CGIAR

RESEARCH PROGRAM ON
Dryland Cereals

A global alliance for improving food security, nutrition and economic growth for the world's most vulnerable poor.

ANNUAL REPORT 2016

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RESEARCH PROGRAM ON
Dryland Cereals

LED BY

ICRISAT
INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

IN PARTNERSHIP WITH

ICARDA
Science for Better Livelihoods in Dry Areas

and public and private institutes and organizations, governments, and farmers worldwide

CGIAR RESEARCH PROGRAM ON DRYLAND CEREALS
PERFORMANCE MONITORING REPORT FOR CALENDAR YEAR 2016

A. KEY MESSAGES

Synthesis of progress and challenges in implementing the CRP: The CGIAR research program on Dryland Cereals **operated for a period of roughly 4.5 years** from June 2012 to December 2016, over an initial phase of 2.5 years until 2014 end, and a following extension phase from Jan 2015 to Dec 2016. Within this short period (as of Oct 2016), the program delivered **85 new varieties** and **34 new hybrids** of barley, millets and sorghum in its target countries, supported the **production and distribution of 14,386 tons of seed** of its small-seeded crops, demonstrated **34 management practices**, produced a total of **217 publications including 102 in ISI journals**, hosted close to **70,000 farmers at farmer field days**, trained **11,448 trainees in short-duration training** programs, trained **28 Masters students** and **24 Ph D students**. At the end of program period, a total of **8,701,562 ha of area was under improved varieties**. Improved streamlining and coordinated reporting makes **2016 the best year yet for the program**, and hence it is a big disappointment that the program has not moved into its second phase. This being the last year of the program in its current form, and due to the excellent results across the entire program, we have tried to include as many of our success stories in this report, and hence have gone a little beyond the prescribed page limit.

During the short period of its existence, the program suffered the turbulence of the massive reform process that attempted to change 40+ years of ingrained culture, continuously adjusted to enormous transaction costs of time for the multiple and simultaneous demands for reporting and evaluations, endured consistently unpredictable budgets, suffered excessive budget cuts, and invested massive amounts of time to prepare two proposals for program continuity, one for the 'extension phase' for CGIAR program synchronization, and the other for the second phase. The transaction cost of time should be especially noted for a program such as the Dryland Cereals which is implemented by the smallest team of researchers, and a small three-member program management unit shared between two programs, because multiple demands of time for reporting and evaluation assessments from already stretched research personnel and program management staff, especially within such a short operational period, can do nothing but undermine execution of planned research. Despite such colossal pressures, Dryland Cereals managed to deliver on its core business of crop improvement satisfactorily, and sometimes beyond expectations, as indicated by the numbers above.

During its existence, Dryland Cereals supported a sub-set of the world's population that is dependent on the program's target crops in dryland areas, for which there are few other suppliers of research. Crop improvement in these geographies are addressed by CGIAR-NARS partnerships, working under constrained R&D environments that are very different from those in developed nations. During 2016, the program worked with much better streamlining than at any time since its inception. Although the Plan of Work and Budget prepared for the year had taken into account a restrictive budget, the program had to further reduce a few activities due to difficulties in stretching the available budget. Our focus centered on ensuring that the necessary continuity of breeding activities and breeding cycles, the essence of CGIAR competency in the developing world, remained intact and uninterrupted to the extent possible. Consequently, activities in Flagship 2, Improved Varieties and Hybrids, were the most supported, while efforts in the other flagships were supported based on immediate necessity. This is reflected in Table 1.

Synthesis of the two most significant achievements/success stories in the year: The year saw more than a couple of significant achievements which are briefly identified here, and further elaborated under Section C. The barley team established a **fully functional laboratory for malting-quality analysis** in Rabat, Morocco, with the ICARDA decentralization budget channeled through Dryland Cereals. This lab is already supporting the identification of superior malting lines sought by barley farmers in Ethiopia and other target countries. The partnership established by the ICARDA barley team with the Institut de Genech in early 2015 has led to the **development of doubled haploid lines** for the first time within

the barley program, from four separate crosses. Another significant achievement is the **validation of the drought phenotyping pipeline** for pearl millet at ICRISAT through the establishment of correlations between pot-based physiological measures and field-based grain and stover yields. The concept of **hybrid sorghum and pearl millet for Africa** has moved significantly past the proof-of-concept stage, especially for sorghum as reported in previous years. Most recently, the heterosis or hybrid vigor demonstrated by pearl millet is being tapped for the development of hybrids for both WCA and ESA, either with material developed locally, or material introduced from India and tested for adaptation in Africa and proven to be successful. Yet another achievement was the development and release of an **open access database for dryland cereals and grain legumes**, the DCL eATLAS, and the accompanied publication providing a synthesis of data supporting prioritization decisions for research investment. Finally, prior research at ICRISAT on **sweet sorghum for biofuel** led to a partnership in India to support the government's goal of ethanol blending in gasoline, and increasing the ethanol % from 5 to 20% within the next five years.

In addition, the year saw the **release of a good number of varieties/hybrids** based on CGIAR germplasm**: 18 sorghum varieties** (2 in Nigeria, 8 in Mali, 6 in Kenya and 2 in Kazhakstan)**; six sorghum hybrids** (1 in Mali, 5 in Kenya); **14 pearl millet varieties** (7 in Niger, 2 in Nigeria and 5 in Mali)**; four pearl millet hybrids** (1 in Mali and 3 in India)**; four finger millet varieties** (all in Ethiopia) and **five barley varieties** (3 in Ethiopia and 2 in Morocco)**,** and the entry of several advanced lines of all four crops into National Performance Trials and Participatory Variety Selection.

Overall financial summary: Cumulative Financial Summary (Report L101)

	(a) Total POWB budget since inception						(b) Actual Expenses - Cumulative						(c) Variance - Cumulative					
Centers	Windows 1 & 2	W1&2 In addition to PPA	Window 3	Bilateral funding	Center Funds	Total Funding	Windows 1 & 2	W1&2 In addition to PPA	Window 3	Bilateral funding	Center Funds	Total Funding	Windows 1 & 2	W1&2 In addition to PPA	Window 3	Bilateral funding	Center Funds	Total Funding
ICARDA *	7,337	-	1,490	5,917	-	14,744	7,337	-	1,038	3,016	-	11,391	-	-	452	2,901	-	3,353
ICRISAT **	20,175	108	23,931	36,533	1,070	81,817	20,175	42	17,716	25,864	1,070	64,867	-	66	6,215	10,670	-	16,950
GCP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**27,512**	**108**	**25,421**	**42,450**	**1,070**	**96,561**	**27,512**	**42**	**18,754**	**28,880**	**1,070**	**76,258**	**-**	**66**	**6,667**	**13,571**	**-**	**20,303**
Percentage	**28%**	**0%**	**26%**	**44%**	**1%**	**100%**	**36%**	**0%**	**25%**	**38%**	**0**	**100%**	**0%**	**0%**	**33%**	**67%**	**0%**	**100%**

* Including Infrastructure
** Including PMU

B. IMPACT PATHWAY AND INTERMEDIATE DEVELOPMENT OUTCOMES (IDOS)

The IDOs for the current extension phase are intrinsically related to the IDOs and sub-IDOs of the second phase, which in turn are related to the Sustainable Development Goas of the United Nations. As identified in the Extension Proposal for Dryland Cereals, the program has been working towards the following IDOs: (1) **Improved productivity** of dryland cereals in smallholder farming systems in Africa and Asia; (2) **Increased and stable access** to dryland cereal food, feed and fodder by the poor, especially rural women and children; (3) **Increased consumption of nutritious** dryland cereals by the poor, especially among nutritionally vulnerable women and children; (4) **Increased and more equitable income** from marketing dryland cereal grain, fodder and products by low income value chain actors, especially smallholder women farmers; and (5) **Increased capacity to adapt to environmental variability** and longer term changes in low income communities in Africa and Asia. The extension phase structure that included five Flagships facilitated fundamental research, breeding and crop improvement, support of scaling of seed delivery, and output markets that together contributed to the outputs, outcomes and impacts described below.

C. PROGRESS ALONG THE IMPACT PATHWAY

C1. Progress towards outputs

For the first time since the inception of the program 4.5 years ago, we have a fully operational Monitoring, Evaluation and Learning Platform which captures and tracks activity-based reporting. Detailed reports of individual projects can also be accessed here.

