Final Narrative

Use this form to provide your final update to your foundation program officer regarding the results achieved for the entire project. In addition, please provide your perspective on key lessons learned or takeaways and input on the foundation's support of your work to ensure that we can capture and share learnings as appropriate both internally and externally.

The Final Narrative must be submitted in Word, as PDFs will not be accepted.

General Information

Investment Title	DRRW Phase II: Durable Rust Resistance in Wheat - II (DFID DF)		
Grantee/Vendor	Cornell University		
Primary Contact	Ronnie Coffman	**Investment Start Date**	February 22, 2011
Feedback Contact[1]	Ronnie Coffman	**Investment End Date**	July 31, 2016
Feedback Email[1]	wrc2@cornell.edu	**Reporting Period Start Date**	October 1, 2014
Program Officer	Katherine Kahn	**Reporting Period End Date**	July 31, 2016
Program Coordinator	Amy Pope	**Reporting Due Date**	September 30, 2016
Investment Total		**Opportunity/Contract ID**	
Remaining Funds (If applicable)	$		

[1] Feedback Contact/Email: the full name and email of the contact whom foundation staff queries for various surveys.

Submission Information

By submitting this report, I declare that I am authorized to certify, on behalf of the grantee or vendor identified on page 1, that I have examined the following statements and related attachments, and that to the best of my knowledge, they are true, correct and complete. I hereby also confirm that the grantee or vendor identified on page 1 has complied with all of the terms and conditions of the Grant Agreement or Contract for Services,

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Date Submitted	[Month DD YYYY]	**Submitted by Contact Name**	
		Submitted by Contact Title	
		Submitted by Contact Email	
		Submitted by Contact Phone	

Progress and Results

1. Final Progress Details

Provide information regarding the entire investment's progress towards achieving the investment outputs and outcomes. In addition, submit the Results Tracker with actual results as requested.

Working together, toward a common endgame, the community of wheat and rust workers, communicators, mentors, and educators made remarkable impact in securing the world's wheat crop.

Objective 21: Improved testing, multiplication, and adoption of replacement varieties

At the end of the project, KALRO's leadership and expertise in wheat research was enhanced, resulting in a fully operational phenotyping platform that opened opportunities for collaborations with other global partners such as USDA, JIC, NIAB and NSF-BREAD along with capacity building of several students and staff working at KALRO.

In the course of the project an estimated 880,000 tons of seed of rust resistant wheat varieties became available for planting: Of that, approximately 85,000 tons of 14 varieties was distributed in Ethiopia and more than 51,000 tons of 5 varieties in Kenya. The rest was made available in SAARC countries, Iran (340,000 tons) and Sudan.

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KALRO and KEPHIS continue to collaborate on wheat NPT in 8 locations (Njoro, Rongai, Lanet, Timau, Eldoret, Endebees, Mau Narok, and Narok). By law, KEPHIS is required to regulate NPT activities for all commodities, including wheat. In the recent past, three institutions (KALRO, Kenya Seed Company, University of Eldoret) have actively submitted lines for NPT evaluation.

The previous goal of lowering CVs to a level below 15% has been informed by the need for reducing noise/error in our replicated yield trials in order to clearly identify statistically significant higher yielding and stable varieties for commercial release. The CVs for both on-station experiments (advanced yield trials) and KEPHIS run NPT still remain higher than 15% (ranges between 20 – 23%). One of the key sources of error arising from the trials is the manual harvesting, threshing, and cleaning of small samples emanating from the trials. Closer supervision and training of casual laborers responsible for handling harvesting activities has been enhanced, but it would also be helpful if the more adept of these individuals could be retained from year to year. Mechanized harvesting equipment (e.g., the need of a small plot combine) and improved seed laboratory space and seed handling equipment would also lead to reduced CV values below 15%.

The three-stage procedure (Ear row > Ear-row derived plot > Bulking of phenotypically similar plots) remains in place. It is meant to ensure variety maintenance and purity, as well as bulking to provide adequate quantities of breeder seed for further multiplication to certified seed. Further bulking is done through the KALRO Seed Unit and/or Kenya Seed Company systems. Any rogue plants are identified and eliminated as rows or plots through joint inspections conducted between KALRO technical staff and KEPHIS.

