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

FY 2016 Annual Project Technical Progress Report
(October 1, 2015 – September 30, 2016)

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 three African and one US locations. Differences between US and African aphid populations were found based on molecular sequence, and three independent resistance QTL were discovered. Cowpea populations segregating for resistance to pod bugs, flower thrips and (or) 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 on-farm and on-station performance tested. Thirteen African students including four women engaged in degree training programs (7 PhD, 6 MS/MPhil). A capacity strengthening award to INERA supported development of modern cowpea seed storage capability in Burkina Faso. Continuous short-term training occurred with each Host Country through iterative data analysis and interpretation cycles, a workshop in Zambia and training visits to UCR.

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. The panel is shown in Table 1. Uniform screens in field locations across all project NARS (Burkina, Ghana, Senegal) and California were conducted in 2014 - 2016 in field plots or in screenhouses, with 4-fold replication, using

standard resistance assessment scales across all test sites. The uniform test design and coordination planning for the aphid resistance assessment was developed by the project team. This multi-site phenotype screening for resistance response was repeated in FY16, following additional seed increases in NARS and UCR, to provide a minimum of 2 years of data at each location.

The resistance donors and susceptible controls were SNP genotyped in FY14, coordinated by UCR. In 2015 in Senegal because of a wet season with heavy rain, the aphid population did not become established enough with uniform infestation in the field to discriminate between genotypes. However, enough seeds were produced for later experimentation. The 2016 screenhouse test in Senegal revealed the following reactions: Resistant (KN1, 58-57, Kvx 295-2-124-99, CB27, INIA 19); Moderately resistant (Sarc-1-57-2); Susceptible (Apagbaala, Bambey 21, IT82E-18) (Table 2). The lines IT97K-556-6, Tvu 1158 and Vita 7 did not germinate. In Ghana, the seedling stage screening of the aphid resistance panel at SARI found IT97K-556-6, KvX-295-2-124-99, SARC-1-57-2, 58-77 and CB27 to be resistant to the cowpea aphids in northern Ghana, confirmed in 2016. In Burkina Faso, the seedling-stage screening of the aphid resistance panel in pots at the INERA Saria Station gave results which confirmed those obtained from previous year screening with aphid from Kamboinse and Saria. Dr. Batieno, INERA received a visit from Dr. F. Kusi, SARI, Ghana at Kamboinse and Saria in September 2016 where he helped with the aphid screening trial (Figure 7). In California, lines Kvx 295-2-124-99, INIA 19, Sarc-1-57-2, IT97K-556-6 and Tvu 1158 were resistant. A comprehensive analysis of the multi-location screening results and preparation for publication are continuing.

In testing the mode of inheritance and the genetic relatedness of these lines, F1 populations were developed between each of these lines with Apagbaala (aphid susceptible popular variety in Ghana) and the resistant lines were also crossed with each other (Figures 1 and 2). These populations were advanced to the F2 at SARI. The segregation ratio in the F2 population between IT97K556-6 and Apagbala (Resistant and Susceptible) fit a 3:1 ratio for a single dominant gene ($\chi 2 = 3.26$, $P = 0.0707$). The F2 were advanced to F3 and F3 families were screened; a (1R:2H:1S) segregation ratio confirming the presence of a major gene controlling resistance. Segregation in the SARC-1-57-2 x IT97K556-6 F2 fit a 15R:1S phenotypic ratio ($\chi 2 = 1.57$, $P = 0.20$) indicating two independent for aphid resistance operated in in the F2 population. The F2 resistant plants were selfed to produce the F3, which segregated into a ratio of 9 homozygous resistant, 6 segregating and 1 homozygous susceptible, indicating dominance at two loci and confirming the F2 test. 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 we were able to map the major resistance locus from this donor to cowpea linkage group (LG) 10, using two SNP-genotypes 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 a major gene on LG7 and a minor gene on LG1 From this work breeders can pyramiding of different resistant genes into elite cowpea varieties.

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 grown under aphid pressure in 2016 at the UC Kearney Research Center. The best performing lines will be multiplied in greenhouse culture this winter for expanded field performance testing in FY17.

