized at the genomic or proteomic level, as a critical mechanism of yield formation. (2020) At least one controlling locus fine-mapped (2019).
- Genomic selection evaluated as a breeding method to increase breeding efficiency for yield and drought yield.
- Offer greater nutritional value and serve as raw products for processed foods
 - **Sub-IDO 2.1.1:** Increased availability of diverse nutrient-rich food
 - Milestone: At least 5 black bean lines for Haiti and Guatemala with drought tolerance and resistant to virus and with ≥ 80 ppm iron (2018)
 - Climbing beans farmer evaluated outside traditional climbing bean areas, to adopt new farming system
 - Milestone: At least 10 Andean beans for East and southern Africa with large seed (≥ 40 g/100 seed) and ≥ 80 ppm iron (2019)

SDG 13: Take urgent action to combat climate change and its impacts, is addressed by varieties that:

- Confront drought, excess rainfall, and/or higher temperatures, with accompanying biotic constraints
 - **Sub-IDO 1.4.1:** Reduce pre-and post-harvest losses, including those caused by climate change
 - Milestone: At least 10 drought tolerant small red beans with yield potential comparable to an elite check (2017)
 - Milestone: At least 5 lines confirmed for acceptable pollen viability and grain filling under heat stress of 22°C night temperature (2017)
 - Milestone: Genetic analysis of heat tolerance, delivering at least one breeding-ready molecular marker (2018)
 - Milestone: At least 3 bean genotypes tolerant to waterlogging (2018)

While ambitious, this effort builds on forty years of experience, with some efforts already producing impact such as nutrient rich, drought tolerant varieties, and other activities with preliminary results that promise success in the mid-term. Furthermore, common beans enjoy vast genetic diversity in its two major gene pools and its multiple races for resistance to diseases, and for tolerance to some abiotic constraints, but faced with extreme climates of the future, sister species of the *Phaseolus* genus offer far better adaptation that results from millennia of evolution in such environments. *P. coccineus* and *P. dumosus* evolved in extremely moist environments, while *P. acutifolius* evolved in hot, desert-like regimes. Pre-breeding with these species is a long term investment in the viability of the bean crop. Alternatively, understanding their genetic systems will permit designing common beans through gene editing or genetic transformation when these methodologies are operational. We see the exploration of interspecific variability as a key to accelerating genetic gain. Our experience with breeding for abiotic stress has shed light on the physiological limitations on yield, especially with the issue of photosynthate transport to grain. Selection of remobilization traits under stress has had a positive effect on yield potential. *P. acutifolius* is especially efficient in this regard and can serve as a genetic model for yield improvement. A more effective root system as derived from *P. coccineus* can improve access to soil water and nutrients.

Staffing and functions for this ambitious plan include:

- Three applied breeders (Ph.D.): While eventually varietal development should be assumed by national programs, applied breeders will have a role in developing materials for strategic traits with direct potential for on-farm use as new traits are introduced. For example, even when sources of drought tolerance were available, a CIAT breeder needed to create a material with varietal potential as a proof of concept, and this variety was released in 2009 in Nicaragua. As a result, other programs have gradually introduced drought breeding into their activities. Breeding for high iron is approaching this state at present, while heat tolerance is a further behind in the

pipeline. Breeders will gradually need to incorporate traits of consumer acceptance such as short cooking time. An international center will continue to have a role of providing elite parental material with good combining ability and a generally acceptable phenotype to NARS breeders, while some countries may never have an effective in-house program and will need to be linked to other entities. Breeders would be based in Colombia, Uganda and Malawi.

- A breeder dedicated to pre-breeding (Ph.D.): Extracting traits from sister species is labor intensive and requires laboratory expertise in tissue culture in the case of crosses with distant species. Extreme environments may require genes for fungal resistance or root traits from *P. coccineus*, and heat and drought tolerance and insect resistance in the case of *P. acutifolius*. Direct access to CIAT's gene bank requires that this person be based in Colombia.
- A molecular biologist/geneticist (Ph.D.): The availability of the common bean genome sequence, and sequencing of sister species and even cowpea and soybean opens new horizons and will give insights into opportunities at many levels, from the creation of more efficient markers for selection, genomic selection, to gene editing when this is feasible. Access to infrastructure and interaction with the breeder in pre-breeding makes it preferable to be based in Colombia.
- A pathologist (Ph.D.): Extreme weather events and excessive rainfall will exacerbate intensity of several soil borne pathogens, and of Phoma foliar blight. While breeding for anthracnose and angular leaf spot resistance is well advanced, monitoring of pathogen variability is warranted in support of breeding. This person could be based either in Colombia or in East Africa.
- A virologist (half time Ph.D. or full time M.Sc.): Drier weather will increase vector pressure and new recombinants of gemini virus are already appearing. These need to be studied in relation to currently used resistance genes; the same can be said for variability of potyviruses. Work on gemini viruses requires the person to be based in Latin America.
- A physiologist (Ph.D.): As part of a team for which abiotic stress is a priority, a physiologist is an indispensable component, focusing on drought and heat mechanisms of tolerance, and identifying which parental materials are contrasting in mechanisms that can be combined. Some attention should be directed toward fertilizer-efficient root systems, and to root penetration capacity, which will be increasingly important as soils degrade and become compacted. Access to infrastructure favors basing this person in Colombia, although a post-doctoral position in Africa would be welcome. Project proposals on physiology of bean have been developed with the University of Sydney, Australia, U. of Washington- Seattle and with Forschungszentrum-Jülich, Germany.
- An entomologist (Ph.D.): While some pest issues remain in Latin America, bean stem maggot (*Ophiomyia* spp) wreaks havoc in Africa in dry years. Irregularity of early season rainfall that is brought on by climate change induces staggered planting dates and can generate insect populations that pass from farm to farm. Genetic differences in resistance are reported, possibly in *P. acutifolius*. This person could be based in Nairobi in the CIAT office on the ICIPE campus.
- A Bioinformatician (half time, with a full time research associate). We anticipate in the coming years, access to a great amount of sequencing data for *Phaseolus* species as well as other relevant legumes species. The expertise will be needed for data mining to guide breeding and accelerate genetic gain. The position will be based in Colombia.
- Biometrics / Data management / Statistics (M.Sc at least) Data management will be an increasingly important component of breeding work. Storage, availability and sharing of

