Partners in Progress
WHEAT

# Wheat Research at OSU 2016

Supported by the

## Oklahoma Wheat Commission

and the

## Oklahoma Wheat Research Foundation

Oklahoma State University
Division of Agricultural Sciences and Natural Resources
Oklahoma Agricultural Experiment Station
Oklahoma Cooperative Extension Service

P-1048

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# Partnerships Enhance Wheat Research

***Partners in Progress*** – Oklahoma State University's long-standing partnerships with the Oklahoma Wheat Commission and the Oklahoma Wheat Research Foundation are valuable assets for our wheat research and Extension programs. The partnerships not only provide partial funding for our research programs, but also provide valuable input from producers to help keep our research programs focused and relevant. It is truly one of the best examples of the Division of Agricultural Sciences and Natural Resources working in a cooperative relationship with commodity groups to achieve common goals. Partial funding for our research and Extension programs comes from wheat producers through the check-off program. We have been and continue to be accountable for the use of these funds.

The *Partners in Progress Wheat Research Report* is one of a series of annual reports from DASNR highlighting research results and impacts of funded projects. This information is utilized throughout the year in educational wheat programs and is distributed to Oklahoma wheat producers to keep them up to date on the latest research findings. The research contained in this report has been directed as closely as possible to meet the needs of Oklahoma wheat producers.

At the beginning of the first section is a summary of accomplishments for fiscal year 2015-2016. The following narrative explains in more detail the progress made during the year.

The long-term continuous support of our wheat research programs from the OWC and the OWRF has allowed our faculty to make significant progress toward the common goal of keeping Oklahoma wheat farmers competitive in regional, national and international markets. This support makes us truly partners in progress.

Keith Owens
Associate Vice President
Oklahoma Agricultural Experiment Station
Division of Agricultural Sciences and Natural Resources
Oklahoma State University

## Oklahoma State University
## Division of Agricultural Sciences and Natural Resources
## Mission Statement

The mission of Oklahoma State University's Division of Agricultural Sciences and Natural Resources is to discover, develop, disseminate and preserve knowledge needed to enhance the productivity, profitability and sustainability of agriculture; conserve and improve natural resources; improve the health and well-being of all segments of our society; and to instill in its students the intellectual curiosity, discernment, knowledge and skills needed for their individual development and contribution to society.

# A Future of Success



A future of successful wheat production starts with beneficial increases in variety development that will offer a framework to generate economic growth, exercise environmental stewardship and strengthen end- quality use for the consumer. The OSU Wheat Improvement Team continues to focus on each of these important influences creating opportunities for producers to help them succeed in an ever-changing marketplace.

In 2016, global production increases impacted the price. The OWC continues to work on marketing efforts in both the domestic and foreign markets, but publicly funded research is vital to maintaining long-term flexible options for wheat producers when providing improved opportunities for increased profitability. This report shows the analysis conducted on 40 to 50 cultivars and experimental lines at five regional test sites to ensure statewide tests are filled with the best adapted cultivars. Data collected includes grain yield under dual-purpose and grain-only production systems, forage yield, disease resistance, response to fungicide application, adaptability to no-till production systems, high temperature sensitivity to germination, plant height, first hollow stem date and heading date.

The data collected from OSU research plots ensure farmers and ranchers have an opportunity to observe the newest genetics in research demonstration plots throughout Oklahoma. The OSU Small Grains Variety Testing Program is unique in that plots are made possible with the team work of OSU extension and farmer cooperators who allow trials in many locations to be studied on privately owned land.

At many universities, these efforts are restricted to research station plots only, but the OSU variety testing program goes the extra mile to ensure wheat varieties are tested by farmers before the advancement of release for real-world settings in Oklahoma wheat fields. OSU wheat variety test plots are distinctly different due to the influence put toward the nature of ***GrazenGrain*** varieties. While dual-purpose wheat gives producers more options for increasing profitability on the farm, studies continue to show grazing capacities on the varieties in the OSU wheat research program are essentially linked to grain quality via adaptation. This gives producers planting OSU varieties an edge, allowing them to plant varieties that have the end-use qualities millers and bakers want, while also having forage opportunities for grazing, should the market influence them to have different management strategies.

The need for wheat research in public institutional settings made possible by programs such as the OSU WIT will not be possible without the continued support from Oklahoma wheat producers. The OWC and the OWRF, along with OSU's WIT and DASNR, continue to work on items beneficial to both the producer and buyer, which is not as heavily emphasized in other public or private research settings. We are making great strides with the wheat research and extension programs at OSU, and want to thank the producers for the support with check-off funds to keep these programs at the front of technology discovery and transfer. The OSU WIT is motivated by desire committed to excellence and provides a framework to help make wheat producers successful; we are glad to be partners in progress.

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Partners in Progress WHEAT

# Genetic Improvement and Variety Release of Hard Winter Wheat

## Wheat Improvement Team

### 2015-2016 progress made possible through OWRF/OWC support

- **OWC-sponsored survey data (conducted by USDA-NASS) showed OAES wheat releases to be five of the top six most widely planted varieties in 2016 (WIT).**
- **Wheat candidates under preliminary or extended seed increase by Oklahoma Foundation Seed Stocks include, but are not limited to, the following (WIT):**

| | |
|---|---|
| OK11D25056 | Gallagher/OK05511 |
| OK10126 | OK Bullet/OK98680 |
| OK12DP22002-042 | Billings/OK08328 |
| OK10430-2 | CS+1V/2*Endurance sib |
| OK12912C-138407-2 | N91D2308-13/OK03926C//OK03928C |
| OK128084C | N91D2308-13/OK04902C//OK05907C |
| OK13209 | OK Bullet/TX00D1390//Shocker |
| OK12DP22004-016 | Everest/OK08328//OK09634 |
| OK13621 | TX00D1390/Billings |
| OK13625 | Billings/Fannin sib |
| OK12D22002-077 | Billings/OK08328 |
| OK14319 | NE01533/OK02125//Duster |
| OK12206-127206-2 | Y98-912/OK00611W//OK03716W |
| OK15115 | Pete/OK Bullet//TX03A0148 |

- **Provided the current class of candidate varieties significant upgrades in stripe rust protection and straw strength (Carver).**
- **Procured novel wheat germplasm from across the world, including our research partners in Romania, Hungary and Turkey (Hunger, Carver).**
- **Analyzed grain samples from the 2015 wheat variety performance tests for milling and flour quality to reveal consistently good quality attributes for TAM 114, Bentley, Ruby Lee, Oakley CL, SY Monument and Winterhawk and relatively poor bread baking potential for LCS Wizard, NF 101, Pete and WB-Redhawk (Marburger, Edwards).**
- **Turned out approximately 4,000 disease ratings or data points in a single year from pre-planned assays and trials, which just happens to be the number of times a dough mixograph rating was visually made and a flour sedimentation volume was measured on WIT germplasm. Disease resistance and quality control go with the grain (Hunger, Carver).**
- **Evaluated 1,421 wheat experimental lines for reaction to the wheat soil-borne mosaic virus/wheat spindle streak mosaic virus, WSBMV/WSSMV complex, of which 45 percent were developed by WIT. The remainder originated from USDA-ARS cooperative nurseries (26 percent), WIT collaborators in Hungary and Romania (1 percent), Syngenta AgriPro (23 percent), and DuPont Pioneer (5 percent) (Hunger).**
- **Among the 640 WIT lines evaluated for WSBMV/WSSMV reaction, 60 percent were additionally characterized for leaf rust, tan spot and stripe rust reactions, and 23 percent were evaluated for Septoria tritici blotch and barley yellow dwarf.**