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, with a view to developing a DNA sequence based fingerprint to distinguish the isolates. For example, in Burkina Faso, aphids were collected from Kamboinse, Pobe-Mengao and Farako-Ba representing three diverse cowpea production zones. Five samples were also collected in different fields in the Bambey, Senegal area. 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 is in preparation. 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 is being conducted in collaboration with Drs. Fatokun and Boukar at IITA, Nigeria.

1.2 Flower thrips resistance: In recent work on QTL discovery, 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 (biparental RIL population from 58-77 x Yacine is available) and Tvx3236. In Senegal, during the 2016 rainy season, the RIL populations Sanzi x Vita 7; 58-77 x Yacine 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 during the off-season and rainy saeson. The M4 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.

At SARI, Ghana, Dr. Kusi received seed in FY15 of the Sanzi x Vita7 and Yacine x 58-77 RIL populations from Senegal for phenotyping for flower thrips tolerance (Figure. Given the limited seeds per line received, the populations were planted to increase seeds. In FY15 each of the lines in the populations was flower-sampled at 7 days after insecticide spray to generate preliminary data to

have a fair assessment of the lines for thrips tolerance. The two RIL populations were planted in two locations during this FY16 main cropping season in Manga in the Sudan Savanna and Tamale in the Guinea Savanna. Initial data on Thrips samples showed high insect counts against some of the lines in Tamale, while the counts in Manga were low. Data from the two locations are currently being compiled and the results will be used for QTL mapping. The aim is to combine the phenotyping data sets from Senegal and Ghana for improved QTL mapping of the thrips tolerance loci.

In Ghana, three Sanzi-derived F7 inbred populations segregating for seed color (including white) and flower thrips resistance were evaluated for QTL discovery and breeding. One parent is IT97K-499-35, now the popular Ghana variety 'Songotra', a high yielding black-eye resistant to Striga but thrips sensitive which can be improved for thrips tolerance. A second parent is SARC1-57-2, which carries aphid resistance. The SARI team is phenotyping these populations using the previously described experimental protocols. 280 single-seed derived F7 families were leaf sampled and the samples sent to UCR where they were DNA-extracted and SNP genotyped using the Illumina iSelect platform. The seeds produced from each of the single-seed descent plants were phenotyped for both flower thrips and Striga resistance. A total of 251 recombinant inbred lines were evaluated for Striga and flower thrips. Different reactions of cowpea RILs to Striga were found in the field and in pot experiments; 27 RILS were found resistant similar to the resistance donor IT97K-499-35, while 224 RILs were susceptible. A low number of flower thrips occurred after the flower sampling, due to the weather conditions. This made the screening for flower thrips more challenging. The level of thrips infestation was very low at the Manga station, as was found in the other populations being phenotyped, and could be due to the bad weather during the dry season. The harmattan period dry season was unusually prolonged over three months and was followed immediately by very high day and night temperatures with very low relative humidity.

In Burkina Faso, nine cowpea genotypes (TVx3236, Nafi, Tiligré, Gourgou, Komcalle, KVx165-14-1, KN-1, KVx780-1, KVx780-6) were screened for flower thrips tolerance (Figures 5 and 11). From this screening genotypes lKVx780-1 and KVx780-6 (both close to release), plus KVx165-14-1, and TVx3236 have shown good tolerance levels to flower thrips. Nafi has shown a higher level of tolerance compared to the other released varieties (Table 3 and Figure 5). Crosses are being made between tolerant genotypes and released susceptible varieties and 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. A second set of segregating materials was developed from crosses between six parents involving the resistant IT86D-716 to provide more viable populations. Leaf material from the new sets at F7 has been collected in FY16 and will be SNP genotyped during late 2016, for QTL mapping resistance to pod bugs, striga, aphids, and bruchids contained in the same population set.

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. Tests on aphid DNA with primers for the COX1 gene demonstrated excellent DNA integrity. 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. A joint paper for this work is in preparation. 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.