Up to 8 farmer field days were held annually, planned and executed by Ministry of Agriculture, KALRO, Cereal Growers Association, and the Kenya Seed Company, in order to promote awareness of new Ug99 resistant varieties, and lines that are candidates for release as varieties.

Objective 22: Increased levels of global investments and coordination in stem rust research and development

Significant scientific advances in stem rust research have been made that would not have been possible without the advocacy efforts of the BGRI and the scientific objectives of the DRRW project.

Communications team and Burness promoted media coverage of the rust problem and the need for sustained support for rust research through key message development, press releases, media training, and media monitoring. In addition, close collaboration with CIMMYT has increased global awareness of Ug99 as well as critical importance of addressing research and distribution of resistant varieties that bear farmer preference traits. Annual BGRI Technical Workshops were held with media campaigns targeted to leverage media attention and make each workshop a global wheat community-building event. One of the most significant was a comprehensive documentary film about DRRW activities and impact in Ethiopia featuring interviews with Ethiopian farmers and scientists working at EIAR and CIMMYT, which was screened at the BGRI 2014 Technical Workshop (https://www.youtube.com/watch?v=4saCoUND7_k). Five annual technical workshops were held with participants from 66 countries. Numbers ranged from 178 at the first workshop in Obregon Mexico, 2009, to 575 in Obregon Mexico, 2016, which was held in conjunction with the Borlaug Summit on Wheat for Food Security.

The project-wide communications/IT team met several times during each year by conference call to discuss ongoing tasks, potential efficiencies, collaborations, and future needs in addition to annual face-to-face meetings. The Cornell team published 89 blog posts on globalrust.org including some written by guest bloggers. In 2013, Cornell provided support in the form of content and expertise to the U.S. Botanic Garden to help develop indoor and outdoor wheat exhibits called "Amber Waves of Grain," highlighting Norman Borlaug's wheat varieties and the importance of wheat. The two exhibits drew 468,000 visitors according to the Botanic Garden.

In response to the 2013 outbreaks of stem rust in Ethiopia we documented efforts to mitigate the emerging threat with pathogen identification, disease surveillance and monitoring. A video featuring David Hodson, *Preventing Emerging Threats of Wheat Rust Diseases in Ethiopia* (https://www.youtube.com/watch?v=P2rjSAAHwOw), was released in August 2014. These pro-active initiatives are ongoing and include visits to the new Director General of EIAR and media (including radio) partners to build awareness, keep farmers and policymakers ahead of outbreaks, and minimize losses.

The online database of screening nursery data has 16,000 entries with additional content such as the Resistance Genes Glossary. From the debut of the redesigned globalrust.org, the site has recorded more than 49,000 user sessions.

At the end of the Phase II project, the BGRI twitter account had 2,266 followers and Facebook "likes" were more than 3,300.

The Gene Stewardship Award, instituted by the BGRI in 2012, continues to be a proactive way to promote the release of durable, long-lasting Ug99 resistant varieties and adult plant resistance in the wheat breeding community. Awardees, who receive the prestigious "Norman" (a copy of the Norman Borlaug statue at CIMMYT), have included: members of the Nepal Agricultural Research Council, in 2012; members of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia, in 2013; and members of the Ethiopia Institute of Agricultural Research in Ethiopia, in 2014; and members of the Kenya Agricultural and Livestock Research Organization, in 2015.

For more details on communications and advocacy activities, please see Appendix A: Logframe Objective 22, and Appendix D: Media and Advocacy Report.

Objective 23: Stem rust populations tracked and monitored

Investment has resulted in the creation of a surveillance and monitoring network unprecedented in scope or scale for crop pathogens. This network covers all the major wheat growing countries of Africa, Middle East and South Asia. Over 23,000 geo-referenced survey records and 5000+ rust isolates records have been collected, resulting in one of the most comprehensive disease databases. For the first time, important stem rust race groups e.g., the Ug99 race group have been successfully tracked in space and time. The successful system is now being applied to other crops and diseases.

