W-3150

Breeding Common Bean (*Phaseolus vulgaris* L.) for Resistance to Abiotic and Biotic Stresses, Sustainable Production, and Enhanced Nutritional

Combined State Reports
Prepared September-October 2020
Immediately after Project meeting held virtually on August 21, 2020

CALIFORNIA

University of California, Davis (prepared by Paul Gepts)

This year's activities have been impacted severely by COVID-19. After a stay-at-home order, first from the county and then statewide, the activities at UC Davis were strongly limited to online teaching and very focused research activities aiming at those experiments with time limitations, but always under guidelines of distancing, masking, and hygiene. As a consequence, we were limited to the following field experiments: a) Cooperative Dry Bean Nursery of common bean; and b) Advanced generation testing of lima bean lines, with emphasis on large-seeded cultivars. These experiments have been harvested; yields and seed weights are being measured and analyzed. Furthermore, certain greenhouse and lab activities continued, including crossing blocks and evaluations of certain metabolites potentially involved in resistance to Lygus bug.

COLORADO

Colorado State University (prepared by Maria Munoz-Amatriain)

Colorado participated in the evaluation of several bean nurseries including the Cooperative Dry Bean Nursery (CDBN), the Midwest Regional Performance Nursery (MRPN), and the Dry Bean Drought Nursery (DBDN). Nurseries were planted on June 8th at CSU's Agricultural Research Development and Education Center (ARDEC). The DBDN was planted under irrigated and non-irrigated conditions. This was an exceptionally dry year in Colorado, and the DBDN only received 1.23'' of total rainfall in the non-irrigated part of the field. Colorado State University also evaluated a Rust Nursery including 486 entries from ProVita, 30 lines received from Michigan State University, and 8 lines from Dr. Timothy Porch (Puerto Rico). Rust inoculations were conducted on July 8, with spreader rows of the susceptible variety Othello spread throughout the field. All nurseries were scored for rust resistance/susceptibility, and results were shared with collaborators. All nurseries have been harvested and grain yields will be evaluated and shared with W-3150 collaborators as well as with the Colorado Dry Bean Administrative Committee.

Also, Colorado State University Crops Testing conducted bean trials in Lucerne, CO. Several W-3150 collaborators sent their common bean lines for testing at this location. A Dry Bean Field Day was held virtually (Dr. Urrea participated in the event), and the recording was made available to the Colorado Dry Bean Committee board and the growers at https://youtu.be/AeSTDhn8VKA.

DELAWARE

University of Delaware (prepared by Emmalea Ernest)

Two snap bean yield trials were conducted at University of Delaware's research farm located in Georgetown. A June-planted trial was exposed to significant nighttime heat stress during flowering and a July-planted trial which experienced more favorable weather conditions. These trials continue efforts to identify heat tolerant snap bean varieties suitable for production in the Mid-Atlantic region. PV 857 (Crites Seed) performed well in the heat stressed trial, as it has in past heat trials in Delaware. Bridger (HM Clause) had not been trialed in the past but did well in the 2020 heat trial. Most other entries produced low marketable yields under heat stress.

Seventy-nine advanced lines from the University of Delaware lima bean breeding program were tested for yield and maturity. In the early-June planted trial several lines matured earlier than the earliest standard variety (Cypress, ADM), with the fastest maturing line harvested at 62 DAP, which was 7 days earlier than Cypress. Some of the early maturing lines are heat tolerant and/or resistant to root-knot nematode and lima bean downy mildew (*Phytophthora phaseoli*).

Delaware State University [prepared by Venu (Kal) Kalavacharla]

Plants survive in unfavorable environmental condition by following strategies which involve a complex network and regulation of molecular interaction by controlling thousands of different gene expressions. Abiotic and biotic stresses, such as drought and fungal stresses, respectively, may negatively affect plants and their ability to survive. Previously, we performed research to identify the epigenomic changes imposed by fungal pathogen stress on resistant and susceptible genotypes of common bean. We employed the use of sodium bisulfite sequencing (BS-seq) to identify methylated cytosines across the common bean genome. Methylation is often associated with the modification of gene function and gene expression (Zhang et al., 2018). By identifying methylated cytosines, we can correlate methylation patterns with resistance and susceptibility profiles of common bean genotypes. Currently, we are interested in identifying drought-related factors in various common bean genotypes. To overcome limitations, such as drought, plants have evolved a strategy, employing reversible modifications of its genome by external factors, which affect gene expression changes without altering the genetic makeup. Since these external factors are above genetics, these are categorized as epigenetic factors. In our present study, we are growing identical genotypes of common bean in various locations, with differing weather conditions, such as in Delaware and Nebraska. The present study is aimed at identifying the direct effect of drought on the region of the genome and induced modification on the regulatory sequence of genes related to important traits in common bean. Epigenetic modifications, such as histone modifications, DNA methylations, Nucleosome positioning affect gene expression changes in response to environmental cues. Studying these epigenetic modifications is important because, under unfavorable conditions, such as drought, gene expression may be regulated at different levels to favor the essential functions for survival, compromising the other important secondary metabolites required for nutrition content. It is anticipated that results from this study may reveal genome-level modifications under drought stress, as well as reveal the effects of drought on the gene expression changes in the identical genotypes between two locations. Also, it helps in understanding the molecular mechanisms behind the common bean interaction with drought stress. We also believe that the present study will reveal the identification of drought stress-specific and location-specific epigenomic modifications as an expected outcome. This may assist in breeding for high yielding, environmentally adaptable common bean genotypes.

