Feed the Future Innovation Lab for
Collaborative Research on Grain Legumes
(Legume Innovation Lab)

FY 2017 Annual Project Technical Progress Report
(October 1, 2016 – September 29, 2017)

Project Code and Title: SO1.A5 Genetic improvement of cowpea to overcome biotic stress and drought constraints to grain productivity

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I. Abstract of Research and Capacity Strengthening Achievements

Multi-location screening of a cowpea aphid resistance panel was completed using uniform test protocols to characterize resistance to aphids and to identify cowpea aphid biotypes in four African and one US locations. Differences between US and African aphid populations were found based on response to resistance source and mitochondrial molecular sequence, and three independent resistance QTL were discovered. Cowpea populations segregating for resistance to pod bugs, flower thrips and aphids were advanced, phenotyped and genotyped for QTL discovery for use in marker-assisted breeding across project countries. Breeder and Foundation Seed were multiplied and distributed to farmers' organizations for Certified Seed production of five recently released large white-seeded varieties in Senegal and four pre-release LIL advanced lines in Burkina Faso. In California, advanced lygus, aphid and disease resistant blackeye lines were tested on-farm and on-station. Seventeen African students including six women engaged in PhD and MS/MPhil degree training programs. Capacity strengthening awards to INERA-Burkina Faso, ISRA-Senegal and SARI-Ghana supported modern seed quality testing and insect culturing and screening development. Continuous short-term training occurred with each Host Country through iterative data analysis and interpretation cycles, and training visits to UC Riverside and Burkina Faso.

II. Project Problem Statement and Justification

The project focus is to 1) discover insect tolerance and resistance QTL for

cowpea breeding; 2) increase African and US cowpea productivity by improved varieties with resistance to insect stresses, drought tolerance or disease resistance; 3) expand farmer marketing opportunities with improved cowpea varieties; and 4) provide training and capacity building in modern cowpea breeding. The project is aligned with FTF research strategic priorities 1) crop resistance to heat, drought, salinity and flood; 2) West African Sudano-Sahelian systems emphasizing insect-resistant cowpea; and 3) grain legume productivity. Strategically, our partner countries Ghana, Senegal and Burkina Faso represent primary agro-ecologies for cowpea production in the Sudano-Sahel.

The project uses genomics and modern breeding to improve cowpea yield by targeting insect tolerance and resistance. By leveraging genomic resources developed with CGIAR Generation Challenge Program and USAID Climate Resilient Cowpea Innovation Lab funding, we apply comprehensive modern breeding tools. Insect pests constrain cowpea productivity in West Africa; the project targets insects attacking early (aphids), mid-flowering and pod-set (flower thrips), and later pod-filling (pod-sucking bugs) cowpea stages. Discovery work through phenotyping, genetic mapping and QTL identification needs to be done for these insect pests, using high throughput SNP genotyping, genetic maps, and QTL discovery. The project breeding programs have segregating populations with target traits, providing valuable trait discovery and breeding resources.

Low productivity of agriculture is central to rural and urban poverty in Africa. On-farm cowpea yields in West Africa average 240 kg/ha, even though potential yields are often five to ten times greater. Most of the loss in yield potential is due to drought, poor soil fertility, and insect pests. By targeting insect tolerance and combining with drought tolerance, cowpea productivity, food security and rural incomes can be increased. To increase marketing options, new cowpea varieties must have features desired by consumers - grain appearance, cooking and processing characteristics. Regionally adapted cowpea varieties with large white grain and large rough brown grain resistant to pests would increase marketing opportunities of cowpea farmers and traders in both West Africa and the US.

III. Technical Research Progress

Objective 1. Discover QTL for insect resistance and apply in molecular breeding for target regions in West Africa and the US.

1.1 Aphid resistance: We have tested the genetic relatedness of five sources of cowpea aphid (*Aphis craccivora*) resistance. Field observations in Africa and California indicate differential effects of resistance sources on aphid populations from different cowpea production areas. Cowpea lines IT97K-556-6, KvX295-2-124-99, an IITA wild donor line (TVNu1158), UCR01-11-52/SARC1-57-2, and 58-77 representing a set of resistance donor genotypes plus known susceptible control lines were seed-multiplied in 2014 and 2015 and the seed shared among partners. Uniform screens in locations across all project NARS (Burkina, Ghana,

Senegal) and California were conducted in 2014 - 2017 in field plots or screenhouses, with 4-fold replication, using standard resistance assessment scales across for all tests. The uniform test design and coordination planning for the aphid resistance assessment was developed by the project team. At least two years of date were collected per project country. Tests failed in some locations/years due to lack of aphid infestation. For example, in Senegal in 2017 no aphids appeared, so no evaluation was possible in the field or screenhouse. A summary of the multi-location screening results is presented in Table 1. The resistance donors and susceptible controls were SNP genotyped in FY14, coordinated by UCR. The same panel was screened again in 2017 by INERA in Burkina Faso using aphids collected at Kamboinsé and Pobé-Mengao, to look for differential lines for aphid resistance between the two aphid colonies. The results are being prepared for publication.

Genetic mapping of the aphid resistance in IT97K-556-6 at UCR had revealed two QTLs on cowpea linkage groups LG1 and LG7, published in 2015 (Huynh et al., 2015). The aphid resistance found by SARI in the Ghana line SARC-1-57-2 was analyzed genetically as part of a recurrent backcrossing program. Inheritance indicated a single dominant gene governing resistance. Using SSR marker analysis for the SARC-1-57-2 resistance together with genomewide SNP markers, as part of Richard Agyare's SARI –UCR training in 2016, we were able to map the major resistance locus from this donor to cowpea LG 10, using two SNP-genotyped biparental RIL populations. This finding also confirmed that the SARC-157-2 aphid resistance is distinct from that in the IT97K556-6 line, which is controlled by gene on LG7 and LG1. This work submitted to *Plant Breeding* in 2017 is under review.

A follow-up study was initiated upon confirmation that SARI's source of resistance (SARC 1-57-2) was distinct from that in IT97K 556-6. The LIL project in Ghana collaborated with The Kirkhouse Trust project in pyramiding the two gene sources into farmer-preferred cowpea varieties in Ghana. Under this collaboration, Kirkhouse Trust fully sponsored a 4-year PhD study of a young scientist (Patrick Attamah) to work on the gene pyramiding. The two aphid resistance QTLs found in IT97K 556-6 will be deployed in marker-assisted backcrossing. The student will also convert SNP markers to PCR-based markers and deploy them in marker-assisted selection at SARI. Screening populations are being developed for both phenotyping and genotyping both in Ghana and at UCR. Conversion of SNP markers and a search for SSR markers that can also be used to select for the two sources of resistance are underway. Leaf samples will soon be sent to UCR for genotyping.

The IT97K-556-6 source of aphid resistance was used to introgress the two resistance QTLs into two main US blackeye varieties, CB46 and CB50 by recurrent backcrossing. Linkage of resistance to pink eye-color was broken and the advanced lines positive for QTL SNP marker alleles (BC5F2) were greenhouse aphid-screened to confirm resistance, and grown in 2016 at the UC Kearney Research Center (KREC) for yield and grain quality evaluation (Table 2). The 3 CB46 aphid resistant lines (designated 2014-008-x) and CB50 aphid resistant lines (designated 2014-010-x), performed equivalent to the recurrent

parent cultivars without aphid pressure (Table 2). The two best performing lines with CB46 and CB50 background were multiplied in the greenhouse and field performance tested in main season 2017. Growth and pod load data looked very promising, and harvested grain is currently being cleaned for yield and grain size data collection.