- Found resistance to occur at a frequency of 22 percent following the first comprehensive evaluation of field-based STB reaction within the WIT elite germplasm pool (Hunger).
- Determined tan spot appears consistently earlier in Oklahoma wheat fields than Septoria/Stagonospora leaf and glume blotch (Hunger).
- Developed and perfected a reliable phenotyping assay for bird-cherry-oat aphid resistance based on aboveground symptom expression in young seedlings, thus clearing a once obstructed path to incorporate this trait into the WIT variety development program (Giles, Zarrabi).
- Produced the first single nucleotide polymorphism, SNP, physical map from a large population of Duster x Billings doubled haploid progeny, totaling 165,654 anchored SNPs and averaging 7,888 SNPs per chromosome. (Chen)
- Identified desirable progeny from the Duster x Billings doubled haploid population with improved drought and heat resistance based on several physiological parameters. (Kakani).
- Validated a major QTL *QYld.osu-1BS* for grain yield and designed a molecular marker to track the favorable allele from Duster in WIT germplasm (Yan).
- Identified the naturally occurring mutant *TaANR1* in wheat, the first known wheat gene linked to nitrogen regulation and subsequent plant development (Yan).
- Provided stakeholders with current first-hollow-stem measurements and first-hollow-stem projections throughout Oklahoma, generated by the web-based first-hollow-stem estimator tool located on the Oklahoma Mesonet ag weather page (Marburger, Edwards).
- Provided 17 in-season wheat disease updates to wheat growers, consultants, Extension educators, and researchers via an electronic format (Hunger).
- Increased WIT web-based and social media presence, with team websites and social media receiving more than 50,000 visits last year (Marburger, Edwards).
- Conducted more than 25 wheat variety tours to provide stakeholders with current information on released varieties and candidate varieties (Marburger, Edwards).
- Confirmed absence of Karnal bunt in 19 Oklahoma wheat grain samples to allow Oklahoma wheat to move without restriction into the export market (Hunger).

After 18 years of uninterrupted service, WIT is one of the longest-running research teams in any capacity at OSU. Faculty from three DASNR academic units form a complete team that combines fundamental and applied components of wheat research to propel a common cause: to advance Oklahoma's wheat industry with development of improved varieties and dissemination of the know-how that best captures their genetic potential. The latest products of this charge are now manifested in the all-purpose hard red winter wheat variety Bentley, and the more specialized hard white variety Stardust.

WIT scientists who received funding from the OWRF in 2015-2016 and reported their findings were David Marburger and Jeff Edwards, information exchange; Bob Hunger, wheat pathology research and development of disease-resistant germplasm; Kris Giles, aphid resistance discovery and introgression; Charles Chen and Liuling Yan, gene discovery and genomic technology; Gopal

Kakani, drought and heat tolerance mechanisms; and Brett Carver, wheat breeding and variety development.

Recurring research projects in wheat disease diagnosis and evaluation, variety testing and placement, and variety development are common themes of WIT's output. These must carry on to sustain or build upon the advances made thus far. However, with each year WIT breaks new ground on several research fronts and brings to the stage through this report exciting new discoveries that lay the foundation for future success.

Significant advances were made in fighting wheat diseases and aphids. Most notable were stripe rust and greenbug, plus a much-needed boost in better selection protocols for Septoria tritici blotch, STB, resistance and bird-cherry-oat aphid, BCOA, resistance. Also featured for the first time is breakthrough research on understanding how key traits important for Oklahoma—those which are complex and controlled by several genes—are regulated throughout the wheat genome and eventually manipulated through a process called genomic selection. Locally adapted germplasm with BCOA or wheat streak mosaic, WSM, resistance is now in the hands of WIT scientists; making this germplasm commercial-ready is achievable and all that lies ahead. WIT also has expanded its reach to more effectively serve wheat producers in the far western areas of the state, having developed a smaller but highly targeted variety development program, VDP, based at Goodwell, as a part of the larger conventional breeding program. In addition to advances in research, almost all WIT members engage with the agricultural community directly to enable wheat growers to make timely, effective management decisions.

## Information Exchange

**David Marburger**
**Jeff Edwards**
Plant and Soil Sciences

WIT has continued its commitment to providing timely information to stakeholders in Oklahoma and across the southern Great Plains. During spring 2016, more than 25 wheat variety tours were held across the state with hundreds of people in attendance. These tours provided producers with the most current information about wheat varieties and their characteristics, as well as showcased advanced experimental lines in the pipeline. Additionally, WIT significantly increased its web-based and social media efforts over the past few years. Since its creation in late 2012, the blog osuwheat.com has delivered technical information and updates in a concise, timely manner. In just a few years, the site has generated more than 73,000 page views, with 9,800 of those views coming from clientele outside the U.S. Other information outlets include several Extension websites, a YouTube channel, Facebook page and several Twitter accounts. In total, these sites receive more than 50,000 visits per year.

The first-hollow-stem estimator developed for the Oklahoma Mesonet in 2014 has been a success. This online tool, found in the agriculture section on mesonet.org, provides a real-time estimate of first hollow stem throughout the state (Figure 1), as well as one- and two-week first-hollow-stem projections based on historical weather patterns. The model for the estimator was developed from an OWRF-funded project and was refined using first-hollow-stem data collected from the OWRF-supported wheat variety performance tests. When combined with current first-hollow-stem measurements from the wheat variety performance tests, the estimator allows Oklahoma wheat producers to make well-informed and timely decisions for removing cattle from wheat pastures.

More than 10 advanced experimental lines were tested as an integral part of the OSU wheat variety performance tests across the state. This data was important in justifying the release of experimental line OK10728W, subsequently released as Stardust in spring 2016. In addition to collecting valuable information for experimental lines, the team continued to increase its knowledge of stripe rust susceptibility and resistance among current varieties. Similar to 2015, stripe rust was the key disease throughout most of the state. This was again a hard lesson for producers to learn about the value of host disease resistance or fungicide use as a control tactic in the absence of host disease resistance. Differences in stripe rust reaction were the primary driver of yield differences statewide in 2016, as shown in Table 1. However, it was not the only driver, as statewide yield of Iba was no different than Gallagher, though Gallagher is known to have much stronger adult-plant resistance to stripe rust. Likewise, the mean yield of OK09915C-1 was intermediate, even though its

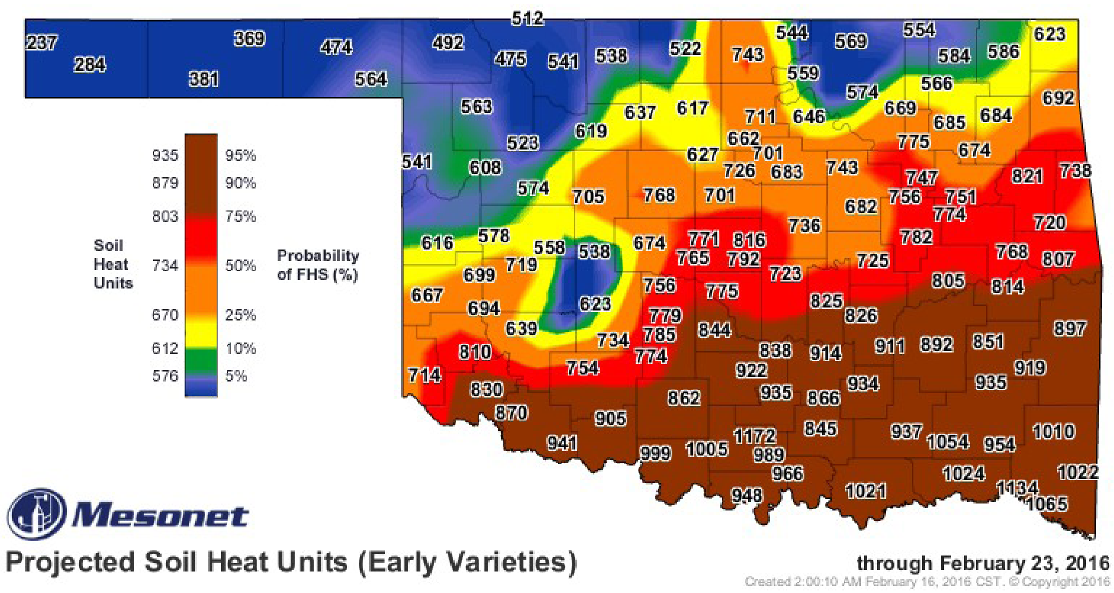


**Figure 1. Screenshot of the Oklahoma Mesonet first-hollow-stem estimator as found on Feb. 23, 2016, indicating very high to very low probabilities of the first-hollow-stem growth stage occurring for early-classified varieties in Oklahoma wheat fields.**