A dynamic community has been built around the surveillance activities. Annual surveillance meetings have attracted 60+ scientists from 30+ countries. A network of partnerships spanning the entire spectrum from advanced to basic research has contributed to the overall success of the surveillance system.

Expanded use of molecular diagnostics and genomics are providing new insights into pathogen population genetics, evolution and migration. Advanced spore dispersal and epidemiology modeling are providing an improved understanding of migration pathways and permitting improved early warning.

Ethiopia is on the way to having one of the most comprehensive rust monitoring systems in the world. Surveillance, and pathotyping are fully functional. Advanced early warning systems are being developed. Early detection and rapid response to race TKTTF (Digalu race) illustrated the functionality of the surveillance system (even though epidemics were not prevented).

The Wheat Rust Toolbox/RustTracker information system has published 28,805 geo-referenced survey records The database represents one of the most comprehensive and valuable data resources for crop diseases, with data being widely used for modeling studies (Cambridge University, University of Minnesota, and most recently Aberystwyth University, UK). In addition, data holdings for stem rust pathotypes are 4,121 isolates from 30 countries, with 17 of those countries now having multiple years of data. In 2015, the targeted early warning information produced after the Egypt discovery was only possible due to the functional spore-dispersal modeling platform created by Cambridge University and the UK Met Office. This is the first time that such a precise, regional early warning has been possible.

Thirteen new races in the Ug99 race group have been detected. The molecular SNP diagnostic assay for race TKTTF (Digalu race, virulent on the Digalu variety, widely planted in Ethiopia for its high yields and YR resistance, was overcome in the 2013 SR epidemic), developed by Dr. Les Szabo, Cereal Disease Laboratory is now being used routinely.

Within the Wheat Rust Toolbox several major updates implemented through collaboration with Global Rust Reference Center, Aarhus University, and direct linkages to CDL data management were developed as well as tools to support population genetics analysis. Direct integration of mobile survey data into the Toolbox is underway.

After several years of prototypes, testing, and trials, field survey data is becoming standardized and reliable. Survey teams in South Asia use the tablet and in 2015 Ethiopia started to collect data using a generic version of the tablet-based Rust Survey app, developed by Sathguru.

Rapid identification of TKTTF as the causal race of the stem rust epidemic on Digelu in Ethiopia in 2013/14 was another indication of the successful rust monitoring system that has now been put in place. The race causing this outbreak was determined to be TKTTF, which belongs to a lineage different from the Ug99 race group. The rapid and coordinated national and international response involving the EIAR national lab at Ambo, the USDA-ARS CDL, University of Minnesota, and the Global Rust Reference Center in Denmark was an outstanding example of collaboration and cooperation at the global scale. The “Wheat Rust Surveillance, Early Warning and Management System” was developed by the Ethiopian Ministry of Agriculture, ATA, and EIAR in collaboration with CIMMYT, and was officially endorsed by the Honorable Minister for Agriculture with a budget allocated by the Government of Ethiopia (Ethiopian Birr 2.2 million/USD 100,000) for implementation of the system. This outcome is a direct result of the activities and efforts of DRRW scientists (esp. David Hodson) in the region.

A wheat variety adoption study in Ethiopia found:

- 42% of surveyed households were affected by 2010/11 stripe rust epidemic. From the affected households 40% of them replaced the old wheat varieties in the next production season.
- A substantial shift in varietal use over the four-year period (2009/10 vs 2013/14). Kubsa and Galema (both highly susceptible to stripe rust in 2010/11) declined in area share – from 29.5% of the total surveyed wheat area in 2009/10 to only 18% in 2013/14 (with 'Galema' only accounting for 1.4% in 2013/14).
- Varieties considered to be rust resistant, namely Digalu, Kakaba, Danda’a, ET-13, Pavon-76 and Madawalabu, occupied 47% of the total surveyed wheat area in 2013/14.
- The biggest area increases being recorded for the new rust resistant varieties Digalu, Kakaba, and Danda’a. Digalu alone covered 27.1% of wheat area surveyed in 2013/14 (vs only 2.1% in 2009/10).
- Reported total average wheat yields showed a modest, but non-significant, increase of 3% in 2013/14 (1.75 t/ha) compared to 2009/10 (1.70 t/ha).
- Despite rising input costs over the four year period, wheat production significantly increased average net income for the surveyed farmers; 4,320 birr/ha in 2009/10 compared to 5,339 birr/ha in 2013/14.
- Digalu is now highly susceptible to the latest stem rust race to be detected in Ethiopia (race TKTTF). As a result, replacement of Digalu is a high priority.