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 Muruca 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. Trials were conducted 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. The genotyping on sampled plants determined those carrying resistance with the highest level of recurrent parent genotype. Ghana BC2 progenies from FY14 were advanced in FY15 and leaf-sampled and SNP genotyped. A change in the Ghana BT cowpea

project leadership put our part in this effort on hold during this main season. The phenotyping of the breeding lines for Maruca is being done in the host countries with funding from USAID through African Agricultural Technology Foundation (AATF). The Ghana and Burkina Faso breeders received extensive hands-on training at UCR in March 2014 and were trained further in March 2015 and February-March 2016 using their own datasets under this objective. The genotyping mostly followed the same general protocol as outlined under the Objective 1 work. Leaf samples from young screenhouse grown plants in the phenotyping and crossing blocks were used for DNA extraction in Burkina Faso and Ghana, and then SNP assayed by LGC Genomics (KASP). The genotype data were analyzed for molecular scores using Backcross Selector software.

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. Additional multiplication will be done during the 2017 off-season for on-farm demonstration. Also the line ISRA-3006 was multiplied which was obtained from a cross between the local variety Baye Ngagne and Mougne, 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. Preparation was made for additional seed multiplication during the upcoming off-season for on-farm demonstration during the next rainy season 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 5 varieties released in 2015 (Lisard, Thieye, Leona, Kelle and Sam) were again multiplied on 0.5 ha each in 2016 for additional Foundation Seed production at the Bambey station. 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 a sub-set of 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 FY16 (October, 2015 - April, 2016), 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. The release petition to the national variety release committee had to be delayed due to non-project issues. Breeder seed of the best

lines chosen for release submission based on main season 2014 and 2015 and off-season 2015 performance data were produced at Saria during the main season 2016 (June – October). About 20 kg of Breeder Seed of each of these lines will be available at the INERA Saria Station, and will be used to initiate Foundation Seed production in the FY17 off-season assuming lines are approved for release. Three field days were organized on these lines being readied for release (Figure 8). The First Lady of Burkina Faso paid a special visit to one of our trial sites at Gourcy, where the project team is supporting farmers for Certified Seed multiplication covering 10 ha (Figures 9 and 10).

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 2014, we conducted on-farm yield trials in a Tulare Co. farmer's field and on-station trials at the UC Kearney Station, Fresno Co., in main season 2015 (harvested in October-November 2015) to assess commercial yield performance. Seed size and yield data from the trials are presented in Tables 4-6, 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 eleven lines plus the standard variety CB46 were tested under insect-protected conditions (Table 4), while a no-insecticide unprotected versus insecticide protected split-plot lygus screening trial was conducted with three lines with lygus bug tolerance. The test design was a four-row 4-fold replicated RCBD or split-plot 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 five 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 4). Two most promising lines were evaluated together with CB46Rk^2 and CB46 in large strip plots in a Tulare County commercial blackeye field. Overall the yields were higher than in 2014. Some advanced lines had higher grain yield than CB46 at Kearney, and two lines had equivalent yield to CB46 at the Tulare Co. farmer field location (Table 5). Some lines also combine the advantage of stronger, broad-based resistance to root-knot nematodes and resistance to Fusarium wilt Race 4 (Table 4). 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, performed best in 2015 at Kearney (Table 4). In 2015 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. They were selected based on their performance in similar trials conducted in 2010 to 2014. Lygus pressure was heavy but late in 2015, resulting in grain yield loss of more than 50% in the check CB46 in comparison with the protected conditions in the same field (Table 6). The unprotected yields were significantly higher than CB46 for two advanced lines, N2 and 07KN-74,

confirming strong yield ability under lygus pressure. From the 2015 trials, we chose the most promising lines (combination of yield, seed quality and resistance) for performance testing in the 2016 main season.

Four trials were planted in May 2016 in Tulare Co. with four lines (CB46, N2, 10K-29, CB46Rk2) in large 0.5 acre field-length 6-row strips (harvested October 2015) in four different farmer fields. Trials at the UC Kearney station were planted in June 2016 with seven lines (CB46, CB46Rk2, two 10K lines and three N lines) in four-extended row 4-fold replicated RCBD. Harvesting, threshing and seed cleaning is underway at time of reporting.