IDAHO

University of Idaho (prepared by Alexander V. Karasev)

A new strain of bean common mosaic virus (BCMV), named BCMV-A1, was collected from lima beans in Hawaii in 2017, with the sequence 93% identical to the peanut stripe virus strain of BCMV. BCMV-A1 induced an unusually severe systemic necrosis in cultivar ‘Dubbele Witte’, and pronounced necrotic or chlorotic reaction in inoculated leaves of five other bean differentials. BCMV-A1 was able to partially overcome resistance alleles *bc-1* and *bc-2* expressed singly in common bean, inducing no systemic symptoms. Phylogenetic analysis of the BCMV-A1 sequence, and distinct biological reactions in common bean differentials, suggested that BCMV-A1 represented a new, lima bean strain of BCMV. In 2017, two BCMV isolates were collected in Idaho from common bean, and based on partial genome sequences were found 99% identical to the BCMV-A1 sequence. The data suggest that the lima bean strain of BCMV may have a wider circulation, including common bean as a host. This new strain of BCMV may thus pose a significant threat to common bean production.

Gardenia Orellana, graduated from University of Idaho in May 2019 with a M.S. degree in Plant Sciences.

IOWA

Iowa State University (prepared by Donna Winham)

Population growth, climate change, and the role of diet in health and disease are putting increased pressures on agriculture to optimize plant foods for human consumption. The *Phaseolus vulgaris* L. species of the legume family have high genetic diversity, climate adaptability, disease resistance, and multiple human health benefits. However, research on the health benefits of beans on the prevention and control of diseases is limited. Few consumer acceptance studies exist and they are needed to better understand food intake choices. Both health and consumer research are critical to justify the expansion of these important crops into marginal lands and to improve the human condition.

At Iowa State University, Dr. Winham has conducted research to evaluate knowledge, attitudes, and practices regarding bean food items and food-related behaviors. We conducted a focus group study with low-income women who participate in Federal nutrition assistance programs. We identified distinct barriers and motivators to bean consumption, such as preparation and household member taste preferences.

Data collection is complete for the evaluation of 100% black bean pastas on the glycemic response, satiety, and gastrointestinal symptoms among young adult healthy participants. Data analysis and manuscript preparation are underway.

We published our findings on the knowledge, attitudes, and consumption practices of dry beans among low-income men in Arizona, and low-income Hispanic and White women in Arizona. Research findings on Registered Dietitian attitudes toward the role of beans in controlling type 2 diabetes were published during this period also.

We conducted an investigation on the knowledge, attitudes, and consumption patterns of male food pantry users in Iowa.

Pasta study research results were presented at a national conference (American Society of Nutrition).

MARYLAND

USDA-ARS (prepared by Talo Pastor-Crorrales)

Bean landraces with broad resistance

The Andean common bean landrace G19833 (Chaucha Chuga) was used to sequence the first reference genome of *Phaseolus vulgaris* (Schmutz et al, 2014). A large quantity of sequence information is available for this landrace which includes BAC libraries, cDNA libraries, SNP databases, gene expression profiles from various tissues (RNAseq), etc. Additionally, G19833 has been used to generate RIL populations for mapping traits such as phosphorous acquisition, agronomic performance, and disease resistance. G19833 has also been reported as resistant to the anthracnose, angular leaf spot, and Ascochyta blight pathogens and susceptible to the bean golden mosaic and bean common mosaic viruses (Broughton et al, 2003). However, little is known about the reaction of G19833 to the bean rust pathogen.

We reported the reaction of G19833 to a set of 13 races of *Uromyces appendiculatus*, the rust pathogen, 10 Mesoamerican and three Andean. Together, these races overcome all known rust resistance genes in common bean. Rust resistance in the under-utilized Andean beans lags that of the Mesoamerican beans. The Andean landrace G19833 was resistant to all thirteen diverse races of the rust pathogen. More recently we have evaluated the reaction of G 919833 to the Mesoamerican races 52, 55, and the Andean races 95 and 103. So far, the spectrum of resistance of G19833 is broader than all known rust resistance genes in common bean, including PI 181996 (*Ur-11*), Ouro Negro (*Ur-14*), PI 260418 (*Ur-Unnamed*), and PI 310762 (*Ur-Unnamed*), known to be resistant to all but one race of more than 80 races of the rust pathogen maintained at ARS-Beltsville.

In addition, G 19833 is also highly resistant to many Andean and Mesoamerican races of *Colletotrichum lindemuthianum*. So far G 19833 is resistant to 10 Mesoamerican races (17, 127,321, 453, 469, 1545, 1601, 1993, 2047, and 3481) and to four Andean races (19, 23, 31, and 55) of *C. lindemuthianum*. The Mesoamerican race 3481 overcomes the resistance of G 2333 that has three anthracnose resistance genes. G 2333 is resistant to all but one of the known races of *C. lindemuthi*anum. G19833 is also resistant to the Mesoamerican race 2047 that overcomes the resistance of 11 of the 12 anthracnose differential cultivars. Hence, it appears that G 2333 is one the best sources of broad resistance to the devastating races of the rust and anthracnose pathogens of common bean.

Mapping rust and anthracnose resistance genes

During this period, we have also studied the inheritance of resistance present in multiple new sources of rust resistance in the Andean beans G 18933 and PI 260418, and the anthracnose resistance genes in Andean bean Beija Flor.