We are working with Dr. B. Pittendrigh and M. Tamo (Project SO1.B1) in the characterization (molecular fingerprinting) of the aphid isolates representing the different aphid populations at each location. This will be especially valuable if, as expected, aphid biotypes are delineated on the cowpea resistance sources. Samples of aphids were collected and stored for DNA extraction and genotyping. For example, in Burkina Faso, aphids were collected from Kamboinsé, Pobé-Mengao and Farako-Ba representing three diverse cowpea production zones. Five samples were also collected in different fields in the Bambey, Senegal area in 2016, although in the 2017 rainy season, no aphid population appeared so samples were not obtained. Aphid samples from SARI, Tamale, Ghana and UCR, Parlier, Fresno Co. California were used to compare old-world and new world *Aphis craccivora* by complete sequencing of their mitochondrial genomes (mitogenomes). The comparison showed only very minor differences between the sequences (99.7% identity), reflecting only very recent divergence of the old and new world forms. A joint paper for this work was published in *Agrigene* in 2017. From the wild donor IITA line TVNu1158 a RIL population has been developed for mapping QTL and it was genotyped using the 60K SNP iSelect by UCR. This work was conducted in collaboration with Drs. Fatokun and Boukar at IITA, Nigeria.

1.2 Flower thrips resistance: We identified and SNP-mapped loci (*Cft-1* and *Cft-2*) for flower thrips (*Megalurothrips sjostedti*) tolerance donated by Sanzi in the cross Sanzi x Vita 7, and these loci are promising for introduction and selection in breeding progenies but require better definition through phenotyping. Additional sources of thrips tolerance are 58-77 and Tvx3236. In Senegal, during the 2016 and 2017 rainy seasons, the RIL populations Sanzi x Vita 7; 58-77 x Yacine and the cowpea MAGIC population were planted each in two trials with flower Thrips control and no spray comparison plots. Data were obtained on number of peduncles and pods and number of Thrips in five flowers for the first population. Thrips damage rating was also obtained for both populations. The families derived from crosses of resistant (Sanzi x 58-77) and large seeded varieties (ISRA-3178 and ISRA-3217) were advanced to the F4 and F5 during the off-season and rainy season. The M4 and M5 generation of selected Yacine lines was also evaluated and additional selections made. Promising results were obtained for the second time after 8 months of Yacine and Melakh M4 lines tests for reaction to bruchids. The resulting lines were bulked for seed multiplication and large scale evaluation for bruchid resistance.

The Sanzi x Vita 7 and Yacine x 58-77 RIL populations from Senegal were phenotyped for the third time for flower Thrips tolerance, both at the Manga station in the Sudan Savanna zone and at Nyankpala in the Guinea Savanna zone. Harvesting is in progress and data will be analyzed together with the data from the two previous seasons. This will help check for lines that show

consistency in supporting low numbers of flower Thrips. We are planning to co-analyze the Senegal and Ghana phenotype data to definitively map the flower Thrip resistance determinants.

In Burkina Faso, 20 cowpea genotypes (TVx3236, Sanzi, NS-1, NS Farako-Ba, Pobe local, Donsin local, Moussa local, Nafi, Tiligré, Gourgou, Komcalle, KVx165-14-1, KN-1, KVx780-1, KVx 780-3, KVx404-8-1, TVu1509, KVx745-11P, KVx780-6, KVx61-1) were screened for flower Thrips tolerance. The screening confirmed resistance in genotypes Sanzi, TVx3236 and TVu1509. For lines released in 2012, the screening confirmed resistance for Nafi. In the lines in the release pipeline, the new line included this year, KVx780-3, was the most tolerant, followed by KVx780-1, but KVx780-6 showed some susceptibility compared to 2016. Also, KVx165-14-1 confirmed its tolerance levels to flower Thrips. Crosses were made using KN-1/Sanzi, KN1/TVx3236, Komcalle/Sanzi, Komcalle/TVx3236, KVx780-3/Sanzi, KVx780-1/ Sanzi, and Tiligre/Sanzi. These populations will be genotyped and phenotyped for genetic analysis and marker discovery.

1.3 Pod-sucking bug resistance: The Heteropteran Coreid pod-sucking bugs (*Clavigralla tomentosicollis* complex) are a major yield suppressor in Burkina Faso, Ghana and neighboring countries. To identify genes or QTL for resistance to pod-sucking bugs we used biparental resistant x susceptible segregating populations in Burkina Faso in FY14 and FY15 to map QTL and initiate their selection as a new breeding target. The primary resistance donor is IT86D-716. Problems with germination in these populations resulted in insufficient data sets for mapping. Two existing F2 populations generated from resistance donor IT86D-716 with parents Kvx771-10G (Nafi), Tiligre, Gourgou, and IT98K-205-8 enable combining Striga resistance with pod-sucking bug tolerance. The parents were genotyped through LGC Genomics and the F2 and F3 populations are being phenotyped for pod bug resistance in Burkina Faso, in collaboration with Dr. Dabire (Figure 1). A second set of segregating materials was developed from crosses between six parents involving the resistant IT86D-716 to provide more viable populations.

The two segregating materials were screened under artificial infestation at Kamboinsé research station for genetic analysis. Results showed that resistance might be under multi-genic additive gene control (Table 3). Leaf samples of F1, F2, and BC1F1 were collected and sent to UCR for genotyping. A local bench genotyping was also done at Kamboinsé using 47 SSR markers to look for markers associated with resistance (Figure 2). Figure 2 shows the results with four markers which amplified the DNA of the resistant and susceptible parents. However, only markers MA127 and MA84 were polymorphic. Amplification with marker MA127 yielded two bands (200pb and 175pb) in the resistant parent and a single 200bp band in the susceptible parent. With marker MA84, the resistant and susceptible parent each has one band at 250bp and 225bp, respectively. Markers MA114 and MA80 were monomorphic, generating bands of the same molecular weight in both parents. Figure 3 shows the typical damage caused by pod-sucking bugs on cowpea. Leaf material from the new sets at F7 has been

collected for SNP genotyping and QTL mapping resistance to pod bugs, Striga, aphids, and bruchids contained in the same population set. New crosses were made using only a single plant for maintaining purity of crosses. Leaf samples of parents and F1 in these crosses were collected and dried for sending to UCR for genotyping and progenies will be phenotyped in Burkina Faso.

Insect characterization: For the three insect groups (aphids, thrips, pod bugs), we collaborated with Dr. Pittendrigh and Dr. Tamo (Project SO1.B1) to utilize our project trial sites to collect insect samples for use in molecular characterization of the insect populations. Collections are being made at all test locations, thereby allowing a robust comparative profiling of insect populations. We have tested a protocol for insect DNA collection, in which insects are placed in plastic bags with silica gel packs; this dries the insect samples and preserves the DNA. As described above under Objective 1.1, aphid samples from SARI, Tamale, Ghana and UCR, Parlier, Fresno Co. California were used to compare old-world and new world *Aphis craccivora* by complete sequencing of their mitochondrial genomes (mitogenomes). The comparison showed only very minor differences between the sequences (99.7% identity), reflecting only very recent divergence of the old and new world forms. In Burkina Faso, pod bugs were collected from Kamboinse, Pobe-Mengao and Farako-Ba. In Senegal samples were obtained for cowpea aphids in the Bambey production area.

The LIL project in Ghana also evaluated the MAGIC population for insect pest resistance both in an insectary and in the field. The insectary screening for aphid resistance using the seedling screening technique identified M031 and M262 as aphid resistant lines. The field evaluation covered all the major pests at the various growth stages of cowpea - vegetative, flowering and podding. Data on the field evaluation are being compiled for analysis. The evaluation will be extended to screening for sources of resistance to cowpea weevil *Callosobrucus maculatus*.

Objective 2. Complete release and validation of advanced cowpea lines developed under the Pulse CRSP in Burkina Faso, Senegal, and US.