genomics data, handling of phenotypic breeding program data, support with statistical planning and analysis, and big data analyses for ex ante and impact assessment requires a specialist in the interface between computational development, bioinformatics, data bases and the field breeding team. Position should be based in Colombia.

This team would need to be in direct contact with colleagues working in marketing (as the production-to-market corridor concept develops); with nutritionists; with seed experts; with gender experts; with professionals in Monitoring and Evaluation; and with regional coordinators who facilitate interactions with national programs.

Networking for Research and for Reaching End Users

Networking with other institutions both in Africa and Latin America, and with ARIs in North America, Europe and Australia makes for an effective and dynamic system for research and delivery. CIAT has a long history of creating regional networks with partners, first in Central America, and later in the Great Lakes region, and in Eastern and southern Africa. The Central American network has not functioned formally since the early 1990's, but collegial relations maintain interchange of germplasm and results, including regional trials, and with the support of the breeder at the Pan-American School (Zamorano). The annual regional agronomy meeting (the PCCMCA) facilitates face to face communication and information sharing.

The Pan-African Bean Research Alliance (PABRA) is a self-governing consortium under CIAT's administration that coordinates cooperation among twenty-nine countries and three regional networks. Annual meetings permit information sharing and joint decision making about priorities and governance. CIAT's two breeders within the region have a triple role of, 1) mentoring national programs including breeding activities where these exist; 2) carrying out breeding for locally important traits and distributing germplasm through regional trials; 3) bridging to CIAT headquarters to communicate needs and to coordinate introduction of germplasm from CIAT-Colombia. Some projects such as the bean component of the Tropical Legumes project funded by the Bill and Melinda Gates Foundation is co-executed between the breeder in Uganda and breeders in CIAT-Colombia.

The largest bean research community in the developed world is in the United States, where the genome sequence of common bean was developed. CIAT interacts both with colleagues in USDA and in universities there. One joint project focusing on breeding for abiotic stress tolerance is funded through USAID and is administered by Pennsylvania State University, facilitating interaction of CIAT researchers with those in three stations of USDA, the University of Puerto Rico, North Dakota State University and Zamorano, on topics as diverse as stress physiology, breeding, and genomics. A second project focused on developing sources of resistance to soil pathogens and was executed under the leadership of Michigan State University. Linkage funds supplied by USAID to the Grain Legumes CRP permitted interacting with Michigan State on processing characteristics of bean, and on photosynthesis research, and with UC Davis on physiology. Several of these partners are also active in the Legume Innovation Laboratory funded by USAID. CIAT's role is often though not exclusively the provision of unique germplasm resources, derived from its ample breeding program and its tropical experience. Scientists on sabbatical leave are welcome to come to CIAT to work on topics of joint interest.

We foresee a particular role for legumes and specifically for beans in the area of health. While the nutritional benefits of beans are widely recognized, the additional benefits on health are emerging and are attracting ever greater interest as populations at every level of the economic scale suffer obesity and associated non-communicable diseases. We anticipate opportunities to develop cooperation with partners such as Michigan State University, Washington University, or potentially through them, with the National Institute of Health (NIH) that has identified beans as having a positive role in cancer prevention.

Budget

Position	Basic cost	Cost, assistants	Cost, technicians & workers	Operations	TOTAL
Breeder, Colombia	150,000	120,000	120,000	160,000	550,000
Breeder, Uganda*	150,000	60,000	40,000	150,000	400,000
Breeder, Malawi*	150,000	60,000	40,000	150,000	400,000
Pre-breeder, Colombia	150,000	60,000	60,000	140,000	410,000
Molecular biologist	150,000	120,000	30,000	140,000	440,000
Bioinformatician (0.25)	38,000	45,000		10,000	93,000
Pathologist	150,000	60,000	60,000	60,000	330,000
Virologist (0.5)	150,000	30,000	30,000	40,000	250,000
Physiologist**	150,000	90,000	60,000	110,000	410,000
Postdoc, physiology	80,000	30,000	10,000	50,000	170,000
Entomologist	150,000	30,000	20,000	80,000	280,000
Research & Technical Support****					821,260
Overhead***					500,969
					5,055,229

* Positions are currently financed by SDC, Switzerland, and GAC, Canada, with partial operational support.

** Position is expected to be funded by BMZ, Germany, without operational support.

***CIAT has an internal policy for Indirect cost which charges actual percentages derived from the Schedule of Indirect Cost Rates reported in our FY Financial Statements, which was audited by Ernest & Young. For 2016, the overhead rate was 11% which we maintain for 2017.

****CIAT Institutional Support is a cost that is only charged to research positions, considering that this support is fundamental when research activities are conducted. Charges include services for Contracts Management, Project Management, Project Communications, Knowledge Management, Intellectual Property, Monitoring & Evaluation, and Partnerships.