The Senegal and Burkina Faso releases will represent tangible project outputs, and offer the opportunity for tracking along the impact pathway as new releases which will be entering the seed multiplication and distribution process in each country. During the 2016 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 2017. Opportunities exist to initiate baseline data for the releases through the impact analyses under the LIL project led by Dr. M. Maredia.

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

Short-term Training: Short-term training of a young scientist from SARI and a member of the LIL research team, Richard Yaw Agyare took place at the UCR from March 29 to September 26, 2016. This training was made possible through the LIL SO1.A5 host country institutional capacity strengthening award to SARI. The objective was to train Richard in modern breeding techniques, to improve research output of the LIL project. Training included greenhouse, laboratory, on-station and on-farm experimentation, and molecular data processing. He made cowpea crosses, phenotyped for aphid and foliar thrips resistance, cleaned bad and non-informative SNPs, handled SNP genotypic data in both bi-parental populations and a diversity collection, constructed genetic linkage maps, applied quantitative trait loci analysis (QTL) and principal component analysis (PCA), and designed cleaved amplified polymorphic SNP (CAPS) primers using Primer 3. He also acquired skills in using computer software MST Map, QTL IciMapping, Merge Map, TASSEL, Microsoft Excel and CurlyWhirly for molecular analysis. His work at UCR found SSR marker CP171F/172R associated with aphid resistance in SARC 1-57-2 and mapped the locus to cowpea linkage group 10. This resistance to aphids in SARC 1-57-2 was found to be different from the aphid resistance loci discovered in IT97K-556-6.

Training in molecular breeding for young trainee breeders and NARS scientists was continued in FY15-16. 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 convened a two-day training workshop in February 2016 in Livingstone, Zambia prior to the

World Cowpea Conference, using training modules developed by the UC-R team and by the CGIAR GCP Integrated Breeding Platform program (IBP) Breeding Management System (BMS). 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. Training materials and protocols used by the NARS breeders were also used to train the technical staff in the NARS programs after NARS breeders had been trained further on the standardized electronic field-book, leaf assay, and field phenotyping protocols.

Degree Training: We conducted degree training for two graduate students in the report period at UCR and eleven in Africa, three in Senegal, six in Ghana and two 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 national Universities to engage five second-year M.Phil. and one Ph.D. students co-supervised on topics developed from the LIL project at SARI. Mahamat Hissene Halime completed on August 2016 her Ph.D. training at Dakar University working on improving drought adaptation through combination of different mechanisms. The RIL from the cross Mouride x IT93K-503-1 was used as the experimental population. Zida Serge Felicien, one of the Burkina team members, registered at the University of Ouagadougou for a Ph.D. and is partially supported. He will be using the UCR platform for genotyping and short time training. Coulibaly Soumabere is conducting his M.Sc. on pod sucking bug resistance in Burkina Faso.

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 and FY16. 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.

Advanced backcross progenies were developed by adding aphid resistance QTLs into recurrent parents CB27, CB46 and CB50 and field tested, to select for California blackeyes with aphid resistance for the US production system.

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 are planned to be made in the 2017 off-season.

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.

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. The line ISRA-3006 with speckled black grain (Mougne type) was also multiplied for Breeder Seed and will be introduced in demonstration on-farm locations next season.

Four pre-release CRSP advanced cowpea lines were re- evaluated in multi-location tests at Saria, Pobe, and Kamboinse during the 2015 main rainy season and re-tested in the off-season in FY16 (October, 2015 - April, 2016), emphasizing yield and grain quality, plus any disease susceptibility. The release petition to the national variety release committee has been re-scheduled for FY17. Breeder seeds of each of these lines was produced at the INERA Saria Station to initiate Foundation seed production in the FY16 off-season.

Thirteen African students (4 female, 9 male) have engaged in degree training programs within the project, including seven PhD and six Master's degree students.