FLAGSHIP PROJECT 1 - *PRIORITY SETTING & ADOPTION:*

Development of **Adoption Tracking Models** is in progress for sorghum and millets in ESA (Ethiopia, Tanzania) and WCA, supported by the bilateral project, HOPE II (Harnessing Opportunities for Productivity Enhancement of sorghum and millets, Phase II). The first of the two components involved, namely, production quantities and seed inventory of major seed producers, was completed

for Ethiopia. As part of a detailed analyses of **gender-differentiated demand** for specific traits and trait combinations driving sorghum adoption in the Sudan Savannah, over 400 research articles since 2002 relating to gender and participatory plant breeding were compiled.

Baseline reports were updated for studies conducted earlier in Mali, Niger, Nigeria and Burkina Faso that involved a total of 2872 households across 319 villages, and newer analysis revealed that: (1) respectively 25%, 21% and 33% of the total area under sorghum was under improved varieties in Mali, Northern Nigeria, and Burkina Faso, (2) respectively 43%, 3%, 25% and 31% of area under pearl millet areas was under improved varieties in Mali, Niger, Northern Nigeria and Burkina Faso, and (3) reasons for non-adoption of improved varieties are lack of seed, lack of resistance to insects and drought, lack of preferred end quality, late maturity, and requirement of fertilizers.

FLAGSHIP PROJECT 2 – *IMPROVED VARIETIES & HYBRIDS:*

An evaluation of 25 open-pollinated sorghum varieties for **tolerance to drought** in Kenya, Tanzania, Uganda, Malawi and Zimbabwe identified five superior varieties in each of the first five countries, and seven in Zimbabwe; these will be evaluated in on-farm trials in dry low-land agro-ecologies for farmer-participatory selection in 2017. A total of 2432 successful new sorghum crosses for tolerance to drought, *Striga*, leaf diseases and midge, and for high Fe, Zn and lysine were generated at the Kiboko field station in Kenya, and a total of 1245 F1, 304 F2, 612 F3 and 474 F4 were advanced. In Ethiopia, a total of 416 A and B pairs of sorghum were selected from 525 A/B pairs developed for drought and *Striga* tolerance in Melkasa. The Guinea Naine Diversified Population (GNDP), containing 112 S3 sorghum progenies from farmers' selections, were **phenotyped under both low and high phosphorous** fields in WCA, and selections were advanced. While commercially viable *guinea* race sorghum hybrids exist now for WCA, there are no hybrids available for the drier zones in the north of Nigeria, the largest sorghum producing area of the region which grow mostly the *caudatum* or *durra* type. Several hybrids were tested for combining ability to establish solid heterotic groups for the breeding material in WCA. In 2016, 27 A/B pairs for **hybrid sorghum production in Northern Nigeria** were selected for further studies from an evaluation of 54 A/B pairs of *caudatum*/*durra* sorghum sourced from ICRISAT Nairobi. In Mali, 16 drought-tolerant populations including over 1700 BC1F3 progenies were developed. **Descriptive statistics for NIR calibration** were established for sorghum stem quality traits for a dataset from Mali in a collaborative study with CIRAD, France. A **competitive grant to IER** led to the conclusion that selected sorghum *hybrids* from a BCNAM population responded better to fertilizer application at higher plant densities than the selected *line* for grain and biomass yields, while the line was more stable than the hybrids at all plant densities, an observation similar to that which led to 100% adoption of hybrid maize in the Americas over the last several decades. **Drought-tolerant BCNAM sorghum populations** were developed with CSM63E, grown predominantly across the sub-Sahelian zone, as recurrent parent, along with seven drought-specific donor parents. **Drought-adaptation studies** in WCA identified sorghum germplasm with superior transpiration efficiency (*Maldandi*), but similar water extraction capacity, under water stress in lysimetric studies in a comparison involving selected parents from a BCNAM population based on Lata from Mali and other germplasm. Classification and quantification of environmental constraints to refine breeding targets for sorghum in WCA, as part of **crop modeling** to identify **climate-smart sorghum plant types**, led to reliable parameterization of photoperiod sensitivity, and to the development of a strategy for water-stress scenario analysis. Further, functions were developed to reflect tillering dynamics of sorghum and pearl millet and incorporated in the APSIM code, while **GxExM modeling for the stay-green trait** in *rabi* sorghum in India is in progress.

Finger millet populations advanced in 2016 include 2498 F_3 lines for diverse traits (Yield, Blast, Striga, drought, high nutrient content, snapping trait, head shape and size, grain color); 158 F_3 & 95 F_2 lines for blast resistance; 94 F_2 lines for *Striga* resistance;192 F_3 lines for high nutrients; 514 F_4, 30 F_3 & 58 F_2 lines for snapping trait; 1955 F_1 lines for multiple traits. 500 F_4 finger millet lines with diverse trait sources were shared with ICRISAT-India to jumpstart ICRISAT-Asia finger millet breeding program. A preliminary yield trial involving 81 finger millet entries at two locations in Kenya identified 20 best

performers for advancement. A total of **83 new finger millet accessions** (17 from Tanzania and 66 from Kenya) were collected in 2016. 269 accessions (134 from Tanzania and 135 from Uganda) collected in 2015 were established at TPRI-Miwaleni, Tanzania and NaSARRI, Uganda, respectively, and are ready for characterization in 2017. Evaluation of 29 **nutrient-dense finger millet varieties** along with the improved check U15 in four locations in Kenya and Tanzania identified three superior varieties (IE 3034, IE 930 and IE 3038) for incorporation into PVS trials towards possible release. In a **genome-wide association mapping effort** for nutrient (primarily Ca) content in finger millet, 400 accessions have been subject to GBS and SNPs identified, with phenotyping and downstream analysis in progress. ICRISAT-Nairobi, in collaboration with the Institute of Biological, Environmental and Rural Sciences (IBERS), Aberystwyth University, UK, set to *Explore the extent of genetic diversity for micronutrient content and factors affecting their bioavailability present in finger millet germplasm*. ICP-OES and enzymatic analyses revealed **variation in minerals and antinutrients** in the various genotypes. Not much correlation was observed between the minerals and antinutrient traits, implying that micronutrient accumulation and bioavailability may be two independent biological processes. GBS generated an average of 0.54 million reads/genotype with overall 93.9% reads with a good barcode. Preliminary post-processing of GBS data produced 55,469 SNPs. Preliminary **screening of 45 wild accessions** of *Eleusine kigeziensis* and *Eleusine africana* subsp. *africana* along with 22 cultivated varieties of finger millet revealed that of the top ten most blast-resistant lines, eight were wild accessions, opening up the possibility of using these for trait introgression.

The barley program in ICARDA evaluated a **total of 22,422 genotypes** during 2016. This included more than 19,000 spring barley genotypes and over 3400 winter barley genotypes. New genotypes with known malting quality were introduced into ICARDA for breeding purposes from UC Davis, California; USDA, Idaho; and other sources. Upon ending of the ICARDA-IASA project, 1582 genotypes spread over seven filial generations were transferred to ICARDA for use in its breeding programs. A total of 504 promising barley genotypes were contributed for constituting the **International trials and nurseries of 2018-19**, (to be multiplied in 2016-17 season at Lebanon) including hulled and hull-less types. About 130 barley genotypes were identified from 2400 advanced genotypes based on **superior vegetative and reproductive growth under drought,** using visual scoring, and advanced to multi-location trials during the 2016-2017 season. In **pre-breeding efforts using wild relatives of barley**, more than 83 accessions of *H. spontaneum* with combined resistance to both powdery mildew and yellow rust were identified from a total of 100 evaluated, and 75 interspecific crosses were made. An additional ten interspecific crosses were made with *H. bulbosum*. **Eleven FIGS subsets** for barley were constituted during 2016, starting in Dec 2015, involving 1225 accessions, and these subsets are under evaluation with partners in Australia and within PhD research of two students from Ibn Tofail University in Morocco. A survey of disease prevalence in 9 agro-ecological zones of Morocco identified net blotch as the sole yield-limiting biotic stress. Screening of a barley FIGS subset containing 96 accessions identified 30 accessions with resistance to net blotch and 17 with resistance to spot blotch. Significant **marker-trait associations were established** in barley for multiple traits including grain yield, with four QTLs located at 2H, 3H, 5H and 7H using a **GWAS panel** assembled to represent a sample of Jordanian barley land-races (150 landraces) for drought tolerance and yield. A parallel GWAS panel involving a collection of ICARDA elite barley material (288 lines) for disease resistance (Yellow Rust, net blotch) and yield enabled the identification of markers associated with Yellow Rust and spot blotch, which aligned with previously identified QTLs for these traits. In a collaboration with USDA-ARS and North Dakota State University under the USAID Linkage Grants scheme, an association mapping panel of 336 barley genotypes was used to evaluate the genetic basis for drought, heat and cold tolerance within the panel, and to identify 67 SNPs associated with grain-nutrient accumulation.