**Table 1. Mean yield and stripe rust ratings for 13 wheat varieties tested at all sites in the 2015–2016 Oklahoma wheat variety performance tests.**

| *Developer* | *Variety* | *Grain yield[a] (bu./A)* | *Stripe rust rating[b]* |
|---|---|---|---|
| OSU | Bentley | 68 a | MR |
| WestBred | WB-Grainfield | 67 ab | R |
| Texas AgriLife | TAM 204 | 66 abc | R |
| OSU | Iba | 64 bcd | I |
| OSU | Gallagher | 63 cd | R |
| Syngenta-AgriPro | SY Flint | 63 d | R |
| OSU | OK09915C-1 | 60 e | R |
| OSU | Doublestop CL Plus | 59 e | MS |
| OSU | Duster | 59 e | I |
| OSU | Endurance | 58 ef | S |
| Virginia Tech University | LCS Wizard | 56 fg | VS |
| Limagrain Cereal Seeds | LCS Pistol | 55 g | VS |
| OSU | Ruby Lee | 51 h | VS |

[a] Yields followed by the same letter are not statistically different at the 5 percent level.

[b] Ratings are based on adult plant reaction provided by Hunger and Carver in 2016. R=resistant, MR=moderately resistant, I=intermediate, MS=moderately susceptible, S=susceptible, VS=very susceptible.

resistance is considered quite strong in Oklahoma.

The complete wheat variety trial results were posted on the small grains Extension website wheat.okstate.edu within several days of harvest, allowing producers quick access to information at any location. Producers were also notified of new data postings via email, Twitter and Facebook. The website was accessed more than 3,700 times during summer 2016 with over 9,800 individual page views. The print version of the small grains variety performance tests was published in late July and distributed to more than 8,000 *High Plains Journal* subscribers throughout Oklahoma.

Subsamples from the wheat variety performance tests were measured for grain protein, and results were distributed in late summer 2016. In addition to grain protein results, WIT has tested milling and baking attributes of grain samples from the wheat variety performance tests since 2014. Results from those tests are published in the Oklahoma Cooperative Extension Service Current Report CR-2165. In 2016, grain subsamples from the Lahoma and Chickasha locations were saved for milling and flour quality analysis, and these results will be published in 2017. Information generated from the past several years of quality testing will provide better insight into wheat varieties that consistently provide top quality for end users.

# Wheat Pathology Research and Development of Disease-Resistant Germplasm

**Bob Hunger**
Entomology and Plant Pathology

WIT experimental lines were evaluated in 2015-2016 for several key diseases, including the WSBM/WSSM complex, leaf rust, powdery mildew, tan spot and barley yellow dwarf. These diseases constitute annual selection targets and lay the foundation for line advancement.

Table 2 estimates the number of experimental lines tested for reaction to these diseases over the last eight years, and Table 3 estimates the number of lines evaluated from 1983 to 2016. One obvious feature of this data is the extraordinary effort dedicated to searching and selecting for resistance to the WSBM/WSSM complex. Only one OSU variety has been released in the past 25 years with susceptibility to this complex (Custer in 1994). One may ask why must WSBM/WSSM reactions be considered when OSU germplasm is rife with resistance. The answer lies in the pedigree of a new variety, where one or more parents originate outside

**Table 2. Number of WIT experimental lines tested for disease reaction in the last eight years. Data do not include ratings collected in breeder trials or Extension trials.**

| Year | Testing location | Disease[a] SB/SS | LR | YR | PM | TS | STB | BYD |
|---|---|---|---|---|---|---|---|---|
| 2009 | Field | 1,500 | | | | | | |
| | GC/GH[b] | | 400 | | 400 | 400 | | |
| 2010 | Field | 1,500 | | | | | | |
| | GC/GH | | 400 | | 400 | 400 | 400 | |
| 2011 | Field | 1,400 | | | | | | |
| | GC/GH | | 324 | | 67 | 262 | 262 | |
| 2012 | Field | 1,030 | | | 65 | | | 573 |
| | GC/GH | | 427 | | 618 | 170 | 105 | |
| 2013 | Field | 2,410 | | | 197 | 95 | | 150 |
| | GC/GH | | 347 | | 150 | 277 | 277 | |
| 2014 | Field | 1,700 | | | | 21 | | 705 |
| | GC/GH | | 466 | | 141 | 411 | | |
| 2015 | Field | 1,500 | | | | | 75 | 160 |
| | GC/GH | | 385 | | 115 | 385 | | |
| 2016 | Field | 1,421 | | | | | 145 | 145 |
| | GC/GH | | 385 | 385 | | 385 | | |
| Total | Field & GC/GH evaluations | 12,461 | 3,134 | 385 | 2,153 | 2,806 | 1,264 | 1,733 |

[a] WSSB/WSSM=complex of wheat soil-borne mosaic and wheat spindle streak mosaic; LR=leaf rust, YR=stripe rust, PM=powdery mildew, TS=tan spot, STB=Septoria tritici blotch, BYD=barley yellow dwarf

[b] GC/GH=growth chamber and/or greenhouse

**Table 3. Summary of WIT experimental lines evaluated for reaction to specific diseases from 1983 through 2016. Data do not include ratings collected in breeder trials or Extension trials.**

| *Disease* | *Year evaluations started* | *Evaluation location*[a] | *Number of lines evaluated* |
|---|---|---|---|
| WSBM/WSSM[b] | 1983 | GC/GH | 500 |
| | | Field | 32,938 |
| Leaf rust | 1983 | GC/GH | 21,360 |
| | | Field | 3,500 |
| Powdery mildew | 2000 | GC/GH | 2,515 |
| | 2011 | Field | 670 |
| Tan spot | 2003 | GC/GH | 2,655 |
| | 2014 | Field | 45 |
| Septoria tritici blotch | 2004 | GC/GH | 1,200 |
| | 2014 | Field | 215 |
| Barley yellow dwarf | | GC/GH | 0 |
| | 2011 | Field | 505 |
| Spot blotch/common root rot | 2014 | GC/GH | 25 |
| | | Field | 0 |
| Total | 1983-2016 | GC/GH | 28,255 |
| | | Field | 37,873 |
| | 1983-2016 | GC/GH + Field | 66,128 |

[a] GC/GH=growth chamber and/or greenhouse

[b] WSBM/WSSM=complex of wheat soil-borne mosaic and wheat spindle streak mosaic

the WIT program, and that parent typically is susceptible to one or both diseases in the complex.

Starting in 2010, OWRF funding has allowed expanded testing for Septoria tritici blotch, STB and tan spot. Whereas growth chamber and/or greenhouse assays, GC/GH, for tan spot reaction have increased steadily the frequency of tan spot resistance among experimental lines, GC/GH assays for STB have not been as successful because infection of known controls has not been sufficiently consistent. Over the past couple years, efforts were made to establish field nurseries to test for reaction to both leaf-spotting diseases. Initial efforts with tan spot in 2013 and 2014 were not successful but revealed having the capability of supplying moisture was critical.