In addition, we are pursuing studies using genomic technologies to map the positions of the rust anthracnose resistance gens in these common beans, and use fine mapping to develop tightly linked KASP markers associated with the three resistance genes.

We have also completed the studies of epistatic interactions between the *Ur-3* and *Ur-5* and between the *Ur-4* and *Ur-5* rust resistance genes. To that end we have used phenotypic and molecular markers. The phenotypic markers are specific races of the bean rust pathogen that separately identify each of these rust resistance genes. We also used the KASP markers SS68 that identifies *Ur-3*, SS240 that identifies *Ur-4*, and SS183 that identifies *Ur-5*. Both the phenotypic and KASP markers revealed that *Ur-3* was epistatic to *Ur-5* and that *Ur-5* was epistatic to *Ur-4*.

MICHIGAN

Michigan State University and USDA-ARS (prepared by Francisco Gomez and Karen Cichy)

The MSU dry bean breeding and genetics program conducted 17 yield trials in 2020 in ten market classes and participated in the growing and evaluation of the Cooperative Dry Bean, Midwest Regional Performance, National Drought and the National Sclerotinia Nurseries in Michigan and in the winter nursery in Puerto Rico. The USDA-ARS Dry Bean Genetics Program performed breeding trials within the cranberry, kidney, yellow, and black-market classes, and organic beans. Bean trials received an average of 9.96” of rain (June - mid Sept). This resulted with an average bean yields up to 30 cwt/acre at the Saginaw Valley Research and Extension Center (SVREC) near Frankenmuth, MI. In addition, common bacterial blight was prevalent on some of the research plots on both research farms. Notes were collected on reaction to the disease to identify those lines that showed some level of resistance. Efforts to breed for anthracnose resistance into large seeded beans including kidney and yellow beans continued this year by continued introgression and screening. Four new bean varieties were planted in Idaho in 2020 for Initial breeder/foundation seed production.

‘Adams’ black bean developed by Michigan State University AgBioResearch was released in 2020 as a high-yielding, upright, full-season cultivar with anthracnose [caused by *Colletotrichum lindemuthianum* (Sacc. et Magnus) Lams.-Scrib] resistance and acceptable canning quality. In 2-yrs of field trials over 27 locations, Adams yielded 3501 kg ha-1, flowered in 45 d and matured in 96 d on average. Plants averaged 51 cm in height, with lodging resistance score of 1.3 and seed weight of 20.9 g 100 seed^{-1}. Adams is resistant to races 73 and 109 of anthracnose present in Michigan and produces a top necrosis reaction to strain NL 3 of Bean common mosaic necrosis virus (BCMNV). Adams produces seed that meets industry standards for export and packaging and was rated acceptable in canned bean color in the black bean seed class. The name Adams was chosen to honor Professor M. Wayne Adams, former bean breeder, for his significant contributions in archetype breeding and establishing the black bean breeding program at MSU.

‘Charro’ pinto bean was developed by Michigan State University AgBioResearch was released in 2020 as a high-yielding, upright, full-season cultivar with excellent canning quality. Charro was developed using the pedigree breeding method to the F_4 generation followed by pure line selection for disease, agronomic and quality traits. In 4-yrs of field trials, Charro yielded 3,230 kg ha-1 at 17 locations in mid-Michigan, flowered in 46 d and matured in 97 d on average. Plants averaged 52 cm in height, with lodging resistance score of 1.6 and seed weight of 41.2 g 100 seed^{-1}. Charro exhibits the top necrosis reaction to strain NL 3 of Bean common mosaic necrosis virus (BCMNV). Charro produces seed that meets industry standards for export and packaging, and canning quality was rated excellent for the pinto bean seed class.

‘Eiger’ great northern bean was developed by Michigan State University AgBioResearch was released in 2020 as a high-yielding, upright, full-season cultivar with anthracnose [caused by *Colletotrichum lindemuthianum* (Sacc. et Magnus) Lams.-Scrib] resistance and acceptable canning quality. Eiger was developed using pedigree breeding method to the F_4 generation followed by pure line selection for disease, agronomic and quality traits. In 4-yr of field trials, Eiger yielded 3166 kg ha^{-1} over 15 locations in mid-Michigan, flowered in 44 d and matured in 98 d on average. Plants averaged 54 cm in height, with lodging resistance score of 1.3 and seed weight of 38.7 g 100 seed^{-1}. Eiger is resistant to races 73 and 109 of anthracnose present in Michigan and produces a top necrosis reaction to strain NL 3 of *Bean common mosaic necrosis virus* (BCMNV). Eiger produces seed that meets industry standards for export and packaging, and canning quality was rated acceptable for the great northern bean seed class.

‘Yellowstone’ yellow bean was developed by Michigan State University AgBioResearch was released in 2020 as a determinate, virus resistant cultivar with highly desirable vibrant dry seed coat color. Yellowstone was developed using pedigree breeding method to the F_3 generation followed by pure line selection for disease, agronomic and quality traits. In 4-years of field trials, Yellowstone yielded 2,902 kg ha^{-1}, flowered in 41 d and matured in 94 d on average. Plants averaged 47 cm in height, with lodging resistance score of 1.8 and seed weight of 46 g 100 seed^{-1}. Yellowstone is well adapted to growing conditions in MI and produces seed with an intense yellow seed coat color under local conditions. Yellowstone exhibits the top necrosis reaction to strain NL 3 of *Bean common mosaic necrosis virus* (BCMNV) conditioned by the *I* gene. Yellowstone produces seed that exceeds industry standards for export and packaging, and canning quality was rated acceptable for the yellow bean seed class.