Eight pearl millet breeding lines with **seed set of 70 to 80% under high-temperature stress** (>42oC) during flowering time were identified from a screen of 235 breeding lines at five locations across three heat-prone target ecologies in India; seed set in the susceptible checks ranged from 30 to 40%. **Nine A-lines of pearl millet** in six diverse genetic backgrounds and with résistance to at least two Downy Mildew (DM) pathotypes were developed and designated (ICMA 16111 to ICMA 16666). Also, **nine**

genetically diverse pollinator lines with resistance to at least two DM pathotypes were designated (ICMR 16111 to ICMR 16999) as restorer parents. A total of 250 B lines of pearl millet were selected and advanced for conversion to different cytoplasmic male sterility systems, while 138 new pollinators were advanced in the restorer conversion program. An additional 47 pollinator lines, parents of promising high-Fe hybrids, were also advanced for restorer conversion. Four advanced backcross populations were generated to develop pearl millet with improved biomass, using four **interspecific crosses** involving *Pennisetum glaucum* and *P violaceum*. **Transgenic tobacco plants** constitutively expressing the pearl millet aquaporin gene, *PgPIP2;6*, were generated, and T1 events with better performance under drought stress, relative to wild-type plants, were identified based on physiological characterization. T1 events were also generated to evaluate stress inducibility of ten promoters, using the GUS reporter gene. In a routine screen to ensure resistance of advanced breeding material to changing virulence spectra, 156 B-lines of pearl millet were tested against six pathotypes of *S graminicola*, the downy mildew pathogen, and 42 lines were identified with resistance to all six pathotypes, another 42 lines to any five pathotypes, 24 to four and 23 to any three pathotypes. In a parallel study, none of the tested 100 lines exhibited resistance to the Pg 138 and 186 pathotypes of the blast pathogen. **Evaluation of virulence diversity** among 7 isolates of *Sclerospora graminicola* (Downy Mildew / DM) and 65 isolates of *Magnaporthe grisea* (blast) facilitated the identification of one highly virulent isolate of *S graminicola* (Sg613) and five isolates of *M grisea* (Pg138, Pg186, Pg204, Pg232 and Pg118 representing geographic and pathogenic diversity) towards greenhouse screening of pearl millet breeding material for resistance to DM and blast, respectively.

FLAGSHIP PROJECT 3 – *INTEGRATED CROP MANAGEMENT*:

Evaluation of the **effect of different sources of livestock manure and fertilizer** on yield of sorghum and millets at two locations in the Sudan savannah of Nigeria revealed that yield advantages in the range of 37 to 55% were obtained in one location, BUK, with poultry manure, poultry + NPK and cow manure + poultry manure, while the same resulted in yield advantages from 47% to 107% at the second location, Minjibir. In pearl millet, the magnitude of yield increase was doubled, with poultry manure + NPK, cow manure + poultry manure, and NPK 60:45:45 recording grain-yield increases between 140% and 220% over untreated control. Sorghum yields obtained from **Integrated *Striga* Management** trials in Mali were 60% higher than those obtained with existing farmer practices, and marketable surplus is estimated at 412 kg ha^{-1}. Effect of **phosphorus on growth, nitrogen uptake, yield and quality of finger millet** was investigated at Kiboko, Alupe and Kakamega in Kenya. P significantly reduced the period to flowering and maturity of all the varieties. Grain yield increased with increasing phosphate levels, with the highest yield of 4.4 t ha^{-1} attained at 25 kg/ha P. Protein content was positively influenced by P application. Increase of P rate increased N uptake, with grains accumulating the highest N content, and improved varieties partitioning higher N.

FLAGSHIP PROJECT 4 – *SEED SYSTEMS & INPUT SERVICES*:

Attempting to build efficiencies across the supply chain from input supply to marketing, a coordinated effort between Dryland Systems, Dryland Cereals and Grain Legumes organized a first of its kind 'Agricultural Inputs Fair' in Kano, Nigeria. The aim was to provide farmers with good quality inputs (improved seed varieties, agro chemicals and equipment), at affordable prices from genuine sources, and link them to agricultural extension services. At the fair, nearly 70% (4,500 kg) of assorted improved varieties of seeds brought to the fair by different seed companies were sold to farmers, amounting to NGN 903,600 (US$3,204). The three-day program was attended by around 1,800 farmers of which 484 were women. A Sorghum Innovation Platform meeting under the Agricultural Transformation Agenda Support Program Phase 1 (ATASP-1) brought together sorghum farmers in Nigeria and other stakeholders who benefitted from seed distributed by the Honeywell Group. The system allows the supply of quality seeds to farmers, and the farmers have an assured buyer for the grain in the Honeywell Group. This facilitates a ready market and supports the transition of farmers from subsistence to market-oriented farming. In 2016, the sorghum varieties, CSR-01 and SK-5912, were planted in Ningi over 1,500 hectares under this system. In Mali, 38 farmer seed cooperatives

were trained in seed-production techniques, and the local rural radio staff were trained in better communication on new variety and hybrid characteristics to enable increased seed dissemination.

FLAGSHIP PROJECT 5 – *POSTHARVEST VALUE & OUTPUT MARKETS*

A **state-of-the-art malting-quality laboratory** for barley was established at Rabat, Morocco, with the decentralization budget to ICARDA through Dryland Cereals. Thus, malting analysis can now be done in-house from sample sizes ranging from 100 g (micro malting) to 12 Kg (pilot scale) providing support to breeding programs for selections based on malting quality. The lab is equipped with instruments including the NIR grain analyzer, San++ for malt diastatic power, wort viscosity, FAN content, malt friability mr, Sortimat, Granomat etc., and can also analyze beta glucan content. Private sugar mills and public sector research institutes are collaborating with ICRISAT to identify and test **sweet sorghum varieties suitable for ethanol production** to help the government of India achieve the national ethanol blending targets of 20% by 2017. Under the framework of CGIAR Research Program on Dryland Cereals, a total of seven sugar mills are associated with ICRISAT in this 3-year project, eleven sorghum varieties from ICRISAT and IIMR are in testing, and a big mill test conducted at Madhucon Sugars, Telangana, showed a primary brix value of 15° which is close to that of sugarcane.

C2. Progress towards the achievement of research outcomes and IDOs

FLAGSHIP PROJECT 1 - *PRIORITY SETTING & ADOPTION:*

An important outcome during 2016 was the delivery of an open access dataset and information resource that provides the basis for future analysis of the geographic dimensions of dryland cereals and legumes, the DCL eATLAS. It is an information resource for the community of stakeholders interested in dryland cereals and legumes. The DCL Atlas includes maps of (1) crop distribution and suitability, (2) abiotic and biotic constraints to crop production, (3) biodiversity of the crop and hotspots for collection of wild relatives of DCL crops, (4) socioeconomic maps related to populations that may produce or consume DCL crop commodities and (5) reference maps on these crops and the farming systems they are found in. A second important outcome was a prioritization exercise for the crops and target countries for dryland cereals and grain legumes was completed by Dr Tom Walker, consulting for the Dryland Cereals and Grain Legumes program, and using value of production as a base and information from 34 separate socioeconomic studies on these crops (reported earlier).

FLAGSHIP PROJECT 2 – *IMPROVED VARIETIES & HYBRIDS*

Two sorghum varieties, 12KNICSV-188 and 12KNICSV-22, were **registered and released to Sahel/Sudan agro-ecologies** in 2016, based on farmer-participatory appraisal across various agroecologies in nine locations, grain yield, early maturity and zinc content. One **sorghum hybrid** SDSA 1 X ICSR 43, with good malting qualities, was released in Kenya, and the East African Malting company Ltd (EAML) has shown interest in its seed production. **Eight multi-purpose sweet sorghum varieties**, including *Soubatimi* and *Niolagne*, were released in Mali, and these had grain yields above 2 t/ha, stover yields around 20 t/ha and Brix ≥15%, and were selected under *Striga* and low-phosphorous stress in a study supporting integrated crop-livestock systems for the Sudanian zone. Two sorghum varieties, ICSV 112 and ICSV 93046, were released in Kazakhstan in 2016. **Two sorghum hybrids**, IESH 22009 and IESH 25007, have been recommended for NPT in Tanzania. Further, on-station quantitative and qualitative data and on-farm data were provided to the Department of Research and Development (DRD), Tanzania, for cultivars Gadam Hamam, IESV 23010DL, Wagita, IESV 92041 SH, IS 8193, IESH 22023 and IESH 25008 proposed for NPT in 2017. Eight hybrid families with superior general combining ability were identified for WCA from over 200 sorghum hybrids developed using diverse A and R lines from different breeding programs and countries. This is a central effort to **develop sorghum hybrids for WCA**, and involves collaboration with IER and the University of Hohenheim. Four **QTLs for fertility restoration**, with significant LOD scores, were identified in sorghum, and 11 candidate genes were selected from these regions based on their similarity to rice *Rf1* and sorghum *Rf1*, to develop SNP markers for molecular screening. A competitive grant to a collaboration involving CERAAS/ISRA (Senegal), IER (Mali) and INERA (Burkina Faso) complemented the IAVAO project of CORAF/WECAARD that aims to develop **a field phenotyping network for WCA**.