As reported in 2015, a small nursery in which wheat straw was retained within the plot area was established at the Entomolgy and Plant Pathology Research Station located west of Stillwater to evaluate lines for reaction to STB (Figure 2). In 2015–2016, sufficient STB symptoms occurred in this nursery to allow evaluation of 145 advanced lines (Figures 3 and 4). Of the 145 OSU lines, 32 had excellent resistance to STB, as indicated in Figure 4. Though Garrison provides an unusually high level of STB protection, Doublestop CL Plus and the candidate beardless

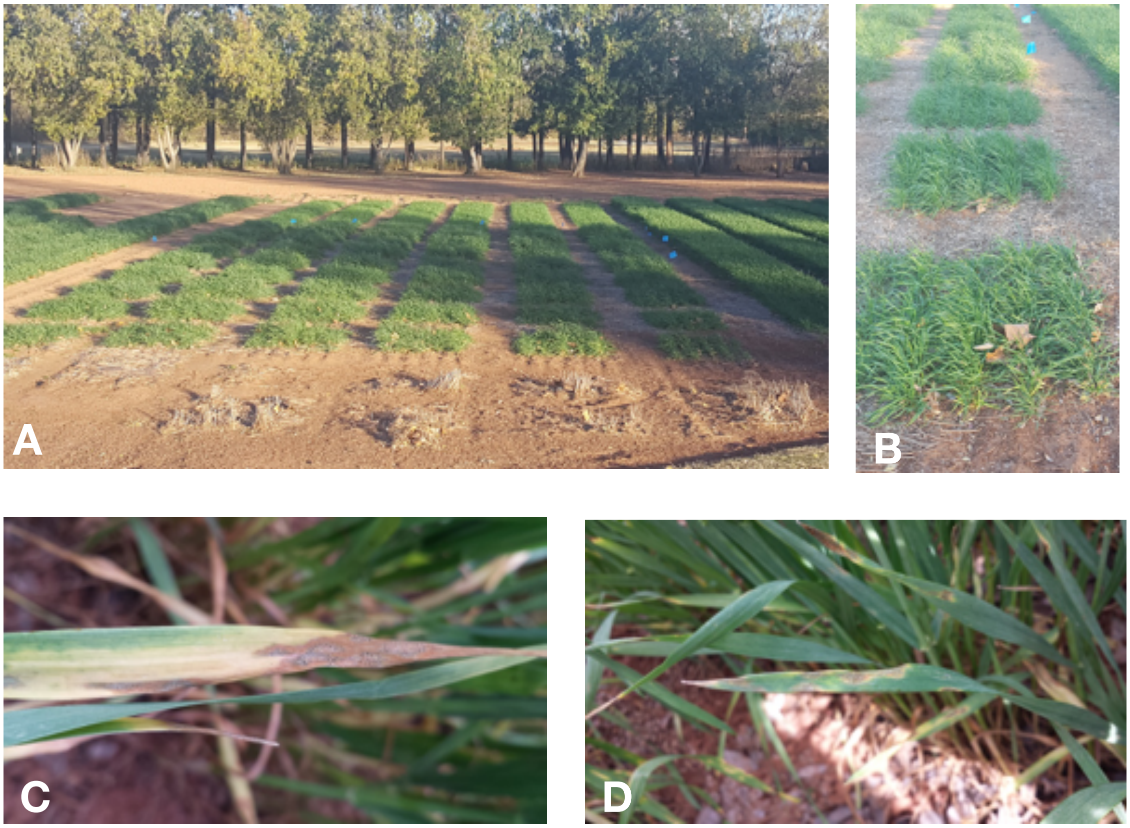


**Figure 2. Field nursery (A) in which advanced OSU experimental lines will be evaluated for reaction to Septoria tritici blotch, STB, in 2017. Note wheat straw residue surrounding each group of four lines (B), and STB symptoms obtained in spring 2016 (C and D).**

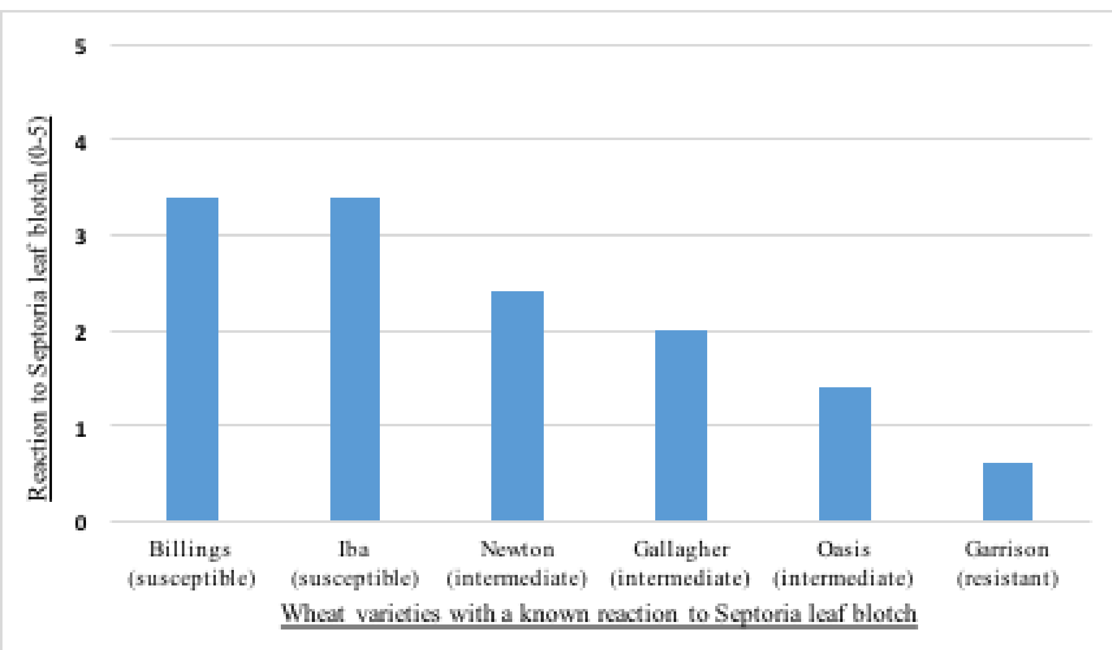


**Figure 3. Reaction (0=resistant; 5=suseptible) of check varieties to Septoria leaf blotch.**

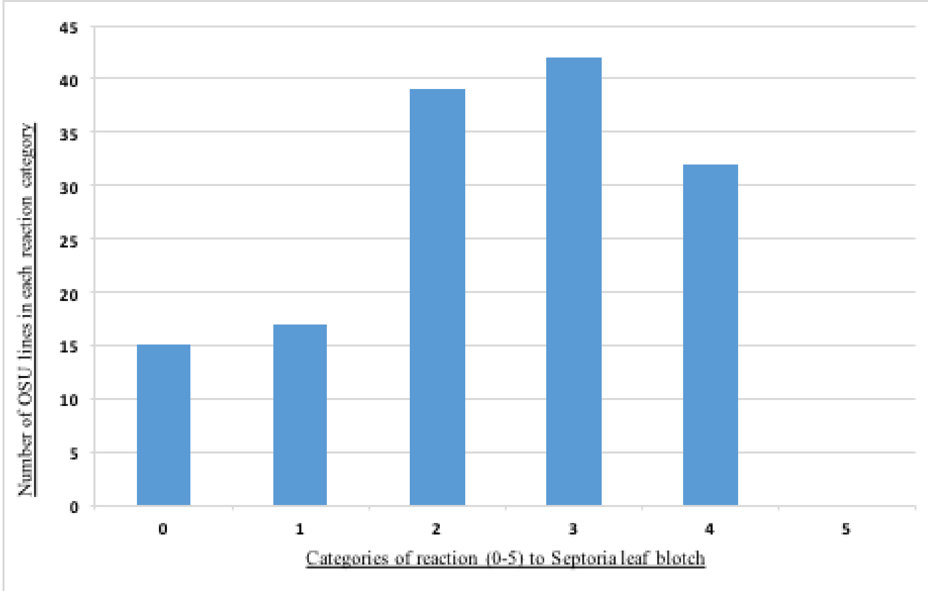


**Figure 4. Numer of WIT experimental lines in each Septoria leaf blotch reaction category (0 = resistant; 5 = suseptible).**

variety OK12206-127206-2 come close. In fall 2016, a similar nursery was initiated for tan spot of wheat to help validate results coming from GC/GH assays. If those results are transferable to the field, then OSU germplasm will have made a quantum leap in tan spot resistance from only 10 years ago.