2.1. We continued to use our genotyping capability to advance the BT gene introgression for Maruca resistance with our SNP marker panel. Genotyping was initiated in FY14 primarily focused on background selection with genome-wide markers in segregating progeny of backcross breeding populations in Burkina Faso and Ghana. The goal is to expedite the selection of lines with the highest percentage of elite recurrent parent content in each country (e.g., improvement of elite variety IT97K-499-35 in Ghana and several elite local varieties in Burkina Faso, including Moussa Local, Gourgou 3, 7 and 11, IT98K-205-8 and KVX 745-11P). In Burkina Faso BC3 were genotyped in FY14. Populations were advanced to the BC3F5 and BC5F3 stages and leaf samples were collected and some were SNP genotyped. Farmers' managed trials in CFTs are ongoing in 2017 at

three locations for agronomic performance and also a single-site trial was conducted under insect net protection for resistance efficacy of the introgressed lines. In 2017, HC partners received training on Tassel for GWAS analysis at UCR in January. Zida Serge Felicien spent the month of January at UCR to learn more about genetic resources handling and genotypic data analysis.

2.2. We are capitalizing on the previous Pulse CRSP breeding effort by completing the release requirements of several advanced breeding lines that are in the final stages of performance testing in Burkina Faso, Senegal and California.

In Senegal, a new version of Melakh resistant to Striga was obtained through marker-assisted selection. The selected BC4 F3 families were multiplied during the rainy season in 2016. These Striga resistant lines were evaluated at 3 sites in 2 farmers' fields at each site in 2017. Also the line ISRA-3006 was seed-multiplied; this line was obtained from a cross between the local variety Baye Ngagne and the Mougne-derived line ISRA-514 which was resistant to aphids in earlier tests, both with the same seed type. This line was yield-tested earlier and had good performance with larger grain size and same color. Dr. Cisse decided to promote it as a variety because it is earlier maturing than the local variety. On-farm demonstration trials were conducted at 3 farmers' fields near the Bambey station in 2017. The cowpea MAGIC population was multiplied during the off-season and introduced in a preliminary yield trial at the ISRA/CNRA Bambey station during the 2016 rainy season. Data were obtained on time to flowering, maturity, numbers of peduncles and pods, 100-grain weight and yield. The same trial was conducted again in 2017. In the 2017 rainy season, 1700 new cowpea lines were introduced in preliminary yield trials at Bambey. These were tested in 17 designs with 2 replications, each having 100 lines. These lines were obtained from elite crosses between Melakh, Yacine and the newly released 5 varieties (Table 4). They were selected for grain quality (size and color). These 5 varieties released in 2015 (Lisard, Thieye, Leona, Kelle and Sam) were again multiplied on 0.25 ha each in 2016 and 2017 for additional Foundation Seed production at the Bambey station. Amounts of Breeder's Seeds of new and current cowpea varieties produced in Senegal in 2017 are given in Table 5. RESOPP received Breeder Seed obtained during the off-season to multiply on 1 ha each for Foundation Seed production during the rainy season. The new version of Striga resistant Melakh and ISRA-3006 were multiplied for Breeder Seed on about 0.01 ha.

In Burkina Faso, 20 pre-release CRSP advanced lines developed by the breeding team were on-farm performance tested in 2013, and the best nine lines were re-evaluated in 2014. Multi-location tests were conducted at Saria, Pobe, and Kamboinse in Burkina Faso during the 2015 main rainy season. The four best performing of the nine lines plus two standard checks were used for testing and these were re-evaluated in the off-season in 2016 and 2017, emphasizing yield and grain quality, plus any disease susceptibility. Trial design was based on using 4-row plots, 5 m long and 4 reps arranged in a RCBD. Breeder Seed of the best lines chosen for release submission was produced at Saria during the main

season 2016. About 20 kg of Breeder Seed of each of these lines was used to initiate Foundation Seed production in the 2017 off-season. During the LIL meeting held in Ouagadougou, a visit was made to the cowpea group supported by INERA through LIL, ILCRC, and TLIII funds at Gourcy (Zindiguesse and Lago) to produce Certified Seed covering 10 ha in Zindiguesse and 5 ha in Lago. INERA is completing forms to be submitted to the National Variety Release Committee for evaluation in 2018. If approved, the varieties will be released by the end of 2018.

In California, advanced breeding lines were field tested for release potential, based on performance data collected in previous on-station trials. These represent CRSP developed lines that carry a combination of lygus bug tolerance, and root-knot nematode and Fusarium wilt resistance. For the best advanced blackeyes from 2015, we conducted on-farm yield trials in 4 Tulare Co. farmers' fields (Table 2) and on-station trials at the UC Kearney Station, Fresno Co. (Tables 6 and 7), in main season 2016 (harvested in October-November 2016) to assess commercial yield performance. Seed size and yield data from the trials are presented in Tables 2, 6 and 7, together with field assays conducted for resistance to three common root-knot nematode species and a greenhouse assay for resistance to Race 4 of Fusarium wilt. The 10 lines plus the standard varieties CB46 and CB50 were tested under insect-protected conditions (Table 2), while a no-insecticide unprotected lygus screening trial was conducted with two lines with lygus bug tolerance (Table 7). The test design was a four-row 4-fold replicated RCBD for the trials with the center two rows machine harvested. Yield weights, 100-seed weights and lygus damage to seed were assayed. All yield and performance data were analyzed by standard ANOVA.

Trials comparing yield and grain quality of nine new blackeye breeding lines together with CB46Rk^2, CB46, and CB50 were conducted under early-planted, double-flush production conditions at the Kearney Station (Table 2). Two most promising lines were evaluated together with CB46Rk^2 and CB46 in large strip plots in four Tulare County commercial blackeye fields. Overall the yields were higher than in 2015. Some advanced lines including four BC5F2 lines with two aphid-resistance QTLs backcrossed into CB46 and CB50, had equivalent grain yield to CB46 at KREC, and one line had equivalent or higher yield compared to CB46 at the Tulare Co. locations (Table 2). Some lines also combine the advantage of stronger, broad-based resistance to root-knot nematodes and resistance to Fusarium wilt Race 4 (Table 2). They have seed size that is consistently the same or larger than CB46 but less than CB50. CB46Rk^2, a new version of CB46 with improved resistance to root-knot nematodes but with slightly smaller seed size, performed similarly to CB46 in the Tulare strip trials and at KREC in 2016 (Tables 2, 6).

In 2016 three lines first selected in 2007-2009 were evaluated under insect unprotected conditions at Kearney. These lines resulted from a long-term breeding effort to combine lygus resistance with high quality grain and high production. Selection and testing over this period resulted in choosing a best line, 07KN-74, for larger scale testing in 2016. Lygus pressure was heavy in 2016,

resulting in grain yield loss of 36% in the check CB46 in comparison with the protected conditions in the same field. The unprotected yields were significantly higher than CB46 for the advanced line 07KN-74, further confirming strong yield ability under lygus pressure. This early maturing blackeye may be suitable as an option for growers desiring shorter season single-flush production.

Three trials were planted in May 2017 in Tulare Co. with four lines (CB46, N2, 10K-29, CB46Rk2) in large 0.5 acre field-length 6-row strips (harvested October 2017) in three farmer field sites. Trials at the UC Kearney station were planted in June 2017 with nine lines (CB46, CB46Rk2, two new lygus resistant lines and two N lines) in four-extended row 4-fold replicated RCBD. Harvesting, threshing and seed cleaning is underway at time of reporting.

During the 2017 main rainy season in Burkina Faso new varieties were multiplied as Breeder Seed on 1.5 ha for additional Foundation Seed production. The resulting products will be provided to Certified Seed producers including new farmer organizations for increase and demonstration in 2018.

Objective 3. Increase capacity of NARS in Burkina Faso, Ghana and Senegal to serve the cowpea sector.

Short-term Training: Short-term training in molecular breeding for young trainee breeders and NARS scientists was continued in FY17. Continuous short-term training occurred through iterative data analysis and interpretation cycles using the phenotyping and genotyping data generated by each of the three Host Country partner teams (about 12 participants). To continue periodic intensive training, we conducted face-to face training and planning with HC partners at UCR in January 2017 and in Ougadougou, Burkina Faso in August 2017. The molecular breeding approach is complex and requires a combination of hands-on experience with self-generated data sets, augmented with periodic intensive training workshops to improve knowledge, skills and problem-solving. The technologies underlying the genotyping capability are in a state of frequent enhancement and upgrade, requiring periodic training input. Thus both young breeder trainees new to the programs and experienced breeders from the HC NARS are in need of this training.