The project was awarded Capacity Strengthening awards from the MSU management entity, which were used for the development of cowpea seed cold storage capability upgrade with backup generator for INERA, Burkina Faso ISRA, Senegal, and off-season field irrigation for INERA, Burkina Faso. This capacity project was completed in Summer 2016 and is now functional and offering optimal conditions for cowpea seed conservation (see Section V).

V. Research Capacity Strengthening

Approval through the LIL was granted to fund INERA, Burkina Faso breeding activity enhancement at Kamboinse research station by developing a seed

storage cold room and to acquire a power generator to ensure access to continuous electricity for the storage of Breeder and Foundation seed by the INERA cowpea breeding program.

VI. Human Resource and Institution Capacity Development

1. Short-Term Training

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

2. Degree Training

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: Mame Penda Sarr
ii. Country of Citizenship: Senegal
iii. Gender: Female

iv. Host Country Institution Benefitting from Training: ISRA
v. Institution providing training: University of Dakar (UCAD)
vi. Supervising LIL PI: Ndiaga Cisse
vii. Degree Program: PhD
viii. Field or Discipline: Plant Pathology
ix. Research Project Title (if applicable): Genetic diversity and temporal dynamics of *Macrophomina phaseolina.*
x. Start Date: 2010
xi. Projected Completion Date: Completed in August 2015
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
i. 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: Active

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
ii. 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 (First and Last Name): Mahamat Hissene Halime
ii. Country of Citizenship: Chad
iii. Gender: Female
iv. Host Country Institution Benefitting from Training: ITRAD
v. Institution providing training: UCAD, ISRA
vi. Supervising LIL PI: N. Cisse
vii. Degree Program: Ph.D. Biotechnology and Plant Breeding
viii. Field or Discipline: Plant Breeding
ix. Research Project Title: Combining different mechanisms for improved drought adaptation
x. Start Date: January 2012
xi. Projected Completion Date: Completed August 2016
xii. Is trainee a USAID Participant Trainee and registered on TraiNet? No
xiii. Training status: Completed

Trainee 13:

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: 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 the LIL project at SARI in collaboration with University of Cape Coast engaged 220 farmers, more than 50% women, in participatory variety selection as part of the effort to develop Striga resistant varieties for the Striga endemic zone of Ghana. 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 as well as other good agricultural practices. In Senegal, 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 was continued. More than 200 women producers were trained in FY15-16. In Burkina Faso, 215 women producers were trained on cowpea production and seed storage and about 50 women conducted demonstration tests in FY16. In the Certified Seed production group of 58 farmers, 39 were women and 19 men. Plans were made for a training program for women on cowpea processing and finance management to be held in November 2016. The project has four female graduate student trainees embedded in the research program.

VIII. Explanation for Changes

The Ghana team is phenotyping for flower thrips resistance of the two RIL populations following seed increases at UCR. The flower thrips population densities were too low to have adequate phenotyping scores and will require repeating.

In Burkina Faso, the pod-sucking bug phenotype screening is on-going. Because of seed failures in 2014-15, additional segregating populations were generated and are being grown for phenotyping in late 2016, and in 2017. Leaf samples were sent in October 2016 to UCR for genotyping.

Genotyping of cowpea materials by UCR is in various stages of progress using both the KASP and iSelect cowpea SNP genotyping platforms depending on the specific objective, and will be completed to match with the phenotype data for insect resistance.

Funds are available to complete all the above activities.

IX. Self-Evaluation and Lessons-Learned

Overall we have had a successful workplan period in 2015-16. The primary challenges to staying on timeline are ones familiar to us in conducting the collaborative cowpea improvement project. Three are worth highlighting: 1) Having enough seed of breeding lines or populations for genetic analysis is a limitation sometimes, because of failure of seed increases due to growing conditions, such as in Burkina with pod bug tolerant populations or in California due to photoperiod sensitivity of African germplasm requiring short daylength for flowering. 2) Phenotyping for biotic stress resistance under field conditions is dependent on adequate, uniform infestations. This is especially difficult with insect screening, such as in Ghana where flower thrips infestation was too low for data collection due to weather events. Multiple years and locations for testing are built into the planning to mitigate this problem. 3) Technical issues continue to arise occasionally with leaf or DNA sample shipments for SNP genotyping, due to delays, shipment loss, or spoilage of leaf samples from inadequate drying before shipping. Re-sampling is required to overcome these problems, and the US and HC team have got much better in handling this outsourcing process. Our team of U.S and Host Country partners works very well together, based on established relationships and the seamless integration of the new team from SARI, Ghana. Frequent communication is seen as a key in planning and

execution of project activities. Of especial value this period has been the face-to-face planning and training meetings at UCR and in Zambia in 2016.