A black bean nitrogen-fixation trial was continued at the SVREC research farm in 2020. The trial was designed to compare the performance of beans produced with no Nitrogen fertilizer to those with standard Nitrogen fertilizer applied (broadcast Urea at planting). The objective of this field trial was to investigate ways to enhance N-fixation ability of current bean varieties. Over the past two years this type of trial has identified black bean varieties that had equivalent and higher yield potential under low Nitrogen conditions.

Relationship between cooking time and canning quality: A study was conducted to determine if cooking time influences canning quality in dry beans and whether reducing processing time could improve canning quality of fast-cooking genotypes. A set of 20 yellow bean genotypes including Ervilha, PI527538 and 18 recombinant inbred lines with fast, moderate, or slow cooking times were canned across five retort times (10, 15, 20, 30, and 45 min). All genotypes performed better when processed for less time than the standard 45 min, but canning quality was highest at 10 min for fast- and medium-cooking genotypes and 15 min for slow-cooking genotypes. Cooking time was correlated positively with texture and intactness. Color changed with retort processing such that longer times produced darker beans with more red and yellow coloration.

NEBRASKA

University of Nebraska (prepared by Carlos Urrea and Bob Harveson)

The 70th annual Cooperative Dry Bean Nursery (CDBN) report was compiled and distributed in March, 2020. During the 2019 CDBN, 25 entries were tested in trials in 7 locations in the U.S. and Canada. Final results were compiled and distributed to all project members and made available to the public via the http://cropwatch.unl.edu/varietytest-Drybeans/2019 web page.

Results of the 2019 Dry Bean Variety Trial were also posted on this web page. In 2020, Dr. Urrea participated in several national and regional trials including the CDBN, which evaluated 24 entries in replicated trials in 7 locations in the U.S. and Canada, Mid-west Regional Performance Nursery (MRPN), which included 6 Nebraska lines, and the Dry Bean Drought Nursery (DBDN), which included 25 lines obtained from and tested in MI, WA, NE, and PR. Dr. Urrea served as coordinator for the CDBN and DBDN in both years. As chairperson, Dr. Urrea hosted a multi-state W_3150 meeting on August 24, 2020 with 25 people attending.

The Shuttle Breeding Program between Nebraska and Puerto Rico continued in 2020. About 65 lines from the fourth shuttle breeding cycle were tested under drought and non-drought stress environments in Scottsbluff; these trials will be replicated in Puerto Rico. Two lines produced through the shuttle breeding process [SB-DT2 (pinto) and SB-DT3 (small red)] will be released as sources of drought tolerance and multiple disease resistance.

Several highly rust-resistant tepary beans through artificial inoculations were identified, with eight of the most representative rust races present in the USA. These races render susceptible all known rust resistance genes in dry beans. Rust evaluations revealed that all dry bean checks were susceptible to one or more of the races of *U. appendiculatus*. Conversely, four domesticated tepary bean accessions (G40142, G40148, G40161, and G40237A) and two improved lines (TARS-Tep 22 and Tep 23) were immune to all eight races. The immune reaction (no visible symptoms) exhibited by six tepary beans is not known to occur in common bean.

Disease resistance trials continued in Scottsbluff during 2020, including the national White Mold Monitor Nursery (WMMN) and ongoing bacterial wilt resistance studies. The G18829/Raven RIL composed of 303 lines, the parental lines, the F_1s, the F_2s in both directions, and the backcrosses to both resistant and parental lines were tested against a pathogenic bacterial wilt isolate. We found a segregation of 13 susceptible: 3 resistant. We are currently confirming this 13:3 segregation ratio in $F_{5:6}$ RILs. DNA is being extracted from the RILs and the mapping bacterial wilt resistance is in progress. Dr. Urrea's PhD student, Erika Sanchez-Betancourt, is involved in these bacterial wilt resistance studies as part of her dissertation research.

Dr. Urrea increased breeder to foundation seed of one great northern line (NE1-17-10) and one slow darkening pinto line (NE2-17-18) at the Kimberly Experimental Station in Idaho. NE1-17-10 has an upright plant architecture, carries the *Ur-3* rust resistance genes and the *I* bean common mosaic virus (BCMV) resistance gene, and shows tolerance to common bacterial blight (CBB). NE2-17-18 carries the *Ur-11* rust resistance gene and the *I* BCMV resistance genes. Both lines have high yield potential and large seed size. Another great northern, NE1-17-36, and two slow darkening pintos, NE2-17-37 and NE4-17-6, are being increased as breeder to breeder seed at the Kimberly Experimental Station. In addition, foundation to foundation seed of great northern cultivars Coyne and Panhandle Pride were increased in 2020.

Collaborations continued in 2020. ‘Kikatiti,’ a pinto bean cultivar developed by the dry bean breeding program at the University of Nebraska, Agricultural Research Division, is in the process of release with Sokoine University of Agriculture in Morogoro, Tanzania. This upright indeterminate pinto bean has high yield potential and multiple disease resistance across Tanzanian production environments. Dr. Urrea participated in screening the yellow bean panel led by Dr. Karen Cichy. Dr. Urrea continued collaborating with plant pathologist, Dr. Bob Harveson, on multiple projects, including evaluating *Phaseolus* breeding lines and germplasm to develop new regionally adapted cultivars with disease resistance to bacterial diseases (wilt, *fuscans* blight, and brown spot). They also collaborated on evaluating new copper-alternative chemicals for managing bacterial and fungal diseases (e.g. white mold, bean rust), new fungicidal products/application methods for controlling rust, white mold, and root rot diseases, and the potential for pathogens associated with new pulse crops to become disease problems in dry beans. They also co-hosted meetings with bean growers on February 11 and August 21 2020 with 60 and 50 growers attending, respectively.