As part of this grant, three experimental sites, one each in Senegal, Mali and Burkina Faso, well distributed in the West Africa weather gradient and positioned in specifics isohyets (500, 700 and 1000 mm) were characterized for hydro-pedology, soil characteristics (texture, pH, N, P, K content), soil compaction profile and crop agronomic response. Variogram analysis identified heterogeneities that will guide future experimental design for improved precision. In Burkina Faso, a competitive grant to INERA led to the identification of 12 sorghum landraces with **tolerance to *Striga hermonthica***. The study launched off with a survey of 337 farmers, 59 processors and 109 traders in 4 provinces in Burkina, followed by selection and evaluation of 24 landraces for tolerance to *Striga*, low nitrogen and phosphorous, water stress, nutritional and processing quality, and for the manufacture of sorghum-based semolina, couscous, pizza and dough. An associated study exploring **high-throughput screening options** for sorghum established the use of a lysimetric system to screen for yield under low P and drought stress, and identified better performers for grain and biomass yield from 28 evaluated varieties.

Consistent resistance to the pearl millet head miner has been observed over the last three years in the varieties PE08043, PE00077, and ICMV 221 WH from Niger, in trials with over 40 lines screened artificially by infesting with head miner eggs. The selected varieties will now be used as resistant donor parents by the WCA pearl millet breeding unit. **Four finger millet varieties** KNE 622, GBK011119A, Acc 229355 and Acc 242617 were released in Ethiopia. **Two improved finger millet varieties**, KNE 628 and KNE 814, performing over the current best varieties, were identified for submission to NPT in Tanzania for release from Participatory Variety Selection involving 6 to 8 advanced varieties in Kenya, Uganda, Ethiopia and Tanzania. KNE 628 is being fast tracked in Tanzania, Kenya and Uganda due to both its high yield and high Fe content. A competitive grant to NaSARRI, Uganda, for the **exploitation of wild species of *Eleusine* for climate-change adaptation** in finger millet, was successful in revealing cross-compatibility between cultivated finger millet and *E kigeziensis* among crosses tested with 22 wild species.

Three new malt barley varieties with potential to triple average yield in Ethiopia were released in 2016 for commercial cultivation as a result of decades of research collaboration with ICARDA. The two varieties, *HB1963* and *HB 1964*, released by the Holetta Agricultural Research Center, can yield up to 6 t/ha as opposed to the average yield of 2 t/ha in Ethiopia. Another variety, Singitan, released by Sinana Agriculture Research Center (Oromia Agriculture Research Institute) is the first malt barley variety with resistance to shoot fly ((Delia flavibasis), one of the major insect pests limiting barley production particularly in southeastern Ethiopia. The varieties also offer excellent malting quality, making them attractive buys for the malting and brewery industry, thus allowing smallholders to use the new malt barley as a cash crop and generate income from it. **For the first time, two huskless barley cultivars have been released for commercial cultivation in Morocco** by INRA from ICARDA germplasm in 2016. Barley is an important food crop in Morocco and availability of huskless barley will **reduce the processing (pearling) of hulled barley** to make it fit for making products for human consumption. Cultivar Chifaa (INRA1791) is a six-row naked barley with high protein, high beta glucan and high iron contents, while another variety Assiya (INRA1793) is a six-row naked barley with high protein, and high iron contents.

The **barley malting quality analysis laboratory** that was established in 2015 at Rabat, Morocco, with the ICARDA decentralization budget, is fully functional and enabled the identification of ten new barley genotypes with very good malting quality, out of the 73 advanced lines evaluated. A collaborative effort with the Institut de Genech to incorporate **doubled haploids into barley breeding** succeeded in the production of 1224 DH lines from four separate crosses through anther culture, the production of 1920 haploids, followed by spontaneous doubling to deliver 1224 DHs. While these DH lines can be used in QTL mapping for net-blotch resistance and for grain Fe and Zn contents, some can also be used towards improved variety development. In Turkey, one advanced winter barley line, Malt12-2, selected from ICARDA germplasm was submitted to State Variety Testing Trials in 2016 by GAPARI, Sanliurfa, based on its malting quality and yield. It has a protein level of 9-10.2 % and yield of 4.8-6.5

t/ha. **Nine new barley genotypes** with improved performance over current best checks across at least two environments were identified from an advanced yield trial of 320 hulled and 90 hull-less types at Marchouch (Morocco), Amlaha (India) and Terbol (Lebanon). In addition, improved performers at a single location were also identified, namely, 35 at Terbol and 13 at Marchouch. A total of **432 sets of International Nurseries** from nine nurseries comprising 432 genotypes of low input, high input, winter hardy and disease screening nurseries of barley have been distributed to 80 co-operators in 32 countries. About 20,000 advance breeding lines of barley were screened for resistance to major diseases during 2014-2016 in Morocco, and the 3rd International Spring Barley Disease Screening Nursery (ISBDSN: 138 entries) was constituted and distributed to 31-cooperators in 17 countries for the cropping season of 2016-2017. A total of 26 SSR markers polymorphic for **grain beta glucan content** in hull-less barley were identified. This resulted from a competitive grant to ICAR, India, for the development of hull-less barley, and involved the phenotypic characterization of 40 hull-less barley lines (including 33 exotic), development of four crosses involving indigenous and exotic lines, assessment of grain beta glucan content in F2 population of Karan 16 (Hulless) x BCU 554 (Hulled), and determination of genomic regions involved in inheritance of high beta-glucan and high protein.

A total of 800 trials in farmers' fields across Rajasthan, India, involving **two advanced pearl millet hybrids adapted to drought-prone environments**, MPMH 17 and RHB 177, demonstrated higher grain yields for both MPMH 17 and RHB 177 relative to the local checks. MPMH 17 performed better under optimum rain-fed environments and RHB 177 performed better under drought environments. Two broad **heterotic pools**, one for seed (B-lines) and one for restorer (R-lines) parents, and a further four heterotic pools (HP1, HP2, HP3 and HP4) were identified for pearl millet, based on genotyping, genetic diversity patterns and test-cross performance in multi-locational trials. The **concept of hybrid pearl millet for ESA** has advanced past the proof stage, and 2016 saw the identification of (1) five hybrids with improved yield from a preliminary yield trial in Kiboko, Kenya, involving 46 top-cross hybrids developed from ESA OPVs and lines from WCA, along with three OPV parents, and (2) another five hybrids with adaptation and improved yield from a regional trial at Kiboko, Kenya and Miwaleni, Tanzania, involving 21 hybrids from India and 3 from ESA. The **drought phenotyping pipeline for pearl millet** at ICRISAT was validated through the co-localization of QTLs for physiological parameters under drought, specifically response to vapor pressure deficit, measured in pot trials, lysimeters or in the LeasyScan phenotyping facility with QTLs for field-based grain and stover yield under drought. Further, the PlantEye scanners of Phenospex's LeasyScan platform have been upgraded with a new algorithm allowing the determination of canopy architecture types on the basis of light penetration. A total of 5,786 pearl millet breeding plots, of which 1,194 were unique seed parents and 1,513 unique restorer parents, were selected by the participants at the **Pearl Millet Field Day** in Sept 2016. Participants included 29 scientists from the public sector and 46 from the private sector, and seed was supplied to partners in December 2016/January 2017. Pearl millet with **improved forage quantity** was identified from evaluations in 2016 at Patancheru, India, and selections including the open pollinated variety ICMV 05777, the germplasm accession IP 10151, and one hybrid are being advanced. An additional pearl millet hybrid with 12% improved biomass yield than the current best check was identified from a screen of 75 three-way hybrids in Telangana, India.