X. Scholarly Accomplishments

Huynh, B.L., Matthews, W.C., Ehlers, J.D., Lucas, M.R., Santos, J.R.P., Ndeve, A., Close, T.J., Roberts, P.A. 2015. A major QTL corresponding to the *Rk* locus for resistance to root-knot nematodes in cowpea (*Vigna unguiculata* L. Walp.). Theoretical and Applied Genetics. 1-9. DOI 10.1007/s00122-015-2611-0

Roberts, P. A., Huynh, B.L., Frate, C.A. 2016. Blackeye improvement. University of California Dry Bean Research Annual Progress Report 2015. 1-8.

Burridge, J., Schneider, H. M., Bao-Lam Huynh B. L., Roberts P.A., Bucksch A., Lynch J.P. 2016. Genome-wide association mapping and agronomic impact of cowpea root architecture. Theoretical and Applied Genetics. In press.

Sinclair T.R., Manandhar A., Belko N., Riar M., Vadez V., Roberts P.A. 2015. Variation among cowpea genotypes in sensitivity of transpiration rate and symbiotic nitrogen fixation to soil drying. Crop Science 55:2270-2275.

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

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. Accepted 10/172016.

Conference Paper Abstract (Edited) – Word Cowpea Conference

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.

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. (Thesis has been defended and will graduate in November 2016).

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. (Thesis has been defended and will graduate in November 2016).

XI. Progress in Implementing 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 and 2016. In Burkina Faso, a set of four white-seed pre-release advanced lines are awaiting formal release action by the national variety release committee. Meanwhile in anticipation of release, Breeder Seed was produced by INERA in 2015 and 2016. In California, advanced breeding lines are in different advanced stages of final testing, which in 2016 included large-scale strip trial testing and warehouse processing using five different farer production fields in the San Joaquin Valley. These date will help to determine decisions on variety releases for the US blackeye cowpea market.

ANNEXES

Table 1: Details of sources of resistance to the cowpea aphid for the differential panel for determining resistance uniqueness and aphid biotype differences.

Name	Type	Origin
58-77	Aphid resistant source	ISRA
INIA19	Aphid resistant source	MSU
IT97K-556-6	Aphid resistant source	IITA
KN1	Aphid resistant source	INERA
KvX-295-2-124-99	Aphid resistant source	INERA
SARC-1-57-2	Aphid resistant source	SARI
TVNu-1158	Aphid resistant source	IITA
APAGBAALA	Aphid susceptible check	SARI
BAMBEY21	Aphid susceptible check	ISRA
CB27	Aphid susceptible check	UCR
IT82E-18	Aphid susceptible check	IITA
VITA7	Aphid susceptible chzeck	IITA

Table 2: Aphid resistance panel screening results, Senegal, 2016: Planting: 24/05/2016. Date of infestation: 03/06/2016. Date 1st observation: 15 06/2016. Date 2nd observation: 22/06/2016.