Zida Serge Felicien from INERA received a one-month training in January 2017 on GWAS and molecular data handling at UCR. Also in Burkina Faso, more than 1000 farmers received training through direct engagement in field practicals, field days or theoretical training for good production practices. This included more 700 women farmers from 5 different associations (YiYE, Gourcy, Sanguié, Pobé-Mengao, and Dedougou).

Degree Training: We conducted degree training for two graduate students in the report period at UCR and 15 in Africa (2 in Senegal, 6 in Ghana and 7 in Burkina Faso). The trainees are described in detail under Section VI 2. In Ghana, the LIL project collaborated with Innovation Lab for Climate Resilient Cowpea and the Kirkhouse Trust to engage graduate students co-supervised on topics developed from the LIL project at SARI. Zida Serge Felicien and SIDIBE Hamadou, two of

the Burkina team members, registered at the University of Ouagadougou for a Ph.D. are partially supported. Zida will be using the UCR platform for genotyping and short time training and SIDIBE is working on flower Thrips resistance. Coulibaly Soumabere defended his M.Sc. on pod-sucking bug resistance in Burkina Faso. Adelaide Ouedraogo, a student registered in the WACCI program is working on aphid resistance using the aphid resistance panel; he is registered at the University of Ouagadougou for a PhD. Alectra and mutagenic cowpea materials were genotyped with the UCR platform -- this genotyping supported two student activities, Dieni Zakara registered at WACCI and Karidiatou Gnakambary at the University of Ouagadougou for PhD.

IV. Major Achievements

Under Objective 1.1 -- Aphid resistance

A differential cowpea panel of aphid resistance sources and control lines was seed-multiplied and used in multi-location field screening and screenhouse seedling screening during FY15-FY17. Using a uniform test protocol for aphid biotype and resistance screening under field and greenhouse conditions, several aphid resistance sources effective against both US and West African aphid populations were identified. This has allowed differentiating biotypes, for example between Senegal and California CB27 has a resistant reaction in Senegal while susceptible in California. Reaction in Senegal and Ghana seems to highlight similar biotypes in the two zones.

Sets of F1 and F2 populations were made from aphid resistant x drought tolerant line crosses at SARI, Ghana.

F1 and F2 populations were made from aphid resistant x Striga resistant farmer-preferred variety crosses by INERA, Burkina Faso. Aphids are being reared to be used in screening for genetic studies under a PhD student project. This student is registered at WACCI. Recent work showed some close resemblance between aphids from Pobé-Mengao and Kamboinse but while awaiting confirmation by molecular characterization, a second round of screening has been undertaken. Agricultural technicians screened the material in Kamboinsé using aphids from Kamboinsé and Pobé-Mengao.

Advanced backcross progenies were developed by adding aphid resistance QTLs into recurrent parents CB46 and CB50 and field tested, to select for California blackeyes with aphid resistance for the US production system.

Three aphid resistance loci were genetically mapped to three different cowpea chromosomes.

The mitochondrial genomes of cowpea aphid populations from Ghana and California were completely sequenced and compared for their relatedness, in cooperation with LIL project SO1.B1.

Under Objective 1.2 – Flower thrips resistance

Segregating populations were developed in Senegal and Ghana from mutagenesis or from hand crosses using three sources of thrips resistance. These are in various stages of phenotyping and genotyping for QTL mapping. Tolerant lines were identified in Burkina Faso and crosses were made in the

2017 off-season. The populations will be used in genetic studies and new lines development. Agricultural technicians screened the material using Thrips from Kamboinsé.

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Under Objective 1.3 – Pod bug resistance

A new segregating population between IT86D-716 and Nafi was developed in Burkina Faso for use in QTL mapping for pod bug resistance, and is under phenotyping and genotyping analysis. F1, F2 and BC1F1 leaf samples were sent to UCR and genotyped and were also phenotyped in Burkina Faso. Genotypic data analysis showed some issues regarding the homozygosity of parents used. Phenotypic analysis showed multi-genic gene action for resistance to these insects.

Under Objective 2.2 – Variety releases

Formal release of five large white-seeded CRSP cowpea varieties in Senegal by ISRA was followed up with additional Breeder and Foundation Seed production of each variety and distribution to Farmers' organizations for Certified Seed development.

An improved version of Melakh with Striga resistance was developed by ISRA, Senegal and multiplied for Breeder Seed, and is currently in demonstration trials in 6 farmers' fields. The line ISRA-3006 with speckled black grain (Mougne type) was also multiplied for Breeder Seed and is in demonstration on-farm locations this season.

Four pre-release CRSP advanced cowpea lines were re- evaluated in multi-location tests at Saria, Pobe, and Kamboinsé during FY15 - FY17, emphasizing yield and grain quality, plus any disease susceptibility. The release petition to the National Variety Release Committee has been re-scheduled for FY19. Breeder Seed of each of these lines was produced and maintained at the INERA Saria Station and used for Foundation Seed production in the FY17 rainy season.

Fifteen African students (5 female, 10 male) have engaged in PhD and Master's degree training programs within the project.

The project was awarded Capacity Strengthening awards from the MSU management entity, which were used to acquire seed quality and viability testing materials for INERA, Burkina Faso, for the development of cowpea seed cold storage capability upgrade with backup generator for ISRA, Senegal, and insect culture and screening facility for SARI, Ghana. These capacity enhancement projects were completed in Summer, 2017 and are now functional and offering optimal conditions for cowpea seed conservation and research (see Section V).

V. Research Capacity Strengthening

Approval through the LIL was granted for $13000 to fund INERA, Burkina Faso breeding activity enhancement at Kamboinsé research station to acquire seed quality and viability testing materials to ensure quality and viable seed are stored or distributed to farmers. The material was acquired and will be used during off-season 2017 to check the long-term

storage of germplasm and quality of seed harvested this year.

Approval through the LIL was granted for $17547 to fund the rehabilitation of the screenhouse for ISRA, Senegal at their Bambey station. This upgrade has been made and implemented to benefit the ISRA cowpea research requiring insect resistance screening capability.

SARI was awarded $17,300 for a Host Country Institutional Capacity Strengthening Award to renovate an old entomology lab at Manga station to be used for flower Thrips culturing and screening for resistance. The lab is now functional and the initial work after the renovation involves training of project staff and students studying under the LIL lab project at the Manga Station in flower Thrips culturing and screening for resistance. Among the students were those who received sponsorship from the Association of Africa Universities (AAU) to come to Manga station for internships to learn flower Thrips culturing and resistance screening. The lab will be used to culture Thrips in large numbers to screen all the breeding lines as well as populations in search for promising lines with resistance to flower Thrips.

VI. Human Resource and Institution Capacity Strengthening

1. Short-Term Training

Please see Section III, Objective 3 for a description of the short-term training activities.