FLAGSHIP PROJECT 3 – *INTEGRATED CROP MANAGEMENT:*

In **biological control of the pearl millet head miner** in the Sahel, the production and release of parasitoid wasps, *Bracon hebetor,* is being optimized. Greatest **mass production of parasitoids** was found to be achieved when *B. hebetor* are given the later larval stage of the rice moth *Corcyra cephalonica* to parasitize, and that a honey and sugar solution is the best medium to support longest parasitoid lifespan. Economic analysis indicated that individual bags must be sold at a price between $1.29 and $3.08 to cover production costs, and first-year profits of $50.95 - $1,996.47 are expected from sale of parasitoids bags to 13-36 villages. Pilot testing of parasitoid multiplication by community-based units is under way. **Crop production demonstrations** for sorghum in WCA across 190 locations in the Sudano-Sahelian agro-ecological zone involving 5 fertility type/source (synthetic fertilizer NPK, NPK 60:30:30, NPK + Urea, poultry manure and the combination of all) and 9 sorghum varieties (7

OPVs and 2 hybrids), showed that the combination of NPK, Urea and farmyard manure produced the highest grain and stover yield, closely followed by NPK 60:30:30. Significant yield improvements were produced in both sorghum and millets in the sudan savannah of Kano State, Nigeria, through **chemical or fertilizer seed dressing**, with the best results with Agrolyser, followed by Single Super Phosphate and Dress Force; other seed-dressing chemicals/fertilizers tested include ApronStar, Muriate of potash (MOP), Single super phosphate (SSP) and Boost extra. For finger millet, 6258 extension staff, agro dealers, processors and farmers were trained in GAPs including timely planting, seedbed preparation, optimal plant population, proper weeding regimes, pest and disease control, proper harvesting and post-harvest techniques. **Integrated Striga Management** generates a net benefit estimated at FCFA 54,410 per hectare against FCFA 30,597 per hectare for the farmers' practice in sorghum production in Mali.

FLAGSHIP PROJECT 4 - *SEED SYSTEMS & INPUT SERVICES:*

Basic seed of the Pilira 1 variety of sorghum (1,400 kg) was contributed by ICRISAT to farmers in Malawi through the Ministry of Agriculture, Irrigation and Food Security, Malawi, for seed production over 280 ha during the 2015-16 cropping season. This is part of the effort towards **diversifying cropping systems in the drought and flood prone areas of Malawi.** Pilira 1 is a medium duration variety with a maturity period of 110 to 115 days and a yield potential of 2-4 tons per ha. **Training of seed producer cooperatives** in Mali during 2014-2016 in a collaborative effort between ICRISAT and IER on seed production techniques, communication tools for seed marketing and internal capacity building of the organization resulted in average increases of 77% in seed sales in the 11 cooperatives involved. One cooperative, ULPC (Union Locale des Producteurs de Semences) at Dioila institutionalized new rules for profit sharing, decision making and information sharing, and made a commitment to produce and sell locally quality seed to farmers, and as a consequence received a grant to build 4 seed stores close to farmers. A second cooperative, COOPROSEM, realized significant economic progress in 2016 with some seed producers gaining more than USD 1,600. In 2015 and 2016, hybrids seed produced and sold in Mali represented 60% of total sorghum seed sold, and over 90% of seed produced were sold by the seed cooperatives. In Kenya, 101 (58 men and 43 women) **community seed producers** in six counties (Busia, Elgeyo Marakwet, Kitui, Machakos, Siaya and Tharaka Nithi) were trained in sorghum seed production techniques, and over 5 t of seed was produced. Similarly, 72 farmers were trained on the production of QDS seed in Kenya and Tanzania. On-station seed production in Kenya by ICRISAT and Kenya Agricultural and Livestock Research Organization (KALRO) Seed Unit produced 0.2 tons of breeder and 37.2 tons of foundation seed of four sorghum varieties (Gadam hamam, KARI Mtama 1, IESV 24029 SH and KAR Mtama 2) and **distributed to 15,659 farmers in western and eastern Kenya**. In Ethiopia, 3 varieties (Melkam, Dekeba and Teshale) were planted on a total of 22.5 ha for seed production at Mieso, Sheraro, Shewarobit and Kobo.

A total of **4111 t of pearl millet seed was produced in WCA** (3870 t in Niger, 215 t in Nigeria and 26 t in Mali), of which 4085 t were distributed, covering roughly 136,000 ha and reaching approximately 272,000 farm households. In the case of **finger millet in ESA**, a total of 8.07 t seed was produced, covering 1014 ha, and reaching 6,654 farm households. A total of 5.25 t seed produced **of pearl millet in India** covered 1200 ha, and reaching roughly 1500 farm families. A total of 2000 t seed of **improved post-rainy sorghum varieties** was produced in India covering 200,000 ha area and reaching 250,000 farm families. In Ethiopia, the **ICARDA-USAID barley project** were able to support **demonstration, seed production and capacity development** of NARS and seed sector stakeholders. About 128 demonstrations were conducted in farmer's fields (25 women) in 24 districts to create awareness of improved barley technologies. A total of 10 field days were organized and an estimated 4645 participants attended. This includes 3,897 farmers (905 women farmers, 23%) including members of farmer associations and/or cooperatives as well as 748 technical staff (86 female staff, 12%) from partner and stakeholder institutions including researchers, seed specialists, development agents, agriculture and cooperative specialists from district, zonal and regional Bureaus of Agriculture and NGOs and the private sector from federal and regional states. About 411.6 t of breeder, pre-basic and basic seed was produced and distributed for further multiplication and 1,406.3 t of certified/quality

seed was produced involving 1326 farmers (17 women) farmers involving 33 seed producer's cooperatives/groups and 2 multipurpose cooperatives. The seed produced is estimated to cover 14,063 ha with potential benefit to 63,346 farm households.

FLAGSHIP 5 – *POSTHARVEST VALUE & OUTPUT MARKETS:*

Association mapping of the AM-15 population of barley from Morocco, comprising 336 diverse accessions of 6-row and 2-row barley, for **grain nutrient contents** of Fe, Zn, protein and beta glucan led to the identification of candidate QTLs, and of molecular markers for use in marker-assisted breeding. Three markers were identified for Fe, close to the candidate QTL 1 on Chr 5, and three markers, one each close to candidate QTLs 3, 4 and 5, respectively on chromosomes 3, 4 and 6, were identified for grain protein. Evaluation of **grain nutrient content of 100 finger millet varieties** comprising of the farmer preferred local cultivars and improved varieties cultivated in East and Southern Africa (Kenya, Uganda, Tanzania, Ethiopia, Malawi and Zimbabwe) and grown in the field at the ICRISAT-Kiboko station, yielded the following results: Calcium content ranged from 350 to 680 mg/100g, with highest estimates in Masindi local, IE 546, GBK 000361A, Emiriot and Kal c; Iron content ranged from 8.33 to 97.3 mg/100g with highest estimates in KNE 1034, KNE 392, KNE 689, RW 127, KNE 1149 and P224. Highest estimates for Zn were in GBK 027189A (5.43 mg/100g), GBK 000.7.A (4.85 mg/100g), Emiriot (4.67 mg/100g) KNE 741 4.67 (mg/100g) and Otara Chilagal, while for protein, the highest estimates were in KNE 741 (21.9 % wt), KNE 392 (21.9 % wt), KNE 1034 (19.7 % wt), GBK 000414A (19.7 5 wt) and Quteke (19.7 % wt). A number of varieties such as Emiriot, KNE 741, P224 and KNE 1149 had high estimates for more than one nutrient. High variability among the local germplasm indicates that trait improvement for Ca, Fe, Zn and Protein can be achieved with germplasm within the region. **Grain nutrient analysis for Fe, Ca, Zn and protein** was also completed for 100 pearl millet accessions during 2016.

C3. Progress towards impact

Phase I of the BMGF-supported HOPE project (bilateral) was completed, and Phase II was approved and became active. Achievements of the Phase I HOPE project have been significant: **49 cultivars** were released by the project countries (25 sorghum; 13 pearl millet; and 11 finger millet); **183,421 farm households** were reached with new production technologies; **8,579 tons of seed** were produced under the program (6,251 tons of sorghum; 2,084 tons of pearl millet; and 244 tons of finger millet); **178,447 mini-packs of seed** were distributed initially at no cost, but at the beginning of the second year a partial cost recovery approach was implemented. The packs were sold to farmers primarily through field days, seed-producing farmers and local agro-dealers. Advanced degrees were received by **50 students** with HOPE support (15 PhD and 35 MSc degrees completed); **3,280 National Agricultural Research Systems (NARS) scientists** took part in HOPE-sponsored short courses.

Due to the interventions of the CRP, the number of farmers currently growing **improved pearl millet** is 432,900 in Niger, 89,956 in Nigeria and 11,780 in Mali. The area covered by improved pearl millet is 865,800 ha in Niger, 42,540 ha in Nigeria and 9,262 ha in Mali.

D. GENDER RESEARCH ACHIEVEMENTS

D1. Significance of the main gender research achievements

In 2016, there was an **increased attention to capacity building** on gender integration of biological scientists and social scientists members in the CRP and the bilateral projects mapped to the CRP. The **first results of on-farm experimentation on labor savings** due to gender responsive tools were recorded in the sorghum systems. **First results from GENNOVATE studies** were shared and a postdoctoral fellowship on gender integration in sorghum systems was commissioned.