Also in 2016, a survey was conducted to determine the incidences of tan spot versus Septoria/Stagonospora leaf and glume blotch in wheat fields across Oklahoma. Such information will help WIT determine which disease is more critical in Oklahoma and where WIT might prioritize its efforts. Preliminary results of this survey indicate tan spot is the most prevalent (Figure 5). It also appears tan spot typically is found earlier in the crop season (late February and early March), while Septoria/Stagonospora typically is found later. However, identification of all isolates is ongoing.

Foliar diseases typically impact wheat yield in Oklahoma. Stripe rust and leaf rust are the primary foliar diseases, but powdery mildew, tan spot and STB also can be involved. In Oklahoma in 2016, stripe rust and leaf rust were severe and caused significant yield reductions as indicated by the statewide loss estimates of 18 percent for stripe rust and 5 percent for leaf rust.

Given the quickness at which the pathogens causing these rusts can adapt to genetic resistance, fungicides need to be considered to help protect yield potential. Consequently, fungicide testing has been a part of the WIT program for many years.

Fungicide testing was conducted near Stillwater in 2016 using the variety OK Bullet, which is susceptible to powdery mildew, stripe rust and leaf rust, but resistant to the WSBM/WSSM complex (Table 4). This combination of traits, along with strong straw strength, make OK Bullet an ideal variety to use in such testing. Adequate rainfall from late August through December (19

### CULTURES ISOLATED

| FIELD | PTR | PYCNIDIA |
|---|---|---|
| A | 62 | 58 |
| B | 90 | 11 |
| C | 51 | 5 |
| D | 31 | 2 |
| E | 4 | 8 |
| F | 57 | 39 |
| G | 44 | 50 |
| H | 21 | 6 |
| I | 40 | – |
| J | 68 | 7 |
| K | 17 | 1 |
| L | 17 | 3 |
| M | 63 | – |
| TOTAL | 565 | 190 |

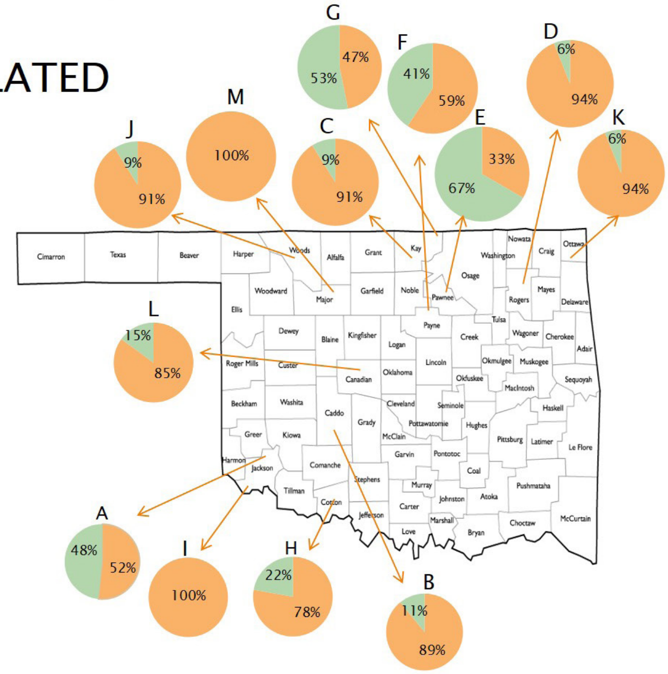


**Figure 5. Occurrence of tan spot and Septoria/Stagonospora from Oklahoma wheat fields (mostly no-till fields) during spring 2016.**

inches) facilitated emergence and stand establishment. January through February was dry (1.25 inches), but moisture during the spring (11.3 inches from March to May) promoted a good crop. Early but low incidence and severity of powdery mildew was observed. In contrast, severe leaf rust occurred later in the season. Stripe rust also was observed but never reached a level that merited rating. No indication of phytotoxicity by any fungicide treatment was observed. Yield varied from the non sprayed check (56 bushels per acre) to a maximum of 77 bushels per acre. Test weight varied from the non-sprayed check (56.9 pounds per bushel) to a maximum of 59.1 pounds per bushel (Table 4). These results indicated the value of using a fungicide for a variety susceptible to wheat rust and indicated protection can be sustained for at least three to four weeks following application.

Finally, timely electronic updates on the status of wheat diseases were provided to wheat producers, Extension educators and others involved with wheat. The 2016 Oklahoma wheat crop was tested for the presence of Karnal bunt. Results from this testing were used to certify Oklahoma wheat was produced in areas not known to be infested with Karnal bunt, which allows Oklahoma wheat to move freely into the export market.

## Aphid Resistance Discovery and Introgression

**Kris Giles**
**Ali Zarrabi**
Entomology and Plant Pathology

Key to finding bird cherry-oat aphid, BCOA, resistance in wheat

**Table 4. Effect of foliar fungicides on severity of powdery mildew and leaf rust, yield and test weight of OK Bullet in Stillwater during 2015–2016.**

| *Treatment number* | *GS* | *Date* | *PM (%)*[d] | | *LR (%)*[c] | | | *Yield* | *TW* |
|---|---|---|---|---|---|---|---|---|---|
| *Fungicide*[a]*; rate* | *applied*[b] | *applied* | *April 28* | *May 03* | *May 06* | *May 11* | *May 15* | *(bu./A)* | *(lb/bu.)* |
| 1 Nontreated check | --- | --- | 18 | 16 | 40 | 73 | 92 | 56 | 56.9 |
| 2 Priaxor; 2 oz/A FB[e] Nexicor; 7 oz/A | 6 FB 9 | March 16 FB April 04 | 4 | 1 | 9 | 46 | 73 | 77 | 59.1 |
| 3 Nexicor; 3.5 oz/A FB Nexicor; 7 oz/A | 6 FB 9 | March 16 FB April 04 | 2 | 2 | 4 | 36 | 66 | 72 | 58.0 |
| 4 Aproach @ 3 oz/A FB Aproach Prima 6.8 oz/A | 6 FB 9 | March 16 FB April 04 | 1 | 1 | 9 | 43 | 65 | 69 | 58.4 |
| 5 Tilt; 4 oz/A | 9 | April 04 | 16 | 10 | 24 | 63 | 95 | 59 | 57.8 |
| 6 Folicur; 4 oz/A | 9 | April 04 | 21 | 2 | 6 | 46 | 73 | 63 | 57.7 |
| 7 Quadris; 8 oz/A | 9 | April 04 | 22 | 1 | 6 | 36 | 59 | 66 | 58.1 |
| 8 TwinLine; 7 oz/A | 9 | April 04 | 13 | 1 | 5 | 43 | 69 | 65 | 57.6 |
| 9 Nexicor; 7 oz/A | 9 | April 04 | 13 | 2 | 9 | 40 | 69 | 66 | 58.2 |
| 10 Nexicor; 13 oz/A | 9 | April 04 | 11 | 2 | 14 | 40 | 73 | 66 | 58.5 |
| 11 Aproach Prima; 6.8 oz/A | 9 | April 04 | 7 | 1 | 4 | 43 | 73 | 68 | 58.6 |
| 12 Aproach; 6 oz/A | 9 | April 04 | 14 | 5 | 14 | 59 | 84 | 66 | 58.2 |
| 13 Trivapro; 13.7 oz/A | 9 | April 04 | 9 | 1 | 2 | 30 | 43 | 72 | 58.7 |
| 14 Quilt Xcel; 10.5 oz/A | 9 | April 04 | 8 | 1 | 3 | 29 | 59 | 72 | 57.8 |
| 15 Alto; 5.5 oz/A | 9 | April 04 | 13 | 2 | 4 | 29 | 46 | 63 | 57.9 |
| 16 Absolute Maxx; 5 oz/A | 9 | April 04 | 10 | 1 | 2 | 33 | 59 | 72 | 58.7 |
| 17 Prosaro 421 SC; 5 oz/A | 9 | April 04 | 10 | 2 | 4 | 30 | 59 | 72 | 58.2 |
| 18 Prosaro 421 SC; 6.5 oz/A | 9 | April 04 | 14 | 2 | 4 | 28 | 49 | 64 | 58.2 |
| 19 Prosaro 421 SC; 6.5 oz/A | 10.5.1 | April 15 | 19 | 0 | 0 | 10 | 14 | 63 | 58.8 |
| Student's t (p=0.05) | 8 | 4 | 9 | 16 | 19 | 9 | NS | | |

[a] Plus 0.125% Induce (volume by volume) for treatments 16-19; plus 0.25% Induce (volume by volume) for treatments 2-4 and 8-15.