Monitoring and characterization of the alternate hosts (*Berberris* and *Mahonia* ssp.), continues to be informative. The GRCC and ICARDA conducted a barberry rust survey in CWANA with infected samples from Iran, Tajikistan, Uzbekistan, Azerbaijan, Georgia and Bhutan (in addition to Sweden and Denmark). All aecial samples collected to date were assigned to the *P. graminis* species complex. These data are available on the Wheat Rust Toolbox. CDL and collaborators also surveyed and collected aecial infections on barberry in Lebanon, Ecuador, Spain, Germany, and Turkey. Iago Hale at the University New Hampshire is supervising a young female PhD student from Nepal who is developing genomic resources for the barberry surveillance teams.

Ninety-four researchers from SAARC countries participated in trainings on pathogen identification and scoring. The two-week course was videotaped and is available as an online course.

Objective 24: World-class stem rust response phenotyping facilities in East Africa

Since 2011, eight successive seasons of international nurseries were tested at KALRO, Njoro and seven successive seasons of International nursery testing were accomplished at Debre Zeit, Ethiopia. Good crop establishment, growth and adequate disease pressure helped to discriminate among different resistance levels along with infection type response. The reliability of the phenotypic data were high with high correlations amongst replications in genomic selection studies. Data were recorded during peak stem rust infections and distributed to collaborators.

The screening capacity was consistent over the last five years, providing reliable and accurate phenotyping against the Ug99 group of races at the quarantined site at KALRO, Njoro. Effective partnership between CIMMYT, KALRO, and DRRW resulted in significant progress and impact for the global wheat community in addressing the threat of Ug99. International stem rust screening nurseries at KALRO and EIAR, coordinated by CIMMYT, played an important role in identifying new sources of resistance, pre-breeding, CIMMYT-Kenya shuttle breeding, pathogen surveillance, varietal release in Kenya, mapping adult-plant resistance (APR) and major genes for rust resistance, and genomic selection. Since 2005, close to 400,000 lines were screened against stem rust race Ug99 and derivatives. The screening capacity at KARI increased from 20,000 to 50,000 lines each year from 20-25 countries and institutions.

Significant investment in infrastructure and facilities from DRRW and CIMMYT ensured reliable phenotypic data over the years. The results from international nurseries showed a shift to higher frequencies of lines with resistance to race Ug99 since 2010. The nurseries were consistent in establishment and disease severity over the last five years and reliable phenotypic data were obtained for the collaborators.

A new race-specific TKTTF screening nursery was initiated in Debre Zeit, as well as a quarantine site in Sinana for the new ‘Digelu’ race. Activities at the nurseries fostered enhanced capacity development for all participating countries in addition to focused training for Kenyan and Ethiopians associated with the nurseries. International screening nurseries continued to serve the world’s wheat breeding efforts, now including resistance to more than just the Ug99 race.

Construction of a new head house was completed containing a minus 80C freezer for long-term storage of a national rust collection.

KALRO, Njoro offered a course specially designed for researchers who wished to learn about stem rust, evaluation of germplasm, standardization of note taking and update themselves with the global knowledge and innovative techniques that would enhance progress and efficiency in their breeding activities. More than 200 researchers, breeders and pathologists were trained at Njoro since 2008.

Objective 25: Durably resistant, high yielding wheat varieties

During the project, more than 900 new high-yield bread wheat lines with near-immune to moderately resistant APR responses based on the highest severity recorded at Njoro, Kenya were included in CIMMYT's international replicated yield trials and non-replicated screening nurseries for distribution to national programs. For durum wheat, 183 resistant or moderately resistant lines were distributed globally.