Genotypes	**Nr plants : 6/3**	**Nr dead pl.: 6/15**	**Nr dead pl. : 6/22**	**Nr plants :6/22**
KN - 1	**6**	**1**	**1**	**4**
58 - 77	**2**	**0**	**0**	**2**
KVx 295 - 2-124-99	**6**	**0**	**1**	**5**
Bambey 21	**5**	**2**	**3**	**0**
Apagbaala	**6**	**3**	**3**	**0**
IT 82E - 18	**5**	**2**	**1**	**2**
CB27	**4**	**0**	**0**	**4**
INIA 19	**3**	**1**	**0**	**2**
IT97K - 556 - 6	**0**	_		
Sarc 1 - 57 -2	**5**	**1**	**2**	**2**
TVU - 1158	**0**	_	_	_

Table 3: Classification of INERA cowpea varieties from Burkina Faso based on their levels of flower thrips susceptibility. 2016

Ranking	Varieties		Mean
1	KN-1		4,5222A
2	KVx165-14-1		1,6250 B
3	Komcallé		1,0000 B
4	kVx780-6		0,9524 B
5	Gourgou		0,5833 B
6	Tiligré		0,5238 B
7	Nafi		0,4167 B
8	KVx780- 1		0,4091 B
9	TVx3236		0,0500 B
R^2 0.727755	CV:75.62488	SqR.MSE =1.099156	Average #Thrips per flower =1.453431
Prob	LSD 5%	Pr > F	<.0001

Table 4. New blackeye breeding lines and checks tested at Kearney REC in 2015: grain yield, 100-seed weight, galling ratings from 2014 field screening with root-knot nematodes *M. incognita, M. javanica,* and *M. incognita* Muller, and 2014 greenhouse screening with Fusarium wilt Race 4.

Entry	Yield (lb/ac)	100-seed wt (g)	Galling M. incognita	Galling M. javanica	Galling M. incognita Muller	Fusarium Race 4 index
CB46Rk2	5218	21.8	1.0	2.7	2.9	0.0
N2	5182	21.6	1.2	1.2	3.8	0.2
N17	4951	22.1	1.1	1.2	3.1	4.8
CB46	4940	21.3	1.6	3.4	4.2	4.9
N5	4899	21.5	0.8	1.5	3.5	0.8
10K-77	4062	24.0	0.9	1.7	3.7	5.0
CB50	3995	27.0	-	-	-	0.0
10K-29	3866	22.9	2.4	2.9	4.2	0.0
Mean	4639	22.8				
CV%	14	4				
LSD(0.05)	928	1.4				

Trial planted on June 2 and cut on October 13 (133 days).
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 5. New blackeye lines and check CB46 tested in a production field strip trial in Tulare Co. in 2015.

Entry	Total area (ac)	Seed weight (lb)	Yield (lb/ac)	100-seed wt (g)
N2	0.558	1590	2849	20.9
10K-29	0.558	1590	2849	23.2
CB46	0.558	1520	2724	21.6
CB46Rk2	0.557	1450	2603	18.8

Trial planted on May 22, cut September 25 (126 days), and machine-harvested on October 12.

Table 6. Grain yield, 100-seed weight, and lygus grain damage of 4 advanced blackeye lines and CB46 when grown under insect-unprotected conditions at Kearney REC in 2015.

Entry	Yield (lb/ac)	100-seed wt (g)	Lygus damage (%)
07KN-74	3276	23.0	25
N2	2698	21.8	22
CB46Rk2	2085	20.7	25
CB46	2054	20.0	36
10K-29	1952	22.3	28
Mean	2413	21.5	27
CV%	10	7	33
LSD(0.05)	387	2.3	14

Trial planted on June 2, cut on October 13 (133 days), and machine-harvested on October 27.

Figure 1. Screening of F2 population between KVX x SARC1-57-2 showing all the progenies resistant to aphids in Ghana – indicating the same gene is controlling resistance in the two parent lines.

Figure 2. Screening of an F2 population between IT99K-556-6 x SARC1-57-2 showing a ratio of 15:1 resistant and susceptible to aphids in Ghana – indicating different genes are controlling resistance in the two lines, confirmed by QTL mapping.

Figure 3. Greenhouse solar dryer using material from the LIL to facilitate drying of cowpea during the rainy season.

Figure 4. Phenotyping of cowpea GWAS lines in Ghana: Field performance evaluation for yield, screening for drought tolerance using both seed-box and field protocols for seedling-stage and terminal drought stage tolerance, repectively.