D2. Main successes of Gender research in 2016

1. Dryland Cereals successfully undertook the **GENNOVATE global qualitative study** that investigated the links between gender norms and capacities to adopt innovations in agriculture. Nineteen case studies were implemented in Mali, Burkina Faso and Niger (for Dryland Cereals) and Tanzania, Ethiopia and India (for Grain Legumes). The year 2016 progressed with data analysis and

reporting. Preliminary results were disseminated at the Dryland Cereals and Grain Legumes annual review meeting at ICRISAT headquarters in Patancheru, India, in Oct 2016. **Four posters were produced and presented** at the annual review meeting: i. Aspirations of the youth: Implications for GLDC AFS; ii. What unleashes innovations in the GLDC AFS: A gendered perspective; iii. Impacts of social norms on women innovation pathways in cereals and legumes systems in Africa; iv. How do agricultural innovations influence socio-economic hierarchies in rural agricultural communities? Findings from Research in rural Rajasthan, India. Abstracts for these posters were published in the book of abstracts. Continued analysis and reporting of the results of the GENNOVATE is lined up for 2017, including publication of four Special Issues.

2. Moving away from a gender neutral and blind approach, steps have been taken towards a gender responsive research with an **increasing collection and analysis of data disaggregated by gender** in the flagships projects. For instance, in CoA1- Sorghum for WCA: **Evaluation of Some Selected Planters** for Improved Productivity of Sorghum Farmers in the Sudan Savannah of Kano State Nigeria. This research was undertaken to identify and promote technologies for use by women and youth to reduce drudgery via small and medium scale sorghum production and processing mechanization. The research objective was to evaluate the selected planters for drudgery reduction, time required for sorghum sowing and its effect on yields. Using a field experiment method with some selected planters, drudgery reduction and its effect on yield parameters was evaluated. The results revealed that the effect of tillage methods was significant on both the grain and stalk yields with highest grain yield (1241 kg/ha) and stalk yield (8204 kg/ha) recorded from flat plain tillage method. Also, there was significant drudgery reduction by 77% for IHP and 63% for LAD over manual sowing (Control). Due to efficiency of planters, the results indicate grain yield was increased by 66% for IHPgreen & IHPred and 44% for locally fabricated animal drawn planters (LADgreen & LADred) over manual sowing with three labours (Control).

3. Furthermore, **gender responsive program/project activity design and planning** is being achieved in the bilateral project, HOPE II. The gender units of DC and GL organized **CRP Drylands Cereals Gender Integration Workshop** held in Nairobi, 3-5 August 2016. The workshop brought together and trained scientists and national partners involved in HOPE II, SOMNI and FTF projects. At the end of the workshop, the Theory of Change, Impact Pathways and Outcome Logic Models for each Project (CRP, HOPEII, SOMNI, FTF) were reviewed. Participants developed a clear understanding of gender research and how to focus gender research in Dryland Cereals research. Gender research questions and well-defined work plans including target areas/persons, finances, and timeframes for gender research in each project were formulated. Participants developed work plans for implementation of gender research in dryland cereals projects under the CRP.

The achievements recorded in 2016 boosted the team's energy and increased excitement for greater milestones and accomplishments in 2017. However, news of the Phase II proposal not being approved has brought feelings of anxiety and apprehension among the gender team.

E. PARTNERSHIP BUILDING ACHIEVEMENTS

A new partnership, the Cambridge-India Network for Translational Research in Nitrogen (CINTRIN), led by the National Institute of Agricultural Botany (NIAB), UK and ICRISAT, was formed as one of four new Virtual Joint Centers in Agricultural Nitrogen, supported by the Newton Bhabha Fund of UK, the Biotechnology and Biological Research Council (BBSRC) of UK, and the Department of Biotechnology (DBT) of the Government of India. The objective of this partnership is to develop new cereal crop varieties that use nitrogen efficiently, which in turn, will support sustainable agriculture by minimizing the negative impacts of excessive use of fertilizers. The partnership will explore natural variations of cereals and conduct basic research in model plants to deliver new cereal varieties with enhanced nitrogen use efficiency.

The advantages of newly developed high biomass sorghum and pearl millet developed in India by ICRISAT and Indian Institute of Millets Research (IIMR) is supporting a new partnership that aims to use these material as feedstock in second generation or **lignocellulosic biofuel production**. India is a

signatory to the UN Climate Change Paris Agreement (COP21) and biofuel production is one of the thrust areas identified to reduce greenhouse gas emissions. The government's current goal is to blend 5% of ethanol in gasoline across the country and increase the blending percentage to 10% in the short run and up to 20% in the next five years. ICRISAT's work in partnership with IIMR and distilleries over the years on developing sweet sorghum value chain for first generation ethanol production is factored into plans for second generation ethanol production in this partnership that involves organizations such as ICRISAT, IIMR, Central Salt and Marine Chemical Research Institute (CSMCRI), and Reliance Industries.

The Dryland Cereals and Grain Legumes Programs held a final joint **program review meeting** during Oct 3 – 7, 2016, at ICRISAT Patancheru, and was attended by all program participants and partners, Research Committee members and Steering Committee members.

The USAID Linkage Grants to Dryland Cereals as well as the Competitive/ Commissioned Grants Program of Dryland Cereals offer significant opportunities for collaborative research as evident from the hyperlinked reports. Collaborative efforts with other CRPs continued from 2014, and included **fodder quality** research with Livestock & Fish; **biofortification research** for pearl millet with A4NH where Dryland Cereals contributed high-yielding adaptable material and A4NH supported the screening for high Fe and Zn; collaborations with PIM on **foresight analysis**; and strengthened collaborations with Dryland Systems to continuously fortify **agronomic and sustainability research** needs within Dryland Cereals.

F. CAPACITY BUILDING

An important capacity development effort launched in 2015, and continued in 2016, was the **Dryland Cereals Scholarship Program** jointly administered by the CRP, in partnership with APAARI for Asia, RUFORUM for East and Southern Africa, and WACCI for West Africa. Supported students from 2015 are continuing their programs, while following calls for newer students could not be continued in 2016 due to budget shortage. The program currently supports 1 Masters' student (partial), 14 Ph D students (fully or partially), 2 post-docs and 2 interns after their Master's degrees. The focus of study is any one of the Dryland Cereals crops. Of the total 19 supported, 7 are women.

ICARDA and partners organized a total of six Training of Trainers courses (ToT) where 205 participants (29 women) from NARS and Office of Agriculture attended. Moreover, 10 partner ARCs trained about 3265 participants. Among these are 2699 farmers (410 women farmers, 15%) and 566 technical staff (121 women, 21%) from partners and stakeholders which include development agents, district extension experts, and heads of cooperatives union. Two double cabin pickup cars to facilitate project activities and 1000 Purdue Improved Crop Storage (PICS) for chemical free seed storage were purchased and delivered to NARS. In the case of **finger millet**, 14,514 people (9,104 women) participated in short-term training courses that addressed emasculation techniques, data collection and seed production; good agronomic practices, agribusiness, post-harvest handling and product quality assurance; nutrition; use of weather and climate information for agriculture. Further, 4,189 farmers attended farmer field days, of which 2,489 were women. With regard to **pearl millet in India**, 440 farmers (110 women) attended farmer field days, and for **pearl millet in WCA**, a total of 968 people (663 women) underwent short-term training courses, while 5162 farmers participated in farmer field days. For **sorghum in ESA**, 25,698 people (16,290 women) attended short-term training courses in agronomy, seed production and post-harvest handling, and 10,247 farmers (3805 women) participated in farmer field days. For **sorghum in India**, 4235 farmers (1147 women) participated in farmer field days. Over 3,800 farmers from 38 farmers seed organizations were trained in seed production, good agronomic practices, seed storage, and cooperative organizational aspects for **sorghum in WCA**.

Dryland Cereals follows the CGIAR Open Access Policy as indicated in the Intellectual Assets Report submitted by the Lead Centre, ICRISAT, for 2016.

G. RISK MANAGEMENT

The risks cited in previous years remain, especially in terms of **fluctuating/reducing budgets** and **instabilities in one or more target countries**. The primary management measure for budget fluctuations has been consistent efforts for resource mobilization through bilateral funding. *As reported for 2015:* Budget fluctuations posed significant hazards to program implementation at all levels. Cyclical breeding activities, other research operations and collaborative implementation with partners are all affected one way or the other. The Dryland Cereals Scholarship Program also was scaled back in early 2016 after its launch just one year earlier. In order to lower transaction costs of program implementation under the existing budget constraints, the **CRP Office became very lean** with one CRP Director, one Administrative Officer and one Program Manager, supporting two CRPs since Sept 2015, Dryland Cereals and Grain Legumes. This placed excessive load on this office during 2016 with the additional demands for preparing Phase II proposals, revisions and responses to reviewer comments. As reported earlier, **sub-optimal staffing** in the participating CG centres in the target countries is a risk, and can prolong the time to impact or dilute the intensity of potential impact. Further, and again as indicated in previous reports, the **social and political instability** in the regions of operation of the program pose risks in both project implementation and staff retention.