2. Degree Training in the US or elsewhere

Trainee 1:
i. Name of trainee: Arsenio Ndeve
ii. Country of Citizenship: Mozambique
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: Eduardo Mondlane University
v. Institution providing training: University of California - Riverside
vi. Supervising LIL PI: Philip A. Roberts & Timothy Close
vii. Degree Program: PhD, Plant Pathology
viii. Field or Discipline: Plant pathology and genetics
ix. Research Project Title: Genomewide selection for disease and drought tolerance in SE African cowpeas
x. Start Date: January 2012
xi. Projected Completion Date: December 2016
xii. Is trainee USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 2:
i. Name of trainee: Sassoum Lo
ii. Country of Citizenship: Senegal
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: ISRA

v. Institution providing training: University of California - Riverside
vi. Supervising LIL PI: Philip A. Roberts & Timothy J. Close
vii. Degree Program: MS initially, now PhD, Plant Genetics
viii. Field or Discipline: Plant breeding and genetics
ix. Research Project Title: MABC for enhanced seed size in cowpea
x. Start Date: March 2014
xi. Projected Completion Date: June 2018 (projected)
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 3:
i. Name of trainee: Binta Sarr
ii. Country of Citizenship: Senegal
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: ISRA
v. Institution providing training: University of Thiès at Bambey
vi. Supervising LIL PI: Ndiaga Cisse
vii. Degree Program: BS
viii. Field or Discipline: Agronomy
ix. Research Project Title (if applicable): Evaluation of Thips resistance in cowpea
x. Start Date: June 2016
xi. Projected Completion Date: Completed in August 2017
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 4:
i. Name of trainee: Zida Serge Felicien
ii. Country of Citizenship: Burkina Faso
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: I. Drabo and J. Batieno
vii. Degree Program: Ph.D. University of Ouagadougou
viii. Field or Discipline: Plant breeding
ix. Research Project Title (if applicable)
x. Start Date: 2016 (field research)
xi. Projected Completion Date: Dec. 2019
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 5:
i. Name of trainee (First and Last Name): Emanuele Yaw Owusu
ii. Country of Citizenship: Ghana
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Ghana

v. Institution providing training: KNUST, SARI and UCR
vi. Supervising LIL PI: R. Akromah (F. Kusi mentor)
vii. Degree Program: MS Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Combining early maturity, seed size and thrips resistance traits in cowpea
x. Start Date: 2014
xi. Projected Completion Date: Dec 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 6:
i. Name of trainee (First and Last Name): Poda Saadon Leandre
ii. Country of Citizenship: Burkina Faso
iii. Gender: male
iv. Host Country Institution Benefitting from Training: INERA, Burkina Faso
v. Institution providing training: KNUST, SARI and UCR
vi. Supervising LIL PI: R. Akromah and F. Kusi
vii. Degree Program: M.Phil. Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Phenotyping cowpea for *Striga* and flower thrips resistance in Northern Ghana
x. Start Date: 2014
xi. Projected Completion Date: 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 7:
i. Name of trainee (First and Last Name): Godfred Agyeman Duah
ii. Country of Citizenship: Ghana
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: UDS, SARI and UCR
vi. Supervising LIL PI: N. Opoku and F. Kusi
vii. Degree Program: M.Phil. Biotechnology
viii. Field or Discipline: Biotechnology
ix. Research Project Title: Genetic relatedness of the cowpea aphid resistance panel
x. Start Date: 2014
xi. Projected Completion Date: 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 8:
i. Name of trainee (First and Last Name): Mohammed Abdul Ganiu
ii. Country of Citizenship: Ghana

iii. Gender: male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: UDS, SARI and UCR
vi. Supervising LIL PI: B. Badii and F. Kusi
vii. Degree Program: M.Phil. Agronomy
viii. Field or Discipline: Agronomy
ix. Research Project Title: Evaluation of aphid resistance panel to *Aphis craccivora,* Koch (Homoptera: Aphididae) in Ghana
x. Start Date: 2014
xi. Projected Completion Date: 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 9:
i. Name of trainee (First and Last Name): Gloria Tetteh-Kubi
ii. Country of Citizenship: Ghana
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: UCC, SARI and UCR
vi. Supervising LIL PI: M. Botchey, F. Kusi and Aaron Tetteh Asare
vii. Degree Program: Ph.D. Entomology Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Improving Field Resistance of Cowpea Genotypes to Cowpea Aphid
x. Start Date: 2014
xi. Projected Completion Date: 2018
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 10:
i. Name of trainee (First and Last Name): Patrick Attamah
ii. Country of Citizenship: Ghana
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: KNUST, SARI and UCR
vi. Supervising LIL PI: R. Akromah and F. Kusi
vii. Degree Program: M.Phil. Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Screening and genetic analysis of drought tolerance in SARI's favorite cowpea lines
x. Start Date: 2014
xi. Projected Completion Date: 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 11:

i. Name of trainee (First and Last Name): Mouhamadou Moussa Diangar
ii. Country of Citizenship: Senegal
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: ISRA
v. Institution providing training: WACCI
vi. Supervising LIL PI: N. Cisse
vii. Degree Program: Ph.D. Plant Breeding
viii. Field or Discipline: Plant Breeding
ix. Research Project Title (if applicable): Cowpea resistance to Striga
x. Start Date: January 2015
xi. Projected Completion Date: August 2019
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 12:

i. Name of trainee: Coulibaly Soumabere
ii. Country of Citizenship: Burkina Faso
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: I. Drabo and J. Batieno
vii. Degree Program: M.Sc. University of Ouagadougou
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Genetics of pod sucking bug resistance in B. Faso
x. Start Date: March 2016 (field research)
xi. Projected Completion Date: March 2017
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 13:

i. Name of trainee: Adelaide Ouedrogo
ii. Country of Citizenship: Burkina Faso
iii. Gender: female
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: I. Dr. J. Batieno
vii. Degree Program: PhD, WACCI
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Aphids' resistance in Cowpea in B. Faso
x. Start Date: November 2017 (field research)
xi. Projected Completion Date: December 2019
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 14:

i. Name of trainee: SIDIBE Hamadou
ii. Country of Citizenship: Burkina Faso
iii. Gender: male
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: Dr. J. Batieno
vii. Degree Program: PhD University of Ouagadougou
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Genetics of Thrips resistance in B. Faso
x. Start Date: November 2017 (field research)
xi. Projected Completion Date: December 2019
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 15:

i. Name of trainee: Gnankambary Karidiatou
ii. Country of Citizenship: Burkina Faso
iii. Gender: female
iv. Host Country Institution Benefitting from Training: Burkina Faso
v. Institution providing training: INERA
vi. Supervising LIL PI: Dr. J. Batieno
vii. Degree Program: PhD University of Ouagadougou
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Mutagenic cowpea for multi-resistance in B. Faso
x. Start Date: November 2016 (field research)
xi. Projected Completion Date: December 2018
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 16: (Kirkhouse Trust/LIL collaborated sponsored PhD)

i. Name of trainee (First and Last Name): Patrick Attamah
ii. Country of Citizenship: Ghana
iii. Gender: Male
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: KNUST, SARI, Kirkhouse Trust and UCR
vi. Supervising LIL PI: R. Akromah, A. W. Kena and F. Kusi
vii. Degree Program: PhD Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Pyramiding two sources of aphid resistance genes in farmer preferred varieties in Ghana
x. Start Date: 2017
xi. Projected Completion Date: 2021
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

Trainee 17:
i. Name of trainee (First and Last Name): Tapsoba Flora Addisa
ii. Country of Citizenship: Burkina Faso
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: Ghana
v. Institution providing training: KNUST, SARI and UCR
vi. Supervising LIL PI: R. Akromah and F. Kusi
vii. Degree Program: M.Phil. Plant Breeding
viii. Field or Discipline: Plant breeding
ix. Research Project Title: Screening multi-parent advanced generation inter-cross (MAGIC) population for resistance to cowpea aphid (*Aphis craccivora*)
x. Start Date: 2015
xi. Projected Completion Date: 2017
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Active

VII. Achievement of Gender Equity Goals

The project continued to give technical support to women farmer groups who are in the cowpea production systems. During the year under review two hundred farmers, about 70% women, were exposed to new improved cowpea varieties that are resistant to Striga and aphids by SARI, Ghana. They were trained in best agricultural practices suitable for cowpea production using IPM principles to reduce indiscriminate application of chemical insecticides. Also in collaboration with AGRA Inoculant project, ten FBOs in cowpea production from ten districts in the Upper East region of Ghana were educated in integrated management of insect pests of cowpea. The LIL project at SARI collaborated with Maize improvement project, ILCRC, and Kirkhouse Trust to train over 1200 farmers and field officers of MoFA in Fall Army worm control strategies (Figures 4-6), at least 50% women. The outbreak of the pest was found very severe on maize, cowpea and other field crops in Ghana. A factsheet – 'Fall Armyworm [*spodoptera frugiperda* (j. e. smith)] outbreak in Northern Ghana – Facts and management approaches,' was produced to guide farmers in identification and control and to serve as training material for MoFA field officers.