More than 65 varieties of wheat resistant to stem rust Ug99 were released in 11 at-risk countries since 2008. Those countries—all of which are located in zones that are climate-variable, food-insecure and/or war-torn—are Egypt, Sudan, Ethiopia, Kenya, Iran, Pakistan, Afghanistan India, Bhutan, Nepal and Iran. Since 2011 an estimated 880,000 tons of seed of rust resistant varieties was distributed to farmers and breeding stations. (In 2012 approximately 750,000 tons of seed of resistant varieties was distributed under the USAID Famine Seed Project. Average distribution for other years was 33,000 tons.)

Please see Appendix F: Impact Metrics for a complete list of Ug99 resistant varieties, breeding lines, and adoption rates by country.

Objective 26: High breeding value wheat lines with two or more marker-selectable stem rust resistance genes

Over the course of the project, more than 40 wheat (or wheat wild relatives) genes were identified as sources of resistance to TTKSK (Ug99) and related variants: *Sr2, Sr9h, Sr12, Sr13, Sr15, Sr21, Sr22, Sr24, Sr25, Sr26, Sr27, Sr28, Sr32, Sr33, Sr35, Sr36, Sr37, Sr39, Sr40, Sr42, Sr43, Sr44, Sr45, Sr46, Sr47, Sr50, Sr51, Sr52, Sr53, Sr55, Sr56, Sr57, Sr58, Sr59, Sr1662, SrTr129, SrTm4, SrTA10187, SrTA10171, SrND643, Sr TH2172, SrTmp,* $Sr1RS^{Amigo}$. Consistent QTL on chromosomes 1A, 1B, 1D, 2A, 2B, 3B, 3D, 4A, 4D, 5B, 6B, 7A, 7B were detected by numerous bi-parental, association mapping, and nested association mapping experiments.

More than 40 plant genes were identified as sources of resistance to TTKSK, of which 30 with markers were added to wheat breeders' toolboxes: *Sr2, Sr9h, Sr12, Sr13, Sr15, Sr22, Sr25, Sr26, Sr28, Sr32, Sr33, Sr35, Sr39, Sr40, Sr42, Sr43, Sr45, Sr46, Sr47, Sr50, Sr53, Sr55, Sr56, Sr57, Sr58, Sr1662, SrTA10187, SrTA10171, SrND643,* $Sr1RS^{Amigo}$. Improved markers for detection of several genes were developed and published. More than 13 wild species-derived genes have not been deployed, including *Sr32*, *Sr39*, *Sr40*, *Sr43*, *Sr47*, *Sr51*, *Sr52*, *Sr53*, *Sr59*, *SrTm4*, *SrTA10187*, *SrTA10171*, and *SrTH2172.*

Fifty-eight leaf, stripe and stem rust resistance genes were protocoled and posted on MASWheat. Marker-assisted selection protocols were generated for over 28 stem rust R genes. Donor lines with a combination of *Sr2* and *Fhb1* in coupling were made available for global protection against both diseases.

DNA markers for 13 (and counting) stem rust resistance genes were used to analyze Ethiopia, Nepal, and Bangladesh wheat varieties and experimental elite variety candidates for durable resistance, and to guide deployment by the National Programs.

Seven candidate varieties were produced by crossing to exhibit a combination of 4 to 7 pyramided *Sr* genes (APR and major genes). After 5 rounds of selfing and marker assisted selection, 31 selections, derived from the 7 original ones, were sent to Kenya for evaluation under an artificial epidemic.

Over 40 crosses (8 per year) were made involving different combinations of resistant and susceptible accessions of *Ae. sharonensis*, *Ae. longissima*, and *Ae. bicornis* to elucidate the genetics of resistance and also allelic relationships among stem rust resistance genes. This information is valuable for selecting accessions for use in the wide crossing programs.