H. LESSONS LEARNED

Overall level of confidence/uncertainty of the indicators provided in Table 1:

The confidence level this year has improved significantly from last year, primarily due to reporting through the new Monitoring, Evaluation and Learning platform. This year, the indicators 33 and 34 represent more than approximations, and are based on seed production and distribution supported by the CRP during the reporting year. Farm household numbers have been calculated in some instances based on average farm size and seed volumes, but not for all. We are not yet at the point of tracking disaggregation of farm households by gender, with regard to indicators 33 and 34.

Uniformity in activities across the five Flagships has suffered due to the focus on Flagship 2 forced by budget reductions.

Description, if relevant, of research avenues that did not produce expected results, and description of actions taken by the CRP, such as new research directions pursued and their expected outputs and outcomes:

Research in 2016 primarily focused on crop improvement, for which the best expertise in the world for the target crops in the target countries reside within the program. As such, almost all research avenues addressed have been successful bar instances of crop failure due to weather reasons beyond our control.

Lessons learned by the CRP from its monitoring of the indicators and from its qualitative analyses of progress:

Aside from points raised in previous years since program inception, the following are critical points of learning. System-level understanding of the following is crucial for the success of a program such as Dryland Cereals: (1) Commodity programs are essentially life science programs for which program timelines are determined by crop life cycles, and outcomes take three years and more. Imposing evaluations before the program even establishes itself achieves nothing more than eating away staff time to cater to multiple, simultaneous calls for reports and evaluations from multiple evaluation entities. Note that the current success of the Dryland Cereals owes quite a bit to continuing pre-program research supported by strong bilateral funding. (2) The approval of the original CRP proposals involved extensive time and effort in preparation of proposals, review, responses to reviews and revisions. The current practice of proposal preparation in similar mode every two years would require a separate unit with 10 to 15 full-time staffers if researcher time is to be protected and program results are to continue unimpeded. (3) Lessons from the industry can be of tremendous benefit to the CGIAR: Proposals are prepared in 5 to 10 pages for investments at all levels; once approved (which means plainly that sufficient thought went into such approval), the effort is usually given a minimum of five years in the plant science industry to prove itself; approval also takes into consideration whether the

effort is positioned for success, which basically means whether it is staffed sufficently and whether it is supported by the right infrastructure. (4) It is preposterous to rank CGIAR programs ignoring the ease or difficulty to function efficiently based on whether the program is led out of a developed nation or a developing nation. This beats the basic reason for which the CGIAR came into existence.

Annex 1: CRP indicators of progress, with glossary and targets.

List of published blog stories and press releases can be accessed here.

CRPs concerned by this indicator	Indicator	Glossary/guidelines for defining and measuring the indicator, and description of what the CRP includes in the indicator measured, based upon the glossary	Deviation narrative (if actual is more than 10% away from target)	2014		2015		2016	
				Target	Actual	Target	Actual	Target	Actual
KNOWLEDGE, TOOLS, DATA									
All	1. Number of flagship "products" produced by CRP.	**Concepts:** Adoption tracking models for sorghum and millets; Gender-differentiated demand for sorghum traits in the Sudan Savannah; Update of baseline studies in WCA; Sweet sorghum for ethanol production in WCA; Hybrid sorghum production in Northern Nigeria; Hybrid pearl millet for ESA; Integrated Striga Management; Biological control of pearl millet head miner; Mass production of parasitoids; Chemical or fertilizer seed dressing in Nigeria; Diversification of cropping systems in Malawi; GENNOVATE studies; Gender-responsive project planning in HOPE II. **Frameworks:** Agricultural Inputs Fair in Nigeria; Sorghum Innovation Platform in WCA; Field phenotyping network for WCA; Evaluation of planters for improved sorghum productivity in Sudan Savannah; Crop modeling for climate-smart sorghum plant types; Malting quality lab for barley in Rabat, Morocco; Pearl millet seed set under high-temperature stress; Virulence diversity of downy mildew pathogen of pearl millet; Training of seed producer cooperatives; Cambridge-India network for translational research in Nitrogen; Second-generation lingo-cellulosic biofuel production in India.		3	9	3	9	17	25

All	2. % of flagship products produced that have explicit target of women farmers/NRM managers.	The dryland cereals crops being considered primarily as women's crops, percentage flagships with target on women farmers will be more than 50%, but is accepted here as 50%.		50	50	50	50	50	50
All	3. % of flagship products produced that have been assessed for likely gender-disaggregated impact.	Adoption tracking models for sorghum and millets; Gender-differentiated demand for sorghum traits in the Sudan Savannah; Update of baseline studies in WCA; GENNOVATE studies; Gender-responsive project planning in HOPE II; Evaluation of planters for improved sorghum productivity in Sudan Savannah. (Total 6 out of 25).		50	11	25	20	20	24
All	4. Number of "tools" produced by CRP	DCL eAtlas; QTLs for fertility restoration in sorghum; Descriptive statistics for NIR calibrations; Reliable parameterization of photoperiod sensitivity; Genome-wide association mapping of finger millet nutrient accumulation; Constitution of 11 new FIGS subsets of barley; Marker-trait associations for multiple barley traits through GWAS; Doubled haploids in barley breeding; Interspecific pearl millet crosses; Wild species of Eleusine for climate-change adaptation.		5	8	5	6	10	10
All	5. % of tools that have an explicit target of women farmers.	The dryland cereals crops being considered primarily as women's crops, percentage flagships with target on women farmers will be more than 50%, but is accepted here as 50%.		50	75	50	50	50	50
All	6. % of tools assessed for likely gender-disaggregated impact.	Could not be planned due to budget restrictions.		50	0	0	0	0	0
All	7. Number of open access databases maintained by CRP.	DCL eAtlas; Dataverse; ICRISAT's ExploreIt; Database on malt barley in Ethiopia		3	5	3	3	3	4

All	8. Total number of users of these open access databases.			300	>300	300	>300	500	>500
All	9. Number of publications in ISI journals produced by CRP.	Please also refer to the Intellectual Assets Report submitted by the Lead Center, ICRISAT, for 2016.		45	47	45	49	45	14
1,2,3, 4, 6	10. Number of strategic value chains analyzed by CRP	Barley seed value chain study in Ethiopia.		4	5	3	3	1	1
1,5,6,7	11. Number of targeted agro-ecosystems analysed/characterised by CRP			NA	NA	NA	NA	NA	NA
1,5,6,7	12. Estimated population of above-mentioned agro-ecosystems			NA	NA	NA	NA	NA	NA
CAPACITY ENHANCEMENT AND INNOVATION PLATFORMS									
All	13. Number of trainees in short-term programs facilitated by CRP (male).	**Short-Term Training:** Barley, Training-of-Trainers, Ethiopia – 125; Barley, other – 2734; Finger Millet, ESA (Agronomy, seed production, post-harvest handling, agribusiness, nutrition, use of weather data in agriculture) – 5410; Finger Millet and Sorghum, ESA (Research Technician Training on Emasculation, Seed Production Technologies) – 8; Pearl Millet, WCA – 305; Sorghum, ESA (Agronomy, seed production and post-harvest handling) – 9398. **TOTAL – 17980.** **Farmer Field Days:** Barley, Ethiopia - 3658; Finger millet, ESA – 1700; Pearl millet, India – 330; Pearl millet, WCA – 2581; Sorghum, ESA – 6442; Sorghum, India – 3088; Sorghum, WCA – 2000. **TOTAL - 17999**		1000	6596	1000	8228	1000	35,979