GWAS
TERMINAL DROUGHT
SCREENING
WET PLOT


GWAS
TERMINAL DROUGHT
SCREENING
DRY PLOT

Figure 5. Plot of flower thrips numbers indicating susceptibility and resistance levels. INERA, Burkina Faso, 2016.

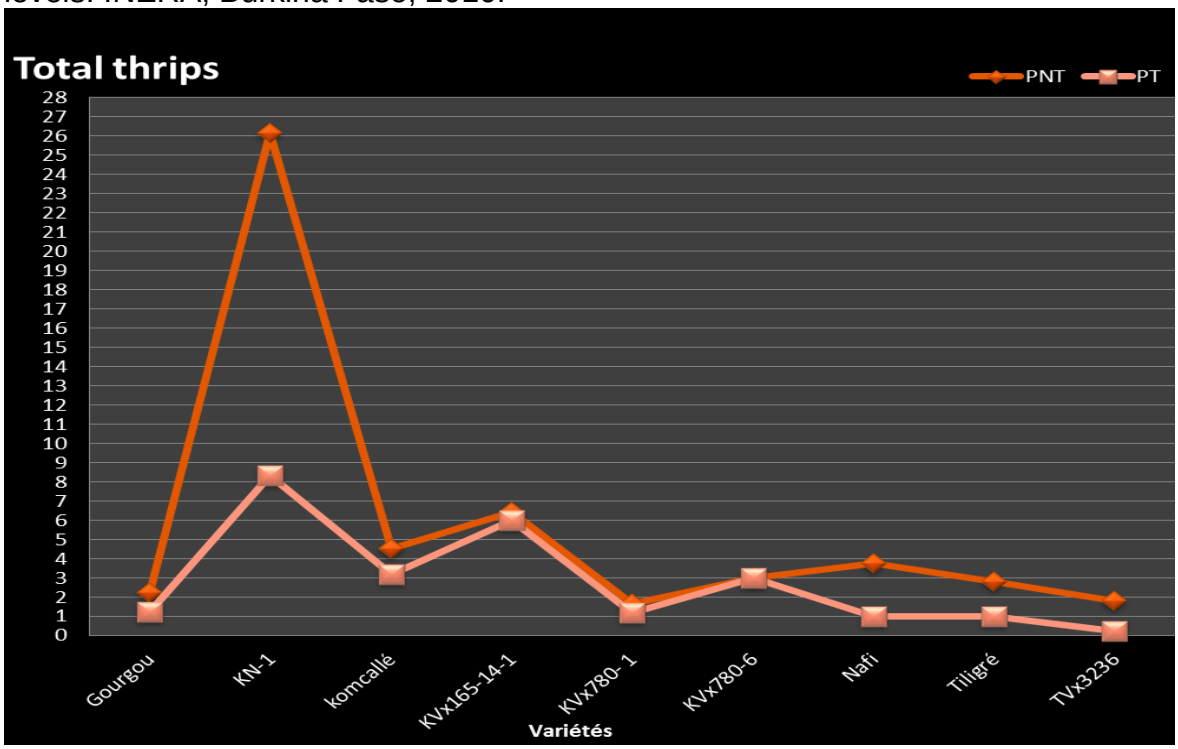

Figure 6. Dr. Kusi from SARI, Ghana visiting the INERA Saria Research Station, Koudougou for research exchange between the project NARS partners.

Figure 7. Dr. Batieno Discussing with Dr. Kusi from SARI, Ghana on the aphid trial at the INERA Saria Research Station, Koudougou, Burkina Faso.

Figure 8. Farmer field day to review LIL-INERA cowpea breeding plots at Pobé-Mengao, October 2016.

Figure 9. INERA-hosted field visit for the Burkina Faso First Lady to review the 10-ha cowpea Certified Seed production plot at Gourcy, Burkina Faso, 2016.

Figure 10. Burkina Faso First Lady receiving explanation by LIL HC PI Dr. Batieno on the 10-ha cowpea Certified Seed production, Gourcy, B. Faso, 2016.

Figure 11. Flower Thrips screening trial setup with infestation containment on plants with netting. INERA, Burkina Faso, 2016.