The LIL project also collaborated with ILCRC, Kirkhouse Trust and University of Cape Coast to host 350 farmers during field days and training at Manga station. Farmers were introduced to strategies to manage insect pests of cowpea, such as using extra-early and early maturing varieties both under sole and maize/cowpea intercrop. Other strategies introduced to farmers were scouting for incidence and severity before deciding on the use of insecticide. This was used to guide the farmers against indiscriminate application of insecticide and its associated problems such as human and animal poisoning, pollution of water bodies and the environment. Use of host-plant resistance was also prominent among the strategies presented to farmers. Forty-five final year Agriculture students from Bawku Senior High School also visited Manga Station to learn about insect pests of cowpea, their management practices and how to breed for insect pest resistant cowpea varieties (Figures 7-9).

In Senegal, ISRA continued to work with the farmers' organization RESOPP and the IITA/USAID Cowpea Out-Scaling Project in West Africa (COSP) training of its members on seed production and post-harvest operations. More than 200 women producers were trained in FY17.

In Burkina Faso, 220 women producers were trained on cowpea production and seed storage and about 70 women conducted demonstration tests in FY17. In the Certified Seed production group of 58 farmers, 39 were women and 19 men, and a group a more than 600 women from YiYE Association of Women were trained. 50 women were trained on cowpea processing and finance management held in March 2017. The project has four female graduate student trainees embedded in the research program.

VIII. Implementation of Data Management Plan

The primary data management plan is submission of the url linkages to data sets published and analyzed in the Open Access publications listed in Section IX. These will be indicated in the USAID DDL, with a completion date for the current datasets of November 30, 2017.

IX. Scholarly Accomplishments

Huynh, B.-L., Ehlers, J.D., Muñoz-Amatriaín, Lonardi, S., Santos, J., Ndeve, A., Batieno B.J., Boukar, O., Cisse, N., Drabo, I., Fatokun, C., Kusi, F., Agyare, R.Y., Guo, Y.-N., Herniter, I., Lo, S., Wanamaker, S.I., Close, T.J., Roberts, P.A., 2016. A multiparent advanced generation inter-cross population for genetic analysis and breeding in cowpea (*Vigna unguiculata* L. Walp.). The Plant Journal (submitted July 2017, under revision).

Kusi, F., Padi, F.K., Obeng-Ofori, D., Asante, S.K., Agyare, R.Y., Sugri, I., Timko, M.P., Koebner, R., Huynh, B.L., Santos, J.R.P., Close, T.J., Roberts, P.A. 2017 A novel aphid resistance locus in cowpea identified by combining SSR and SNP markers. Plant Breeding (Submitted to, May, 2017, under minor revision).

Santos, J.R.P., Ndeve, A., Huynh, B.L., Matthews, W.C., Roberts, P.A. 2017. Transcriptome analysis of cowpea near-isogenic lines reveals candidate genes for root-knot nematode resistance. PLoS ONE (Submitted to, August, 2017, under revision).

Roberts, P. A., Huynh, B.L., Frate, C.A. 2017. Blackeye improvement. University of California Dry Bean Research Annual Progress Report 2016. 1-8.

Burridge, J., Schneider, H. M., Bao-Lam Huynh B. L., Roberts P.A., Bucksch A., Lynch J.P. 2017. Genome-wide association mapping and agronomic impact of cowpea root architecture. Theoretical and Applied Genetics 130(2): 419-431 DOI 10.1007/s00122-016-2823-y.

Sun, W., Huynh, B.-L., Ojo, J.A., Brad S. Coates, B.S., Kusi, F., Roberts, P.A., Pittendrigh, B.R. 2017. Comparison of complete mitochondrial DNA sequences between old and new world strains of the cowpea aphid, *Aphis craccivora* (Hemiptera: Aphididae). Agri Gene 4: 23-29. doi:10.1016/j.aggene.2017.03.003.

Boukar O., Fatokun C. A., Huynh B.L., Roberts P.A., Close T.J. 2016. Genomic tools in cowpea breeding programs: status and perspectives. Frontiers in Plant Science 7:757 (pp 1-13). doi: 10.3389/fpls.2016.00757

Ndiaye M., Sarr M.P., Cisse N., Ndoye I. 2015. Is the recently described *Macrophomina pseudophaseolina* pathogenically different from *Macrophomina phaseolina*? African Journal of Microbiology Research 9(45):2232 -2238. DOI: 10.5897/AJMR2015.7742.

Lalsaga W.J.A., Nana R., Sawadogo M., Sawadogo N., Kiebre M., Drabo I. 2016. Field assessment of ten cowpea genotypes [*Vigna unguiculata* (L.) Walp.] for drought tolerance. International Journal of Innovation and Applied Studies 14(4):1005-1014. ISSN 2028-9324.

Batieno B.J., Danquah E., Tignegre J.B., Huynh B.L., Drabo I., Close T.J., Ofori K., Roberts P.A., Ouedraogo T.J. 2016. Application of marker-assisted backcrossing to improve cowpea (*Vigna unguiculata* L. Walp) for drought tolerance. Journal of Plant Breeding and Crop Science 8: 273-286. DOI: 10.5897/JPBCS2016.0607. ISSN 2006-9758, 273-286.

Muñoz-Amatriaín M, Mirebrahim H, Xu P, Wanamaker SI, Luo M, Alhakami H, Alpert M, Atokple I, Batieno BJ, Boukar O, Bozdag S, Cisse N, Drabo I, Ehlers JD, Farmer A, Fatokun C, Gu YQ, Guo Y-N, Huynh BL, Jackson SA, Kusi F, Lawley CT, Lucas MR, Ma Y, Timko MP, Wu J, You F, Roberts PA, Lonardi S, Close TJ (2016) Genome resources for climate-resilient cowpea, an essential crop for food security. The Plant Journal. DOI: 10.1111/tpj.13404. Pp.1-13.

Batieno B.J., Tignegre J.B., Sidibé H., Zongo H., Ouedraogo T.J., Danquah E., Ofori K. 2016. Field Assessment of Cowpea Genotypes for Drought Tolerance. International Journal of Sciences: Basic and Applied Research 30(4): 358-369. ISSN 2307-4531

Barro A., Batieno B.J., Tignegre J.-B., Dieni Z., Sidibe H., Sawadogo M. 2017.

Diallel analysis of cowpea populations for resistance to cowpea aphid-borne mosaic virus disease (CABMV) in Burkina Faso. Journal of Plant Breeding and Crop Science 9(7): 90-97.