NEW YORK

Cornell AgriTech (prepared by Phillip Griffiths)

In 2020 a greater focus was placed on the development of dry beans with improved seed-coat color. This included the development of two new black bean breeding lines (BB6 and BB13) with very high seed-coat color retention after cooking/canning. Additional studies were undertaken for the evaluation of nutritional components. Additionally, the kidney bean lines Cornell LRK-6, Cornell DRK-1 and Cornell 612 all have promise for commercialization as varieties based on replicated research plots, on-farm trials and performance in national dry bean nursery trials in 2017/2018. Line DRK-1 shows promise in the dark red market class as its maturity is several days earlier than checks including 'Montcalm' while the yield is typically much higher. Line LRK-6 also shows high promise based on high yields against checks over multiple seasons. Based on these findings, new crosses have been made between DRK-1 and LRK-6 to move high canning quality into an early maturing, high yielding dark red kidney variety going forward. The upright line ‘Cornell 612’ also looks promising as a potential variety especially for organic systems based on yield, upright plant type and tolerance to white mold. Based on increased consumer demand for more color and variability within products introgressions of novel colors have also been targeted. These multi-colored kidney bean lines include the introgression of black and purple seed-coat color into a kidney bean background with multiple additional colors selected out of upright architecture populations providing white, pink, mottled and chestnut seed-coat colors. When combined with new populations for introgression of a yellow and blue seed-coat color, fourteen different color types now exist as part of this set. Based on initial canning studies the black kidney beans have had excellent color retention when compared to black bean controls, and good canning quality based on can-pour and splitting. As the black kidney has a slightly wider seed type that most kidney beans, it requires a shorter soak time for canning. To circumvent this for fixed cooking protocols at canning facilities, it has been crossed to DRK-1 and LRK-6 to normalize the seed size and type. New lines have now been selected out of these crosses, the most promising of which is black kidney bean BK33, with a very attractive elongate seed shape.

New upright LRK and DRK breeding lines have been selected following crosses with Middle American market classes that have the upright vine morphology from Michigan State University (navy, great northern and black bean parents). Selections from these populations have been used to improve plant architecture in the LRK and DRK market classes potentially enabling higher yields in combination with improved tolerance to white mold and other diseases. These lines were planted in Freeville NY in 2019 and greenhouse increased in 2020 as field trials were limited based on Covid-19. New selections include a promising purple kidney bean UPRK45 that cans to a very dark purple-red color making it a novel candidate for this market class. The pink seed-coat genotype UPRK27 also looks highly promising with a plant type similar to an upright black bean cultivar, advances in seed quality are being advanced to field testing. The upright line UPRK49 which has chestnut seed-coat color has the most promising upright architecture for high density planting and disease avoidance in kidney beans. The yields of UPRK49 are currently not competitive, but this plant type has been crossed to Cornell DRK1 and LRK6 and populations developed to select higher yielding types in with this architecture. Populations developed from these three upright selections were all increased in greenhouses in Ithaca and Geneva together with populations advancing the color retention into black bean, black kidney seed-coat color and yellow kidney seed-coat color. Selection of new cultivars in this type going forward could result in the development of new kidney bean varieties for NY that could be planted at higher density with reduced disease spread and easier cultivation. A new, intriguing line is a mini-dark red kidney bean NYD4 that cans very well. Due to the small seed size of this line, and the upright architecture, it could lead to a variety where pod shattering is not a concern enabling harvest using similar equipment for upright black beans. Preliminary yield trials in 2020 (and yield trials in 2019) also show very high yields compared to standard kidney beans (>3000lb/acre).

Fig. 1: New Cornell Dry Bean Breeding Lines. Mini-Kidney NYD4, High Seed-Coat Color Retention Black Bean BB13, Purple Kidney Bean UPRK45 and Black Kidney Bean BK33

NORTH DAKOTA

North Dakota State University (prepared by Juan Osorno and Phil McClean)

Cultivars developed by the program are shared with the dry bean growers in the region. The breeding program conduct field research at 8 locations in North Dakota and Minnesota, accounting for ~40 acres (~9,000 plots) of research trials if all locations are pooled. Hundreds of breeding lines and thousands of early generation genotypes are tested and selected as part of a complex breeding pipeline that moves genetic material in a stepwise manner every year. Activities include both phenotyping (both field and greenhouse) and genotyping, as well as statistical and genetic analyses. In addition, new germplasm is tested against biotic and abiotic stresses commonly found in the region. Results from both basic and applied research are shared frequently at meetings, conferences, field days, and other extension activities (e.g. bulletins) allowing the dissemination of the information and results gained by project to the general public. Collaboration among programs not only within NDSU, but also with scientists from other universities and institutions have been facilitated by having a multistate project like the W-3150. Most findings and results from this project are shared through journal publications, extension bulletins, as well as in talks at field days with growers and other grower-related meetings. In addition, most results are also shared at bean scientific meetings such as the Bean Improvement Cooperative (BIC). Finally, most results are also available at the USDA-NIFA REEport website and the BIC website.