[b] GS=Growth Stage. Reported according to Feekes' scale, where GS 6=first node detectable at base of main tiller; GS 9=flag leaf fully emerged; GS 10.5.1= beginning of flowering/anthesis.

[c] PM=powdery mildew. Rated on F2 leaves and lower leaves.

[d] LR=leaf rust. Rated on flag and/or F-1 leaves.

[e] FB=followed by.

germplasm is to know how to look for it. Methods existed but lacked utility and reliability – until now. A highly sensitive and reliable phenotyping assay was developed with OWRF support according to these procedures: 1) infestation of emerging wheat seedlings with 22 aphids per plant (14 hours photophase at 20 C), 2) resistance classification within six days post-infestation based on development of a second leaf and 3) termination of assay 18 days post-infestation, with reactions further classified based on leaf development and levels of chlorosis. Reactions can be qualitatively described as in Figure 6.

During 2016, this assay was used to phenotype 70 selected WIT lines and cultivars chosen to represent either elite germplasm in the variety development program, VDP, or diverse non-elite germplasm having parentage closely linked to *Triticum tauschii*. Unfortunately all were categorized as highly susceptible to BCOA.

The next logical step was to search further back in the variety development pipeline, i.e., before the inbreeding stage in which fixed lines are developed and to phenotype segregating plant populations. Hence, 23 fourth-generation populations, $F^4$, were chosen from a panel of several hundred possibilities based on their prior performance in the presence of the common viral pathogen barley yellow dwarf virus.  This virus is biologically linked to BCOA, circulating within the insect hemocoel and efficiently transmitted to wheat plants via salivary glands.

In five of the 23 populations assayed, a significant proportion of individual $F^5$ seedling plants were categorized similar to the highly resistant check. Because each plant in a given population is genetically unique, these desirable plants were isolated for propagation to recover progeny. Selfed progeny from the resistant candidate plants is expected

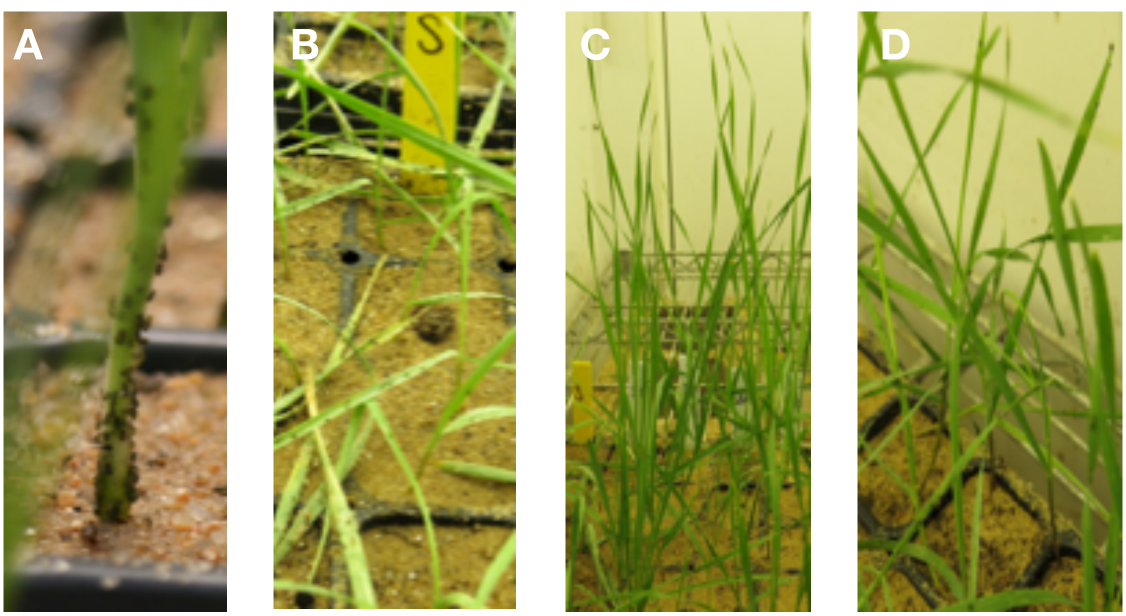


**Figure 6. Qualitative differences in bird cherry-oat aphid reaction using the Zarrabi and Giles aphid-wheat seedling assay, described as A) tolerant, B) susceptible, C) resistant–antibiosis and D) resistant – tolerant.**

to be resistant, though any given family may show a homogeneous or heterogeneous reaction among individual plants. Further research is needed to advance lines or plants selected within families and incorporate them into the mainstream VDP.

## Gene Discovery and Genomic Technology

**Charles Chen**
Biochemistry and Molecular Biology

Genomic selection, GS, is a promising pathway to accelerate genetic gain per unit of time by reducing the length of the breeding cycle. It also decreases the error inherent to selection decisions made on phenotype alone, thereby improving genetic gain per generation via improved breeding efficiency. Application of GS first requires derivation of a prediction function using both phenotypic (what is actually measured) and genotypic information (DNA sequence) from genome wide-distributed DNA markers. These markers are typically generated due to genetic variation at the most fundamental level, or at the level of single nucleotide polymorphisms, SNPs, which are recorded in training populations. Training populations serve as the model germplasm pool, from which genetic predictions may be applied to actual breeding populations forming the VDP. Genetic predictions may come in the form of genomic-estimated breeding values (GEBVs), which are calculated from model-based SNP effects and can be used to replace or supplement phenotypic values for selection.

Genotyping-by-sequencing, GBS, a next-generation sequencing technology that collects hundreds of millions of short-read sequences for numerous barcoded DNA samples, has emerged as one of the most promising genotyping platforms. By simultaneously sequencing and genotyping to bypass intricate and laborious marker assay development such as gel electrophoresis, GBS delivers genotypic data at unprecedented quantities and speed, resulting in greatly reduced cost per data point. With affordability and flexibility of GBS, the capacity to produce a large number of affordable SNPs has enabled a wide range of technological and scientific advancements. These include association mapping to identify causal SNP variants governing agronomic traits, assays for genetic diversity and the underlying population or family structure, and genomics-enabled crop improvement strategies more fitting for species with large and complex genomes like hexaploid wheat.

Funded through National Science Foundation, OSU's Biochemistry and Molecular Biology Array and Bioinformatics Core Facility acquired an Illumina Next-seq desktop sequencing system to facilitate research at the whole-genome scale. This purchase allowed WIT to essentially leverage OWRF funding to examine GBS profiles of Oklahoma wheat varieties and DNA libraries of a Duster x Billings doubled haploid, DH, population. In total, 1,137,153 unique sequence tags were identified and aligned with the most current wheat pseudo-molecules published by the International Wheat Genome Sequencing Consortium in June 2016. Each pseudo-molecule represents one of the 21 pairs of wheat chromosomes. After removing sequence tags that had a high degree of uncertainty of alignment, 165,654 SNPs were called or identified and then anchored, averaging 7,888 SNPs per chromosome. Chromosome 3B accommodated the largest number of SNPs (10,952) and chromosome 4D contained the fewest (4,802) SNPs. This SNP build was named Buster SNPv2014. After removing SNPs low in polymorphism or with very low allele frequency (minor alleles), the informative number of SNPs totaled 16,916. A summary of unfiltered and filtered SNP numbers, relative to chromosomes and subgenomes, is provided in Table 5.