During the project potential new sources of resistance in 12 different *Aegilops* species and in rye were identified. The moderate (17%) to high (100%) frequency of resistance in these *Aegilops* species was considered very promising and suggested that many unexploited stem rust resistance genes were present in this genus. More than 500 accessions with resistance effective against the most prevalent members of the Ug99 African race group were identified. Continuing studies within a number of *Aegilops* species elucidated the genetics of stem rust resistance in these valuable wheat relatives. Additionally, the University of Minnesota hosted Mahbubjon Rahmatov in his Ph.D. thesis research for characterizing the rust resistance of wheat-rye, wheat-*Leymus* and wheat-*Thinopyrum* alien translocation lines. A new stem rust resistance gene (*Sr59*) effective against race TTKSK was discovered in a wheat-rye introgression line.

Recent results supported the successful transfer of multiple "new" resistance genes into hexaploid wheat. A manuscript was initiated to document these new resistance genes and seeds were shared with the Wheat Genetics Resource Center at Kansas State University to facilitate their further chromosome manipulation and distribution and maintenance of the genetic stocks. We also successfully transferred at least two additional TTKSK-effective genes from a near-immune wild relative, *H. villosa*. These stocks were made available for other programs to continue genetic manipulation and work towards their long-term use in wheat improvement. Additional projects are ongoing with accessions of other wild species. For several years we have contributed to serving various collaborators, national programs, and breeders with germplasm characterization, distribution, phenotyping, and genotyping.

Under two special initiatives (28.e.1-2), 55 international *Pgt* isolates were increased and pathotyped. This set expanded the set of African isolates (1980s) and added isolates from Asia (India, Pakistan and Turkey), Europe (Austria, Czech Republic, Hungary, Italy and Spain) and the Middle East (Egypt, Israel and Syria). These were genotyped, along with a selected set of U.S. isolates using a

SNP chip (PgtSNP 1.5k). Also 4 germplasm accessions were produced by crossings to pyramid combinations of 4 to 7 Sr genes (APR and major genes).

Objective 27: Optimized wheat improvement system in Ethiopia

The Kulumsa-based spring bread wheat breeding program and the Debre-Zeit durum wheat program were strengthened to conduct two cycles per year. Varieties were released from introduced-germplasm and the national program with resistance to TTKS and other stem rust variants, stripe rust, and *Septoria*. All wheat based research centers evaluated candidate varieties. Agronomic, pathologic and end-use objectives were prioritized, and introductions from international nurseries were evaluated and selected with these priorities in mind.

Investments were made that contributed to efficient breeding programs, allowing the necessary delivery of genetic progress that will contribute to improved varieties, and result in a contribution to food security for Ethiopia. Investments included:

- Mechanization of the wheat breeding program at the Wheat Research Center of Excellence at the Kulumsa Agricultural Research Center.
- Construction of a greenhouse and head house at the Ambo Plant Protection Center, which facilitated the development of routine pathoytpe analyses, and the rearing of clean, uncontaminated inoculum for field screening activities. This was under Dr. Getaneh's direction.
- Establishment of irrigation infrastructure at the WRCoE at KARC that enabled off-season seed multiplication. This was done in collaboration with EAAP, CIMMYT, and EIAR.
- The construction of seed cold-room storage to enable long-term, safe storage of germplasm resources for the breeding programs at KARC and at DZARC, and for the safe storage of nuclear (pre-breeding, pre-basic, etc.) quantities of seed for multiplication.
- High-speed wireless communications installed at four Kulumsa locations.

EIAR wheat staff developed technical skills, which enabled efficient evaluation of introduced germplasm in screening nurseries that fit national agro-ecologies. Training opportunities in research skills for technical staff included applied field research, nursery management, data collection, and data entry and compilation. EIAR scientists were trained through exchange visits with ARIs and sister institutions, as well as longer-term training through visits to ARIs.

For details of activities in Ethiopia please see Appendix A, Objective 27 logframe.