The Dry Bean Variety Trials grown at more than 8 locations in North Dakota and two in Minnesota includes all the public and private varieties plus breeding lines at final stages of testing. Some of these trials are grown at the ND Agricultural Experiment Station Research and Extensions Centers (RECs) across the state. Results from these trials are published in the annual extension Bulletin A-654. This is a great decision tool not only for growers but for public and private breeding programs when deciding about a new variety release. The NDSU dry bean breeding program continues to test and screen every year thousands of early generation genotypes, hundreds of preliminary and advanced breeding lines, commercial cultivars, and other genotypes. This breeding pipeline is grown in field experiments across six locations in North Dakota and two locations in Minnesota. In addition, variety testing is made at most of the Research and Extension Centers (REC), so bean growers have a better idea of how each available cultivar may perform in their own region.

Breeding activities mainly involved phenotypic selection at early generations, yield testing of preliminary and advanced breeding lines, and some genetic/agronomic studies. The main breeding method used is a modified pedigree and the program is subdivided by market class (currently, the breeding program works with seven market classes), Intra-racial crosses are very common in order to keep specific seed quality parameters. For example, crossing pinto with great northern (Durango race) or navy with black (Mesoamerica race) is a very common practice and allows to obtain material segregating for multiple market classes. However, every market class is handled separately, making the breeding program to be subdivided into small programs, which creates some logistic and technical issues. Inter-racial and/or inter-pool crosses are less common and only used when attempting to transfer specific traits. Breeding targets include high seed yield and quality, disease resistance, early maturity, plant architecture for efficient mechanical harvest, and canning quality, among others. Greenhouse activities complement the field work by doing disease screening (bean Rust, BCMV, Anthracnose, and Common Bacterial Blight, among others), crossings, and seed increases. Winter nurseries were conducted in Puerto Rico, and New Zealand in order to speed up the breeding process, especially at the early generations (F_1 to F_5). The results and new findings were always reported in peer reviewed journals, grower meetings, bulletins, magazines, phone calls, and informal conversations with all the stakeholders. Specific research on slow darkening pintos, waterlogging/flooding tolerance, resistance to diseases in close collaboration with Dr. J.S. Pasche (root rots, rust, anthracnose, common bacterial blight), improvement of upright plant architecture, and soybean cyst nematode infection in dry bean, and the variation in seed nutritional content by cultivar and location. Efforts on association mapping of important traits (GWAS) and other genomic tools are also underway in close collaboration with Dr. Phil McClean (see publications). Greenhouse screening for disease resistance have allowed the identification of some genotypes with improved resistance to some of the most important pathogens in the area, especially for rust, white mold, common bacterial blight, and anthracnose.

OREGON

Oregon State University (prepared by James Myers)

Introduction: Approximately 10,000 A of snap beans are grown in western Oregon for processing. With the bankruptcy of Norpac in 2019, we are now down to one major processor (National Frozen Foods) in the region. This processor has picked up the acreage dropped by Norpac, so there has been no net loss in acreage. The vegetable breeding program at Oregon State University focuses about 50% time on snap bean breeding with the primary objective being the development and release of bush blue lake type green beans for western Oregon growers and processors.

Accomplishments: The primary research objective of the OSU snap bean breeding program has been to identify and introgress white mold resistance into elite cultivars. GWAS of snap bean diversity panels has been used to identify white mold resistance QTL in snap beans. Thirty-nine regions of the genome were identified as having significant associations with white mold resistance. Those snap bean accessions with the highest genomic breeding values were identified from the diversity panel and are being used to create two 8-parent MAGIC populations to facilitate recombination of resistance QTL found in snap beans. One population is made up of purely snap beans, the other has both snap and dry beans with the objective of making snap bean resistance QTL available to the dry bean breeding community.

We participate in growing the common bean National Sclerotinia Initiative nursery with both field production and straw tests in the greenhouse. Data from this are provided to the University of Nebraska for compilation and reporting. We also provide a field nursery for private breeding programs to screen lines for white mold resistance.

Another thrust of the OSU snap bean breeding project has been to investigate pod and leaf color, and chlorophyll content in snap beans to determine the interaction of these factors on pod quality and plant productivity. Mainly, we are measuring traits in the Snap Bean Diversity Panel using a colorimeter, Multispeq and unmanned aerial systems to acquire data. Two years of field data have been acquired and we are now in the process of digitizing images and compiling data for statistical analysis and GWAS.

A recently completed project on the *persistent color* (*pc*) trait in snap beans has revealed the basis for poor germination of these types compared to white- and colored-seeded snap beans under field conditions. This trait confers superior color to pods but has deleterious effects on germination if the seeds are not first treated with a fungicide. First found in Flageolet dry bean types, *pc* is a member of the stay-green gene family. Beans with this trait have pods that are uniformly dark green, foliage that remains green during senescence, seeds that are pale green and bleached white cotyledons upon emergence. The stay-green phenotype is caused by a disruption of chlorophyll catabolism during senescence. Key to this study was the use of near isogenic pairs that were with white- or green-seeded as well as a pair that had white- vs. colored-seed. No differences in germination percentage were observed in the laboratory. Treatment with fungicides increased field germination and emergence, and in untreated seeds, infections with *Fusarium* and *Rhizoctonia* diseases were prevalent. *Pc* seeds had significantly higher electrical conductivity, more rapid imbibition and had more seed coat cracking during imbibition. When seed coat anatomy was observed microscopically, a significantly thinner osteosclereid layer was found in *pc* types compared to white- and colored-seeded types. Our model for why *pc* types show reduced field emergence is that the thinner seed coat allows more rapid water uptake, which causes mechanical stress across the seed. Seeds coats are inherently more fragile and crack more easily which allows early and copious solute leakage into the surrounding spermosphere. Pathogens sense these solutes, migrate to and rapidly colonize seeds before seedlings have had a chance to emerge. The implications of this research are two-fold. In terms of cultural modifications, *pc* seed should be regarded as extremely fragile and should be handled accordingly during harvest and conditioning. Seeds should be planted into moist soil rather than being “watered up”. Seed coating and priming to reduce rate of water uptake may help as well. From a varietal improvement standpoint we are investigating the possibility of selecting *pc* types for thicker seed coats.