Conference Paper Abstracts

1. Kusi, F. 2016. Participatory Integrated Pest Management for Increased Cowpea Production in Northern Ghana. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
2. Tetteh Kubi, G., Botchey, M., Asare T.A., and Kusi, F. 2016. Improving the Field Resistance of Cowpea Genotypes to Cowpea Aphid. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
3. Poda L.S., Kusi F. Akromah R., Ouedraogo T.J., Tignegre J.B., Batieno J. 2016. Genetic Mapping of Striga and Thrips Resistance in Cowpea Population in Northern Ghana. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
4. Agyeman-Duah G., Kusi F., Opoku N. 2016. Genetic Relatedness of Cowpea Aphid Resistance. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
5. Attamah P., Akromah R., Kusi F., Nyadanu, D. 2016. Screening and Genetic Studies of Drought Tolerance among SARI Favourite Cowpea Lines. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
6. Owusu Y. E., Akromah R., Kusi F., Denwar. N. 2016. Inheritance of Extra-Early Maturity in Cowpea. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
7. Kusi F., Padi F.K., Obeng-Ofori D., Sugri I., Asante SK. 2016. Deployment of the Cowpea Aphid Resistance Gene for Cowpea Improvement in Ghana. Proceedings of Joint 2016 Pan African Grain Legume and World Cowpea Conference, 28 February to 4 March 2016, AVANI Victoria Falls Resort and Conference Centre Livingstone, Zambia.
8. Drabo I., Batieno B.J., Barro A., Dabiré C., Neya J.B., Zida E., Ilboudo D., Ouedraogo T.J. 2016. Progress in Cowpea Improvement and Production in Burkina Faso. Pan-African Grain Legume and World Cowpea Conference, Livingstone, Zambia, 27 Fevrier-4 Mars 2016.
9. Batieno B.J., Tignegre J.B., Danquah E.Y., Drabo I., Close T.J., Roberts P.A., Huynh BL., Ouedraogo T.J., Ofori K., Ehlers J., 2016. Marker

assisted backcrossing to improve cowpea for drought tolerance. Pan-African Grain Legume and World Cowpea Conference, Livingstone, Zambia, 27 Fevrier-4 Mars 2016.

10. Poda L.S., Kusi F., Akromah R., Nyadanu D., Attamah P., Sugri I., Ouedraogo T.J., Tignegre J.B., Batieno B.J., Huynh B-L., Munoz-Amatriain M., Close T.J., Roberts P.A. 2017. Phenotyping for *Megalurothrips sjostedti* (Trybom) and *Striga gesnerioides* (Willd.) resistance in cowpea (*Vigna unguiculata* (L.) Walp.) in northern Ghana. Feed the Future Legume Innovation Lab Grain Legume Research Conference, 13–18 August 2017, Laico Ouaga 2000 Hotel, Ouagadougou, Burkina Faso.
11. Agyeman D.G., Kusi F., Opoku, N., Attamah P., Huynh B.-L., Santos J.R.P., Munoz-Amatriain M., Close T.J., Roberts P.A.. 2017. Inheritance of resistance of IT97K 556-6 to cowpea aphids in Ghana. Feed the Future Legume Innovation Lab Grain Legume Research Conference, 13–18 August 2017, Laico Ouaga 2000 Hotel, Ouagadougou, Burkina Faso.
12. Kubi G.T., Kusi F., Asare A.T., Botchey M. 2017. Employing Host Plant Resistance (HPR) in the control of cowpea aphids and *Striga gesnerioides* in Northern Ghana. Feed the Future Legume Innovation Lab Grain Legume Research Conference, 13–18 August 2017, Laico Ouaga 2000 Hotel, Ouagadougou, Burkina Faso.
13. Agyare R.Y., Kusi F., Santos J.R.P., Arsenio N., Sassoum L., Yi-Ning G., Munoz-Amatriain M., Huynh B.L., Close T.J., Roberts P.A. 2017. Training in molecular technology and molecular breeding of cowpea at University of California, Riverside. Feed the Future Legume Innovation Lab Grain Legume Research Conference, 13–18 August 2017, Laico Ouaga 2000 Hotel, Ouagadougou, Burkina Faso.
14. Kusi F., Attamah P., Agyare R.Y., Sugri I., Atokple I.D.K., Huynh B-L., Santos J.R.P., Munoz-Amatriain M., Close T.J. and Roberts, P.A. 2017. The Legume Innovation Lab S01.A5: The progress made so far at SARI, Ghana. Feed the Future Legume Innovation Lab Grain Legume Research Conference, 13–18 August 2017, Laico Ouaga 2000 Hotel, Ouagadougou, Burkina Faso.

Student Theses (Defended)

Attaamah P. 2016. Screening and genetic analysis of drought tolerance in SARI's favorite cowpea lines. M.Phil. Thesis, Kwame Nkrumah University of Science and Technology, 99 p.

Poda, S. L. 2016. Phenotyping for *Striga gesnerioides* and *Megalurothrips sjostedti* resistance in cowpea populations in Northern Ghana. M.Phil. Thesis, Kwame Nkrumah University of Science and Technology, 116 p.

X. Achievement of Impact Pathway Action Plan

Under Objective 1, the primary thrust of the impact pathway progress centers on identifying QTLs determining traits for insect tolerance and resistance. As described in the technical section under Objective 1, this involves a combination of phenotype screening in the target areas (combination of greenhouse and field-based screens), together with high-throughput SNP genotyping with genomewide markers and followed by ICI-mapping to identify significant QTLs. The various populations for QTL discovery are at different stages of this process and require multi-year and multi-location data collection from the phenotyping trials.

Under Objective 2, the primary impact pathways are release of new cowpea varieties. As reported in the technical section, five all-white large seeded varieties (Lisard, Thieye, Leona, Kelle and Sam) were released in Senegal in 2015, and entered the seed development pipeline with Breeder and Foundation seed production in 2015 - 2017. In Burkina Faso, a set of four white-seed pre-release advanced lines are still awaiting formal release action by the national variety release committee. Meanwhile in anticipation of release, Breeder Seed was produced by INERA in 2015, 2016 and 2017. In California, advanced breeding lines are in different advanced stages of final testing, which in 2016 and 2017 included large-scale strip-trial testing and warehouse processing using five different farmer production fields in the San Joaquin Valley. These data will help to determine decisions on variety releases for the US blackeye cowpea market.

ANNEXES

Table 1: Summary of cowpea aphid resistance responses of the differential panel for determining resistance uniqueness and aphid biotype differences across five countries. (R = resistant; MR = moderately resistant; S = susceptible.

Cowpea line	Burkina	Senegal	Ghana	Nigeria	Cal-USA
58-77	MR	R	R	R	MR
INIA19	R	R	--	S	R
IT97K-556-6	R	--	R	R	R
KN1	R	R	--	S	S
KvX-295-2-124-99	R	R	R	S	R
SARC-1-57-2	R	MR	R	R	S
TVNu-1158	--	--	--	R	R

APAGBAALA	S	S	S	MR	S
BAMBEY21	S	S	S	MR	S
CB27	S	R	R	S	S
IT82E-18	S	S	S	S	S

Table 2. Grain yield and 100-seed weight of new blackeye breeding lines and checks tested at Kearney REC in 2016. Root-galling ratings from 2014 field screening with root-knot nematodes *M. incognita, M. javanica,* and *M. incognita* Muller; Fusarium wilt Race 4 disease index from 2014 greenhouse screening.

Entry	Yield (lb/ac)	100-seed wt (g)	Galling *M. incognita*	Galling *M. javanica*	Galling *M. incognita* Muller	Fusarium Race 4 index
CB46	3354	21.4	1.6	3.4	4.2	4.9
2014-008-51-82	3321	21.3	-	-	-	-
N2	3256	21.3	1.2	1.2	3.8	0.2
2014-008-51-77	3234	20.5	-	-	-	-
N5	3213	21.1	0.8	1.5	3.5	0.8
2014-008-51-89	3027	20.7	-	-	-	-
2014-010-41-25	2995	24.7	-	-	-	-
CB46Rk2	2919	21.2	1	2.7	2.9	0.0
10K-29	2875	22.6	2.4	2.9	4.2	0.0
2014-010-41-69	2853	25.0	-	-	-	-
CB50	2733	24.9	-	-	-	0.0
2014-010-41-47	2320	24.8	-	-	-	-
Mean	3008	22.4				
CV%	14	3				
LSD(0.05)	617	0.9				

Trial planted June 8, cut October 17 (131 days), machine-harvested October 31.
Root-galling score on scale of 0 (no galling) to 8 (severe galling).
Fusarium wilt disease index (0 to 5; where 0 = no wilt symptoms and 5 = plant death).

Table 3: Results of Chi-square test for F2 segregation of resistance to *C. tomentosicollis* (pod-sucking bug) in Burkina Faso.