Objective 28: Project management, communication, and coordination

All subcontracts were completed for the project, with no-cost extensions given to KALRO and CIMMYT. Regular reporting and milestone tracking were sustained. The project impact metrics were updated and shared regularly with BMGF and UK's DfID. The metrics also were utilized internally, especially for communications deliverables. The team and objective leaders communicated regularly through phone calls and face-to-face meetings, as did specific working groups in the project. The External Project Advisory Committee (EPAC) met annually to guide the strategic activities of the DRRW project as well as the BGRI. The Communications Team based at Cornell worked closely with other partners to support and coordinate activities and management to take advantage of advocacy opportunities. The BGRI website <globalrust.org> was enhanced and migrated to a new open-source content management platform and thus made more sustainable for the future. The BGRI YouTube channel featured xx videos Views (157% increase from a year ago), 67,271 minutes of BGRI content watched (169% increase), 66 "shares," and 117 "likes." The BGRI Linked-In group membership grew 70% to more than 600 vetted subscribers, with 70 posts of funding and job opportunities, workshops, training, and other relevant announcements. The e-mail community grew to 1,400.

With this project the BGRI grew from a small group of interested scientists responding to Norman Borlaug's alarm to an active community of more than 2,000 stakeholders worldwide, including significant numbers of women and early career scientists. The community encouraged and modeled the open access and sharing of ideas and data. With the establishment of the Gene Stewardship Award, national agriculture programs were made aware of the prestige gained by releasing durable varieties with multiple resistance genes.

Twenty-nine recipients of the Jeanie Borlaug Laube Women in Triticum Early Career Award received training at CIMMYT, Mexico. Five established scientists (men and women) received Mentor Awards. Students were encouraged to participate by entering the Competitive Graduate Student Research Program. Based on the quality of their research 13 graduate students, selected from more than 150 entrants, made oral plenary presentations at the BGRI Technical Workshops.

Collaboration between Cornell and CIMMYT was strengthened through the appointment of an early-career female researcher hired by Cornell to lead CIMMYT's Genomic Selection program in Mexico.

2. Geographic Areas to Be Served

Provide the final list of countries and sub-regions/states that have benefitted from this work and associated dollar amounts. If areas to be served include the United States, indicate city and state. Add more rows as needed. More information about Geographic Areas to Be Served can be found here.

Location	Foundation Funding (U.S.$)

3. Geographic Location of Work

Provide the final list of countries and sub-regions/states where this work has been performed and associated dollar amounts. If location of work includes the United States, indicate city and state. Add more rows as needed. More information about Geographic Location of Work can be found here.

Location	Foundation Funding (U.S.$)
Australia	
Brazil	
Canada	
Denmark	
Ethiopia	
India (and other SAARC countries)	
Israel	
Kenya	
Mexico	
Sweden	
South Africa	
Turkey (and other CWANA countries)	
USA: Davis, California	
USA: Manhattan, Kansas	
USA: St Paul, Minnesota	
USA: Durham, New Hampshire	
USA: Ithaca, New York	
USA: Raleigh, North Carolina	
USA: Fargo, North Dakota	
USA: Pullman, Washington	

4. Lessons Learned

Describe the top one to three takeaways or lessons learned from this project.

- Project scientists have made extensive evaluations of *Aegilops* species and found legions of accessions with excellent resistance to not only African stem rust, but also leaf rust and stripe rust. To not have these resistance genes be used in agriculture would be a terrible waste. Continued investment into this research would leverage the progress made to date. Having worked for several years now with excellent cooperators using conventional wide-hybridization techniques for introgressing genes into wheat, we are fully convinced that we must embark on a on different path: a systematic gene cloning effort to produce a library of R genes for the wheat “defense arsenal.” With multiple cloned R genes in hand, we can develop various gene cassettes that can be introduced into an already suitable wheat cultivar without the problem of linkage drag. The public still needs to accept the idea of genetically modified organisms, but perhaps the research could be done using the CRISPER Cas9 technology, which is not considered GMO by the USDA.

- While replacement varieties continue to flow from CIMMYT and (to a lesser extent) from ICARDA and national programs, there is no clear plan or model either in place or under development in any country that would provide a rational and more food secure system of variety replacement and more stable wheat production.
- Retaining talent in Ethiopia and Kenya was an issue that will be addressed in the DRRW supplemental award (Delivering Genetic Gain in Wheat). Through its Talent Pipeline objective, DGGW will support PhD training of national researchers as well as support NARS scientists with mentoring skills to mentor up-and-coming researchers.