There is a concerted effort in western Oregon to grow dry beans without irrigation and relying only on residual moisture from winter rains. We have contributed three black bean advanced lines derived from crosses to tepary beans for trial in the Dry Farm Project. This project has also sourced lines from the USDA-ARS-TARS tepary breeding program in Puerto Rico for their trials.

PUERTO RICO

University of Puerto Rico (prepared by Consuelo Estevez)

Early Generation Nurseries: F_3 and F_4 lines derived from crosses between elite lines having traits of economic value such as disease resistance and/or tolerance to abiotic stress were planted at the Isabela Substation. Pedigree selection was used to choose adapted individual plants with good pod set, erect growth habit and absence of disease symptoms. Individual plant selections were made from these nurseries based on seed type and agronomic traits including seed yield potential. The most promising F_4 lines will be screened in the greenhouse for resistance to

BCMNV and the presence of molecular markers for BGYMV, BCMNV, common bacterial blight (CBB) and rust resistance.

Advanced Generation Nurseries: During 2019, several performance trials of promising bean breeding lines, that include elite pink bean and white bean breeding lines with resistance to BGYMV, BCMNV, CBB and ALS (white lines) were planted in field trials at the Isabela Substation. Pink bean and white lines were identified and mean seed yields > 2,000 kg/ha.

Snap bean breeding lines developed between a cross of a source of BGYMV and BCMV resistance and a snap bean with heat tolerance were advanced to the F_5 generation in trials planted at the Isabela Substation. These lines were screened with molecular markers for BGYMV and in the greenhouse for resistance to BCMV. Lines were selected that have the *bgm* gene and the SW12 QTL for BGYMV resistance. These lines will be tested in the field in 2021.

Yield trials of Andean and Mesoamerican bean breeding lines that combine resistance to bruchids and diseases were planted at the Isabela in 2019. Andean lines that yielded as well as the light red kidney bean cultivar 'Badillo' were identified. Black, dark red and white bean lines with bruchid resistance and genes for resistance to BGYMV, BCMV and BCMNV also performed well.

W-3150 Dry Bean Winter Nursery: In December 2018, the project planted 5,145 bean breeding lines from the USDA-ARS, Michigan State University, the University of Nebraska and North Dakota State University in winter nurseries as a cooperative activity of Regional Hatch Project W-3150. A few lines with traits of economic value were selected from the winter nursery for use as parents in the UPR bean breeding program. The Cooperative Dry Bean Nursery was planted at Isabela, Puerto Rico in January 2019. Local white bean cultivar 'Bella' and two pinto bean lines from Puerto Rico produced seed yields similar to elite bean cultivars from the U.S.

Cultivar and Germplasm releases: A paper describing the release of the pinto bean lines PR1572-19 and PR1572-26 was published in the J. Plant Reg. A paper identifying recent releases of bean cultivars in Central America and the Caribbean was published in the 2020 Annual Report of the Bean Improvement Cooperative.

Screening against Fusarium solani: The virulence of *Fusarium solani* isolate ISA-Fs-008 was characterized in the BASE 120 nursery. The severity in four plants form each genotype ranged from 1 to 7 and the genotypes with no visible symptoms of *F. solani* infection were: SEQ 342-39, SEQ 342-89, G21212, MEN 2201-64ML, SB2-170, RCB-593 and FBN 1205-31. Nodulation data was also recorded.

USDA-ARS-TARS, Mayaguez, PR (prepared by Timothy Porch)

TARS-LH1, a broadly adapted pinto bean germplasm with resistance to the leafhopper pest was released with resistance to *E. krameri* and *E. fabae* in collaboration with MI and PR. A description of germplasm was published in JPR of two ADP that are being released in Tanzania, 'Yunguilla', tested as ADP-447, and Baetao-Manteiga, tested as ADP-190, a collaborative effort with WA, Tanzania and South Africa. TARS-Tep 23 (*Phaseolus acutifolius*) with broad drought and heat adaptation and resistance to CBB and rust will be released in collaboration with PR, NE, CA, and Honduras. TARS-Tep 93 with improved culinary characteristics and with leaf hopper resistance and tolerance to BGYMV will be released in collaboration with PR, MI, IA, MD, and the Dominican Republic. The NE and PR shuttle breeding program will be releasing a small red and pinto with drought tolerance.

A phylogenic analysis on angular leaf spot, caused by *Pseudocercospora griseola*, using isolates from Puerto Rico, Central America and Tanzania confirmed the existence of the Afro-Andean clade. Sources of resistance to angular leaf spot were also identified in common bean through greenhouse screening.