All	14. Number of trainees in short-term programs facilitated by CRP (female)	**Short-Term Training:** Barley, Training-of-Trainers, Ethiopia – 25; Barley, other – 531; Finger Millet, ESA (Agronomy, seed production, post-harvest handling, agribusiness, nutrition, use of weather data in agriculture) – 9099; Finger Millet and Sorghum, ESA (Research Technician Training on Emasculation, Seed Production Technologies) – 5; Pearl Millet, WCA – 663; Sorghum, ESA (Farmer training on Agronomy, Seed Production and Post-Harvest Handling) – 16,290. **TOTAL - 26613** **Farmer Field Days:** Barley, Ethiopia – 991; Finger millet, ESA – 2489; Sorghum, ESA – 3805; Pearl millet, India – 110; Pearl millet, WCA – 2581; Sorghum, India – 1147; Sorghum, WCA – 1800. **TOTAL - 12923**		750	3503	750	~2320	1000	39,536
All	15. Number of trainees in long-term programs facilitated by CRP (male)	Total Ph.D and Masters students, interns and post-docs supported either partially or fully by the Dryland Cereals Scholarship Program.		20	22	20	24	10	21
All	16.Number of trainees in long-term programs facilitated by CRP (female)	(see above, but for female)		15	7	10	11	5	7
1,5,6,7	17. Number of multi-stakeholder R4D innovation platforms established for the targeted agro-ecosystems by the CRPs	Glossary: To be counted, a multi-stakeholder platform has to have a clear purpose, generally to manage some type of tradeoff/conflict among the different interests of different stakeholders in the targeted agro-ecosystems, and inclusive and clear governance mechanisms, leading to decisions to manage the variety of perspectives of stakeholders in a manner satisfactory to the whole platform. Indicate the focus of each platform in this cell, including geographical focus.		NA	NA	NA	NA	NA	NA
TECHNOLOGIES/PRACTICES IN VARIOUS STAGES OF DEVELOPMENT									
All	18. Number of technologies/NRM practices under research in the CRP (Phase I)	The numbers are very large, and can best be appreciated from information presented in the text. Please see the descriptive text of the report.		750	6329	2500	>2500	2500	>2500

All	19. % of technologies under research that have an explicit target of women farmers	The papers, web pages, blog stories, press releases and policy briefs supporting indicator #x must have an explicit focus on women farmers/NRM managers to be counted		50	50	50	50	50	50
All	20. % of technologies under research that have been assessed for likely gender-disaggregated impact	Reports/papers describing the products should include a focus on gender-disaggregated impacts if they are to be counted		50	10	10	15	10	15
1,5,6,7	21 Number of agro-ecosystems for which CRP has identified feasible approaches for improving ecosystem services and for establishing positive incentives for farmers to improve ecosystem	Use the same classification of agro-ecosystem as for indicator 11 above, including geographical location and agro-ecological zone		NA	NA	NA	NA	NA	NA
1,5,6,7	22. Number of people who will potentially benefit from plans, once finalised, for the scaling up of strategies	Indicate the potential number of both women and men		NA	NA	NA	NA	NA	NA
All, except 2	23. Number of technologies/NRM practices field tested (phase II).	The numbers are very large, and can best be appreciated from information presented in the text. Please see the descriptive text of the report.		700	2173	700	>700	700	>700

1,5,6,7	24. Number of agro-ecosystems for which innovations (technologies, policies, practices, integrative approaches) and options for improvement at system level have been developed and are being field tested (Phase II)	Clearly identify in this cell the type of technology and the geographical location of the field testing/pilot projects, and use the same classification of agroecosystem as for indicator 11, specifying the type of agroecosystems in which field testing is taking place		NA	NA	NA	NA	NA	NA
1,5,6,7	25. % of above innovations/approaches/options that are targeted at decreasing inequality between men and women			NA	NA	NA	NA	NA	NA
1,5,6,7	26. Number of published research outputs from CRP utilised in targeted agro-ecosystems			NA	NA	NA	NA	NA	NA
All, except 2	27.Number of technologies/NRM practices released by public and private sector partners globally (phase III)	**18 sorghum varieties** (2 in Nigeria, 8 in Mali, 6 in Kenya and 2 in Kazhakstan)**; 6 sorghum hybrids** (1 in Mali, 5 in Kenya); **14 pearl millet varieties** (7 in Niger, 2 in Nigeria and 5 in Mali)**; 4 pearl millet hybrids** (1 in Mali and 3 in India)**; 4 finger millet varieties** (all in Ethiopia) and **5 barley varieties** (3 in Ethiopia and 2 in Morocco)		15	8	10	8	10	51
POLICIES IN VARIOUS STAGES OF DEVELOPMENT									
All	28. Numbers of Policies/ Regulations/ Administrative Procedures Analyzed (Stage 1)	Draft seed policy for barley in Ethiopia.		4	4	3	3	1	1

All	29. Number of policies / regulations / administrative procedures drafted and presented for public/stakeholder consultation (Stage 2).	….. ……that underwent the second stage of the policy reform process. The second stage includes public debate and/or consultation with stakeholders on the proposed new or revised policy / regulation / administrative procedure. Clearly identify in this cell the type of policy, regulations and so on, and the geographical location of the consultations		1	1	0	0	0	0
All	30. Number of policies / regulations / administrative procedures presented for legislation (Stage 3).	: … underwent the third stage of the policy reform process (policies were presented for legislation/decree to improve the policy environment for smallholder-based agriculture.) Clearly identify in this cell the type of policy and the country/region concerned		1	1	0	0	0	0
All	31. Number of policies / regulations / administrative procedures prepared passed/approved (Stage 4).	: …underwent the fourth stage of the policy reform process (official approval (legislation/decree) of new or revised policy / regulation / administrative procedure by relevant authority). Clearly identify in this cell the type of policy and the country/region concerned		1	1	0	0	0	0
All	32. Number of policies / regulations / administrative procedures passed for which implementation has begun (Stage 5).	: …completed the policy reform process (implementation of new or revised policy / regulation / administrative procedure by relevant authority). Clearly identify in this cell the type of policy and the country/region concerned		1	1	1	1	0	0
OUTCOMES ON THE GROUND									
All	33. Number of hectares under improved technologies or management practices as a result of CRP research.	Barley – 14,063 ha; Finger millet – 1,014 ha; Pearl millet, WCA – 136,000 ha; Pearl millet, India – 1200 ha; Sorghum, ESA – 8,000 ha; Sorghum, India – 200,000 ha; Sorghum, WCA – 80,000 ha. These are based on seed production and distribution supported by the CRP during the current reporting year.		20,000 in WCA 15,000 in ESA 15,000 in WA and NA 30,000 in SA	30,800 in WCA; 30,000 in ESA; 15,000 in WA and NA; 222,000 in SA	20,000 in WCA 15,000 in ESA 15,000 in WA and NA 30,000 in SA	30,000 in WCA; 20,000 in ESA; 15,000 in CWANA; >100,000 in SA	200,000	440,277

All	34. Number of farmers and others who have applied new technologies or management practices as a result of CRP research	**Number of farm households:** Barley – 63,346; Finger millet – 6,654; Pearl millet, WCA – 272,000; Pearl millet, India – 1,500; Sorghum, ESA – 15,659; Sorghum, India – 250,000; Sorghum, WCA – 150,000. These are based on seed production and distribution supported by the CRP during the current reporting year. Though the numbers of men and women farmers are not disaggregated yet, the primary growers of dryland cereal crops are women farmers and as such the number of women farmers is considered to be more than 50%.		10,000 in WCA 5000 in ESA 30,000 in WA and NA 25,000 in SA	31,000 in WCA; 30,000 in ESA; 5000 in WA and NA; 311,000 in SA	10,000 in WCA 5000 in ESA 30,000 in WA and NA 25,000 in SA	30,000 in WCA; 30,000 in ESA; 30,000 in CWANA; 50,000 in SA	150,000	759,159

Annex 2: Gender mainstreaming in Dryland Cereals

Annex 2: Performance Indicators for Gender Mainstreaming in CRP DC		
Performance Indicator	**CRP performance meets requirements**	**CRP performance exceeds requirements**
1. Gender inequality targets defined	**Participatory gender responsive approached employed** in CRP DC in traits selection and farmer field school training and other trainings now include more number of women farmers being targeted and sought for **Baseline data with sex disaggregated data produced in 2016**: On-farm evaluation was conducted by 20 farmers belonging to 10 villages in 4 zone **Increased decision-making power** for women in their households through success in carrying out barley cultivation. https://mel.cgiar.org/uploads/reporting/PnqjPBpT0x8gZZJF74OQm6gulMcQ3u.pdf	**Project's outcome targeting intervention for women** through the *Evaluation of Some Selected Planters for Improved Productivity of Sorghum Farmers in the Sudan Savannah of Kano State* Nigeria.
2. Institutional architecture for integration of gender is in place	Understanding of the significance of gender responsive research among scientists and Senior Managers **fostered collaboration and improved research outputs and outcomes**	Two Postdoctoral Fellows and a gender scientist recruited to lead and carry out gender research in CRP DC Improved capacity of biophysical scientists and national partners to design and implement gender responsive research. The outcome of the PDF research lead to a research activity that Identified the traits or combination of traits that drive farmers demand for and or experimentation with hybrids, determine if hybrids fill specific niches (and which), and if farmers manage for varieties with different traits. https://mel.cgiar.org/dashboard/powb2