Though the throughput provided is incredible, GBS genotyping techniques are typically challenged in wheat by low coverage of available SNPs for analyses. Missing data commonly result from either the absence of restriction sites in the genome or technical issues related to DNA digestion or amplification. To accommodate this issue, the bioinformatics team at OSU developed computational algorithms to estimate genotypic values that failed to be directly assayed by sequencing. Two separate computational algorithms were developed and tested, namely Genetic Algorithm and kNN-Fam Imputation, both taking advantage of machine-learning methods in data science. The first utilizes local linkage disequilibrium among linked SNP markers (haplotype method) and the second uses underlying genomic similarity between DH individuals.

**Table 5. Number of Duster x Billings doubled haploid population single nucleotide polymorphisms anchored to IWGSC-WGA-v0.4 pseudo-molecules.**

| *Chromosome* | *Number of SNP pre-filtered* | *Number of SNP post-filtered* |
|---|---|---|
| 1A | 6,558 | 696 |
| 1B | 8,919 | 928 |
| 1D | 6,956 | 598 |
| 2A | 8,464 | 1018 |
| 2B | 9,984 | 1193 |
| 2D | 8,713 | 704 |
| 3A | 7,466 | 894 |
| 3B | 10,952 | 1,653 |
| 3D | 8,004 | 629 |
| 4A | 7,268 | 735 |
| 4B | 5,805 | 435 |
| 4D | 4,802 | 215 |
| 5A | 7,243 | 505 |
| 5B | 8,925 | 1,068 |
| 5D | 7,057 | 274 |
| 6A | 6,252 | 716 |
| 6B | 8,744 | 1,273 |
| 6D | 6,301 | 481 |
| 7A | 9,408 | 998 |
| 7B | 9,165 | 1,249 |
| 7D | 8,668 | 654 |

As illustrated in Figure 7, the global pattern of genomic variation in subgenomes A, B and D revealed a consistent but expected nonrandom distribution pattern across chromosomes. Higher genomic diversity occurred in regions closer to telomere locations (near the ends of chromosomes) with much-reduced polymorphism near the centromere (constricted central regions of chromosomes). Also, sequencing errors were biased upward toward the telomere regions as indicated by the maroon-colored bar components in Figure 7. Despite an overall very minor degree of sequencing error whereby DH progeny showed unexpected genotypic values, Duster (blue components) and Billings (yellow components) parental alleles exhibited nearly 50-50 segregation in this population. The missing data ratio was distributed evenly across the genome, except for a slightly elevated proportion in the centromere region of chromosome 3B. Note SNP discovery is ongoing, and Figure 7 is provided only for preliminary demonstration and therefore not a finalized SNP physical map for Duster x Billings DH progeny.

Geared with this genomewide SNP database, GS applicability for the Duster x Billings DH population was investigated under two scenarios: 1) within-year cross-validation to evaluate algorithm performance, and 2) validation across years to understand the potential GS applicability for wheat breeding by WIT. Several GS models have been developed for predicting phenotypes using large numbers of markers. To analyze the applicability of GS for breeding in Oklahoma, seven prediction algorithms were evaluated, and selected results from two parametric algorithms and two nonparametric algorithms are listed

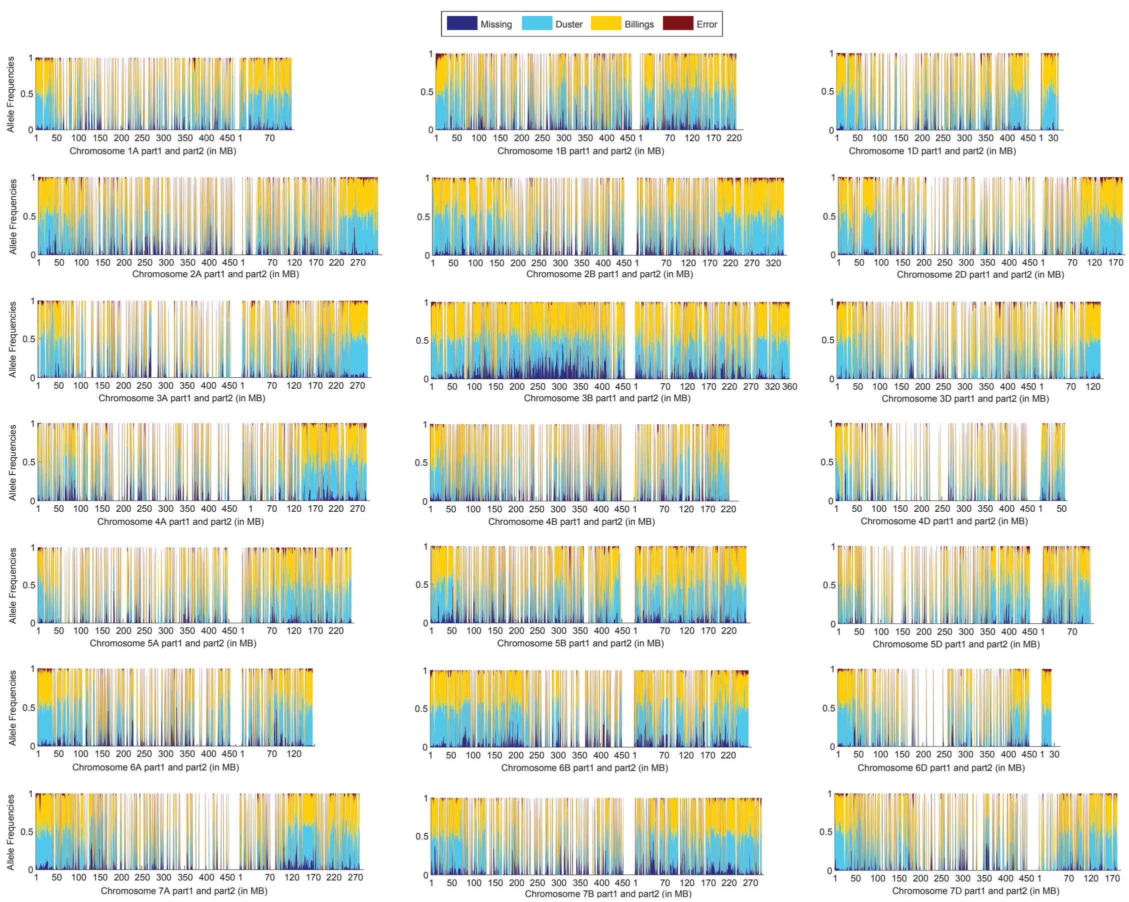


**Figure 7. Single nucleotide polymorphisms alignment overview of Duster x Billings double haploid population on the IWGSC-WGA-v0.4 pseudo-molecules.**

**Table 6. Correlation between observed phenotype andgenomic estimated breeding value for four genomic selection algorithms.**

| | *Training data set* | *Validation data set* | *Pearson product-moment correlation (p value)* RR-BLUP[a] | *BL*[b] | *RKHS*[c] | *RF*[d] |
|---|---|---|---|---|---|---|
| Within-year cross validation | 2014 | 2014 | 0.56 (0.02) | <u>0.57</u> (0.01) | <u>0.57</u> (0.02) | 0.55 (0.02) |
| | 2015 | 2015 | 0.52 (0.02) | 0.53 (0.01) | 0.53 (0.02) | <u>0.58</u> (0.01) |
| Across-year validation | 2014 | 2015 | 0.27 (0.02) | 0.27 (0.02) | 0.28 (0.02) | <u>0.36</u> (0.02) |
| | 2015 | 2014 | 0.30 (0.02) | 0.28 (0.01) | 0.31 (0.02) | <u>0.40</u> (0.01) |

[a] RR-BLUP=ridge regression best linear unbiased predicition
[b] BL=Bayesiant LASSSO
[c] RKHS=reproducing kernel Hilbert space
[d] RF=random forest
Note: The algorithms with highest correlation are underlined for each validation scenarion. Results are based on 100 replactes of five-fold cross-validation.

in Table 6. These models mainly differ in the assumptions of marker effects contributing to the total phenotypic variance. Linear methods such as ridge regression best linear unbiased prediction, RR-BLUP, assume homogeneous marker effects across all loci, whereas bayesian methods (such as Bayesian LASSSO, BL) allow for heterogeneity among markers with some markers having higher effects than the rest. In addition, nonparametric algorithms, such as random forest, RF, and reproducing kernel Hilbert space, RKHS, are thought to include epistatic effects or gene interactions, a likely scenario with complex yield-related traits.