WASHINGTON

USDA-ARS, Prosser, WA (prepared by Phil Miklas)

Interesting info from a regional Ag-Newsletter: Based on August 1, 2020 conditions, dry bean production in Idaho is forecast at 917,000 cwt., down 14 percent from 2019. Expected harvested area is 39,000 acres, down 6,000 acres from last year. Yield is expected to be 23.50 cwt per acre, down 20 pounds from the previous year. **Dry bean production in Washington is forecast at 1.08 million cwt., up 62 percent from 2019. Expected harvested area is 40,000 acres, up 15,000 acres from last year.** Yield is expected to be 27.00 cwt. per acre, up 40 pounds from the previous year.

New cultivar: USDA Rattler (PT11-13-31) pinto, drought and low fertility tolerant with *I* and *bc-3* for BCMV resistance and *Ur-3* and *Ur-11* for rust resistance.

New markers for MAS of rust resistance genes Ur-3, Ur-7, and Ur-11 (Miklas, Alvaro Soler, McClean, Talo, Oscar Hurtado). Physical position for *Ur-7* is between *Ur-3* and *Ur-11*. *Ur-3* and *Ur-11* combinations exist but not *Ur-3* and *Ur-7* or *Ur-7* and *Ur-11* – likely because of the tighter linkages.

5 bp deletion in a NAC gene is the likely causative mutation for bgm-1 gene (Beaver, Beebe, Bodo, Oladzad, McClean, JC Rosas, Alvaro Soler, Miklas)

BCMV resistance gene characterization (McClean, Hart). *bc-u* (3 loci) – two of the genes are well characterized and the third in progress. *bc-2* (two distinct mutations – Michigan navy Robust, Durango Landrace)

BAT93 EMS Tilling population (Porch, Soler). BAT93 has *I* gene but one mutant line has the *I* gene knocked out – such that it is susceptible to BCMV. Deep resequencing of the mutant line has been conducted to search for the mutation that knocked out the *I* gene.

Kikatiti pinto (DDP-94) – Nebraska pinto is to be released in Tanzania (Urrea, Porch, Nchimbi). *I*, *bc-3, Ur-3, Ur-11*, SAP6 QTL for moderate CBB resistance, does okay against ALS, upright architecture.

Germplasm releases pending (Porch, Fourie)

Two RILs from the Rojo/CAL 143 population with HBB4.1, HBB5.1, and *Pse-2* for resistance to halo blight, QTL for rust resistance, protected *I* gene, and moderate resistance to ALS are pending release.

Cooperative nurseries grown in WA in 2020: CDBN, BWMN, DBDN

WYOMING, Univ. Wyo., Powell REC, and Dept Plant Sciences (Jim Heitholt et al.)

Line Development and Progeny Advancement. In 2019, we grew out F_3 progeny from about 20 crosses. From those plots, single-plant selections were made. Several of those are being grown in 2020 as three-row or six-row plots and we expect to make single-plant selections again in Sept 2020. The lines were also scored for flowering date and maturity. As part of our increases, seed from five popping (nuña) beans lines (bred by Colo State and Univ. Wisconsin) were grown out and shared with the University of Wyoming human nutritionist and one individual within the Washington State system. About one-quarter of our breeding program is focused on popping beans and we are working with some of the photoperiod-sensitive lines during the winter months in the greenhouse.

Cooperative Dry Bean Nursery. At Lingle 2019, we grew 44 entries in a four-replicate trial (22 were CDBN). All entries were scored for flowering date, maturity date, yield, seed size, upright stature, height, and iron deficiency chlorosis. The study was damaged slightly by hail storms in early July and late August.

Screening for Reduced Input Management. As part of our program to screen genotypes for tolerance to low soil N and low soil P, we grew six F_5 progeny (sister) lines from a Long's Peak-by-UI537 cross along with three commercial checks and the parents (Powell 2019). Full N and full P fertilizer were also included as treatments. No fertilizer-by-genotype interactions were detected. Yields averaged 4090 pounds per acre but were not significantly affected by fertilizer. Soil/leaf blade N/P concentrations were also unaffected by the fertilizer treatments. However, leaf blade concentrations of N, P, K, Ca, Zn, Mn, Cu, Fe, and B did different among genotypes. La Paz out yielded all entries. The yields of the F_5 progeny lines were competitive with the other two commercial checks and the two parental lines. Interestingly, yield of the six sister lines were negatively correlated with canopy temperatures on two of the four sampling dates. These latter results with canopy temperature continue to support our previous studies that suggest that low canopy temperature may be able to serve as a selection criteria in situations where collecting grain yield is not feasible.

N-Use Efficiency. We are nearly finished summarizing several years of work with plus/minus N fertilization on different cultivars from across the dry bean belt. Despite measuring multiple plant traits across several years of studies, N-by-genotype interactions continue to be largely absent. Other labs throughout the world have documented differential responses to N by different genotypes (i.e., identified genotypes that are more N-use-efficient) but we have not yet started crossing with any of those lines yet.

Genotype-by-Planting Configuration. After two years of row spacing tests (7-inch vs. 22-inch), we documented a 15% yield increase with 7-inch rows. In 2018, we found a significant row spacing-by-genotype interaction with La Paz responding to narrow rows and Poncho not responding. In 2019, narrow rows out yielded wide rows by 8% but no row spacing-by-genotype interaction was detected. Other treatments were included such as seeding rate and irrigation rate but we are not discussing those in this report. We are continuing this research in 2020 but with minimal focus on genotype for now; we expect to test multiple genotypes for interaction with row spacing in 2022.

Genotype-by-Planting. In 2020, we launched a year one of a study with six cultivars (differing in maturity) and three planting dates. The first planting date was optimal for our region (late May), the second planting date is borderline for our area (10 June), and the third was assumed to be too late for our region (25 June).