Number of F_2	Number of resistant observed	Number of susceptible observed	Number of resistant expected	Number of susceptible expected	Ratio	X^2 (ddl=1)[a]	P
70	28	42	35	35	1 : 1	2,8	0,05

Table 4: Breeding populations and lines of Dr. Cisse in 2017 preliminary yield trials in Senegal.

Pedigree	**Traits of interest**	**Donor**	**Generation**
Melakh x IT97K-499-39	Striga	IT97K-499-39	F2
3211 x IT97K-499-39	Striga	IT97K-499-39	F2
Melakh x (Melakh x IT97K-499-39)	Striga	IT97K-499-39	BC3F3
Pakaw x (58-77 x Sanzi)	Thrips	Pakaw	F5
3178 x (58-77 x Sanzi)	Thrips	3178	F5
(Melakh x Yacine) x Yacine	Resistance multiple	Melakh	F5
(Melakh x Yacine) x Melakh	Resistance multiple	Yacine	F5
Melakh x Yacine	Resistance multiple	Yacine	F6
(Melakh x 3217) x Melakh	Grain quality	3217	F5
(Melakh x 3211) x Melakh	Grain quality	3211	F5
(Yacine x 3217) x Yacine	Grain quality	3217	F5
(Yacine x 3211) x Yacine	Grain quality	3211	F5
Melakh x 3178	Grain quality	3178	F6

Melakh x 3201	Grain quality	3201	F6
Melakh x 3205	Grain quality	3205	F6
Melakh x 3211	Grain quality	3211	F6
Melakh x 3217	Grain quality	3217	F6
Yacine x 3205	Grain quality	3205	F6
Yacine x 3217	Grain quality	3217	F6
Mouride x Yacine	drought	Yacine	F6
Suvita2 x IT93K-503-1	drought	IT93K-503-1	F6

Table 5: Breeder's Seeds of new and current cowpea varieties produced in Senegal in 2017.

Varieties	**area (m^2)**	**Breeder**	**Period**	**Production (kg)**
Kelle	2500	G0	Off season	20
Kelle	5000	G0	Rainy season	287
Leona	2500	G0	Off season	146
Leona	5000	G0	Rainy season	127
Lizard	2500	G0	Off season	115
Lizard	5000	G0	Rainy season	314
Melakh	2500	G0	Off season	437
Melakh	5000	G0	Rainy season	306
Sam	2500	G0	Off season	96
Sam	5000	G0	Rainy season	353
Thieye	2500	G0	Off season	204
Thieye	5000	G0	Rainy season	289
Yacine	2500	G0	Off season	338
Yacine	5000	G0	Rainy season	214

Table 6. New blackeye lines and check CB46 tested in 4 grower production field strip trials in Tulare Co. in 2016.

Parameter	Trial I	Trial II	Trial III	Trial IV
Area (ac)	0.558	0.558	0.388	0.455
Yield (lbs/ac)				
N2	5784	6074	1517	2174
CB46	5639	6074	1543	1894
CB46-Rk2	5639	6123	1202	2112
10K-29	5058	6268	1289	1304
100-seed wt (g)				
N2	18.7	19.1	19.4	21.0
CB46	19.2	19.4	19.6	20.3
CB46-Rk2	17.4	16.7	19	21.5
10K-29	17.4	19.7	20.8	23.0

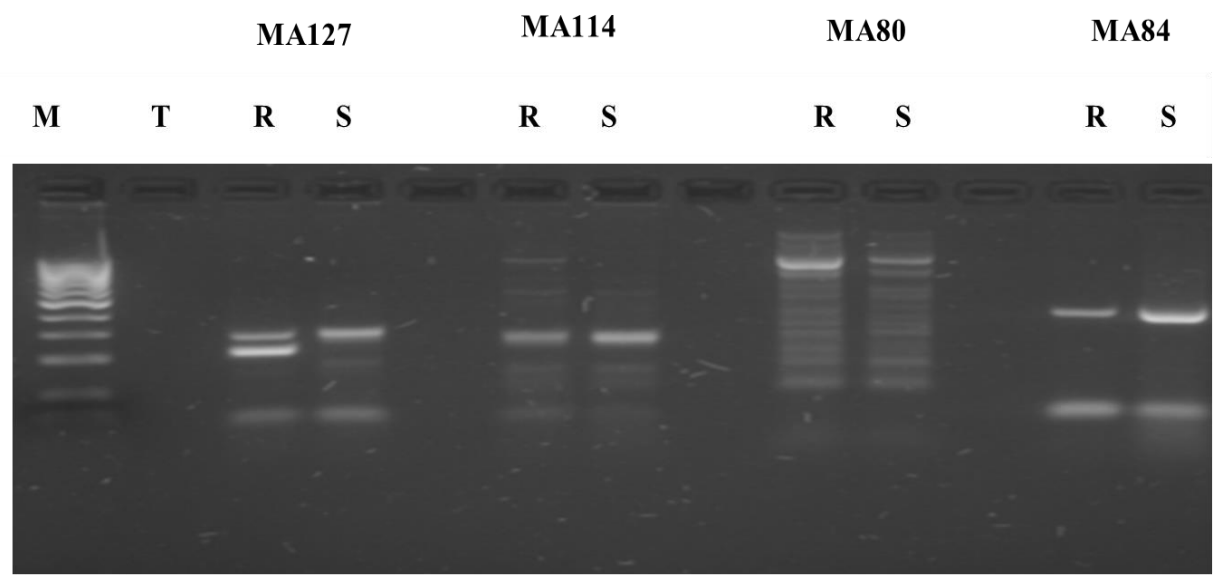
Trial I planted May 11, cut September 23, harvested October 6 (148 days)
Trial II planted May 25, cut September 26, harvested October 11 (139 days)
Trial III planted May 28, cut August 18, harvested September 4 (99 days)
Trial IV planted June 25, cut October 4, harvested October 25 (122 days)

Table 7. Grain yield, 100-seed weight, and lygus grain damage of 2 advanced blackeye lines and CB46 when grown under insect-unprotected conditions at Kearney REC in 2016..

Entry	Yield (lb/ac)	100-seed wt (g)	Lygus damage (%)
07KN-74	2485	23.0	27
N2	2138	20.0	27
CB46	2138	19.7	29
Mean	2254	20.9	28
CV%	5	2	15
LSD(0.05)	251	1.0	9

Trial planted June 8, cut October 17 (131 days), machine-harvested October 31.

Figure 1: Screening method used for phenotyping for resistance to pod-sucking bugs (*C. tomentosicollis*) trial at Kamboinsé, Burkina Faso.



M : marqueur de poids moléculaire de référence de pas égal à 50pb.

T: Témoin

Voltage: 75 V; Temps de migration: environ 1heure

Gel d'agarose de concentration 2%.

Figure 2. Banding profiles of four SSR markers tested for linkage to resistance to pod-sucking bugs (*C. tomentosicollis*), Kamboinsé, Burkina Faso.

Figure 3. Damage caused by pod-sucking bugs (*C. tomentosicollis*) on cowpea pods and seeds in Burkina Faso.

Figure 4. Women dominated cowpea farmers based organization (FBOs) at a field day and training in IPM for cowpea production at Manga station during 2017 cropping season.

Figure 5. On-farm training of Agricultural Extension Agents (AEAs), FBOs and seed producers in seed production and the use of host plant resistance in effective pest management during 2017 cropping season.

Figure 6. Training of cowpea farmers in good agricultural practices for profitable cowpea production.

Figure 7. Training of agricultural science students from Bawku Senior High School (Bwaku SHS) in identification of the major insect pests of cowpea and their management strategies.

Figure 8. Practical training of agricultural science students from Bawku Senior High School (Bwaku SHS) and their teachers in breeding method to combine aphid and striga resistance in farmer preferred cowpea varieties.

Figure 9. Teaching of agricultural science students from Bawku Senior High School (Bwaku SHS) and their teachers in principles of host plant resistance.