Using within-year five-fold cross validations and after 100 replicates, BL and RKHS showed similar predictability for 2014 grain yield data, whereby RKHS had slightly higher variation. For 2015 grain yield, RF outperformed others by about 5 percent in accuracy. Grain yield predictability significantly was reduced when using 2014 data to predict 2015, and vice versa, reflecting a large discrepancy between years likely linked to extremely divergent environmental conditions between spring 2014 and spring 2015. However, non-parametric models such as RF consistently displayed its superiority, regardless of years or validation methods (Table 6).

As a reminder, the theoretical advantages of using GS in crop breeding are two-fold: 1) acceleration of genetic improvement via reduction in time required to complete a breeding cycle, and 2) more accurate selection decisions assisted by GEBVs. If GEBVs are used to accelerate breeding cycles, reliability and robustness of GS for cross-year prediction is required, which can be a challenge given the high degree of climate variation in the southern plains. As indicated by these preliminary results, to deliver predictability, training information should be collected at sites or in years when environmental bias is minimal (Table 6).

While wheat breeding strategies which solely rely on GS might remain a distant but realistic possibility, GEBVs can be valuable in making selection decisions in the short term. For example, in the line development stage practiced by WIT, consider 2,000 headrow families are selected among 50,000 families for advancement. Table 7 shows the accuracy measures for selection based on different types of information, such as phenotype alone, GEBVs alone and optimal selection, OS, which combines phenotypic values and GEBVs. If only the top 10 percent progenies were selected and advanced, a predictability of 80 percent based on 2014 grain yield would be reached using the 2015 training population, whereas the typical method of only phenotypic selection, PS, resulted in 58 percent accuracy. Neither PS nor GS alone were as effective as combining information from both sources.

**Liuling Yan**
**Carol Powers**
Plant and Soil Sciences

Increasing genetic potential for grain yield is the ultimate objective of wheat improvement programs worldwide. Moreover, the National Institute of Food and Agriculture, the extramural research arm of the U.S. Department of Agriculture, has made wheat yield improvement a primary focus in the third installment of WheatCAP, a multi-institutional five-year research project. Many quantitative trait loci, QTL, also called genomic regions, have been mapped for grain yield, key yield components, and yield-related agronomic traits using segregating biparental populations or association analysis on existing germplasm ranging from landraces to modern varieties and advanced lines. However, most of these QTL have miniscule effects on grain yield, and they may be subject to large genotype x environment interactions, the sum of which has inhibited rapid utilization of yield markers in wheat breeding. Compounding their limited utility is the low likelihood that a minor QTL discovered in a distantly related germplasm pool will have relevance to germplasm utilized by WIT. Thus, the burden is on WIT to do its own discovery work.

**Table 7. Prediction accuracies of optimal training populations selected from year 2015 using four selection methods to predict year 2014.**

| | *Pearson product-moment correlation coefficient (p value)* | | | |
|---|---|---|---|---|
| *k %*[a] | *OS*[b] | *PS*[c] | *GS*[d] | *RS*[e] |
| 10 | 0.81 (0.01) | 0.58 (0.04) | 0.54 (0.04) | 0.21 (0.20) |
| 20 | 0.71 (0.01) | 0.57 (0.01) | 0.50 (0.02) | 0.33 (0.11) |
| 30 | 0.65 (0.01) | 0.49 (0.01) | 0.52 (0.01) | 0.38 (0.06) |
| 40 | 0.53 (0.01) | 0.44 (0.01) | 0.44 (0.02) | 0.40 (0.03) |
| 50 | 0.50 (0.01) | 0.40 (0.01) | 0.40 (0.01) | 0.40 (0.01) |

[a] k %=proportion of the population selected
[b] OS=optimal selection
[c] PS=phenotypic selection
[d] GS=genomic selection
[e] RS=random selection
Note: Pearson product-moment correlation coefficient generated based on 100 replicates of five-fold cross validations for each of the four training poulaton selection methods.

Purely in an unexpected manner, a major QTL for grain yield called *QYld.osu-1BS* was discovered using GBS markers in the same Duster x Billings DH population used by Chen. While Duster offers durability and yield protection across a diverse set of environmental conditions, Billings shows larger kernel size and superior yield potential in high-yielding environments. Nevertheless, across 211 replicated yield trials in every imaginable Oklahoma environment from 2010 to 2015, grain yields of Duster and Billings have been the same (44 bu./A). However, genetic mechanisms underlying the high grain yield of these two winter wheat cultivars has remained a total mystery until now.

*QYld.osu-1BS* was found using 2,358 GBS markers genotyped in 260 DH lines. As an indication of the magnitude of this locus, *QYld.osu-1BS* explained more than 23 percent of the total phenotypic variation in grain yield measured in the field in 2014 (a drought year) and 2015 (a year of wide precipitation swings), as shown in Figure 8A. One yield gene accounting for almost a quarter of the total yield variation in a biparental population is extraordinary. The Duster allele at the *QYld.osu-1BS* locus increased yield by 16 percent in 2014 and by 23 percent in 2015; by statistical default, the Billings allele decreased yield at this particular locus. *QYld.osu-1BS* was located in the distal region of the short arm of chromosome 1B (Figure 8B). The peak of *QYld.osu-1BS* was linked with 42 GBS markers that strangely showed no crossover among the 260 DH lines. *QYld.osu-1BS* has been confirmed not to come from rye chromosome arm 1RS using available markers for rye translocations, including RIS, NOR and SCM9.

Six genes from this genomic region were sequenced based on the order of genes in the wheat genome (Figures 8C and 8D). Gene NMR showed many SNPs between Duster and Billings and was mapped in the targeted region. Gene Di19 in the distal region and genes NR, TPT, HK and VT in the proximal region showed no difference between parents, suggesting an inversion event may have occurred in the short arm of 1BS in Duster or Billings. Further study will be performed to identify candidate genes for *QYld.osu-1BS*, though a molecular marker will be designed for NMR detection, and more importantly, for tracking the Duster allele for this all-important yield locus.

Genetic improvement of wheat nitrogen use efficiency, NUE, has long remained elusive using traditional phenotypic methods. Apparent nitrogen use and assimilation in wheat is only about 30 to 35 percent, with the balance mostly lost through gaseous plant emission, soil denitrification, surface runoff, volatilization or leaching. Elusiveness of this trait is owed to its complexity, with as many as 25 genes estimated to be involved in regulating NUE in the simpler diploid model plant Arabidopsis. No gene has been specifically characterized in hexaploid bread wheat until now.

The N-related genes are divided into two classes. One includes genes involved in growth and maintenance such as *Arabidopsis nitrate regulated 1, ANR1,* that plays a key role in regulating lateral root growth in response to changes in external nitrate supply in Arabidopsis. The second

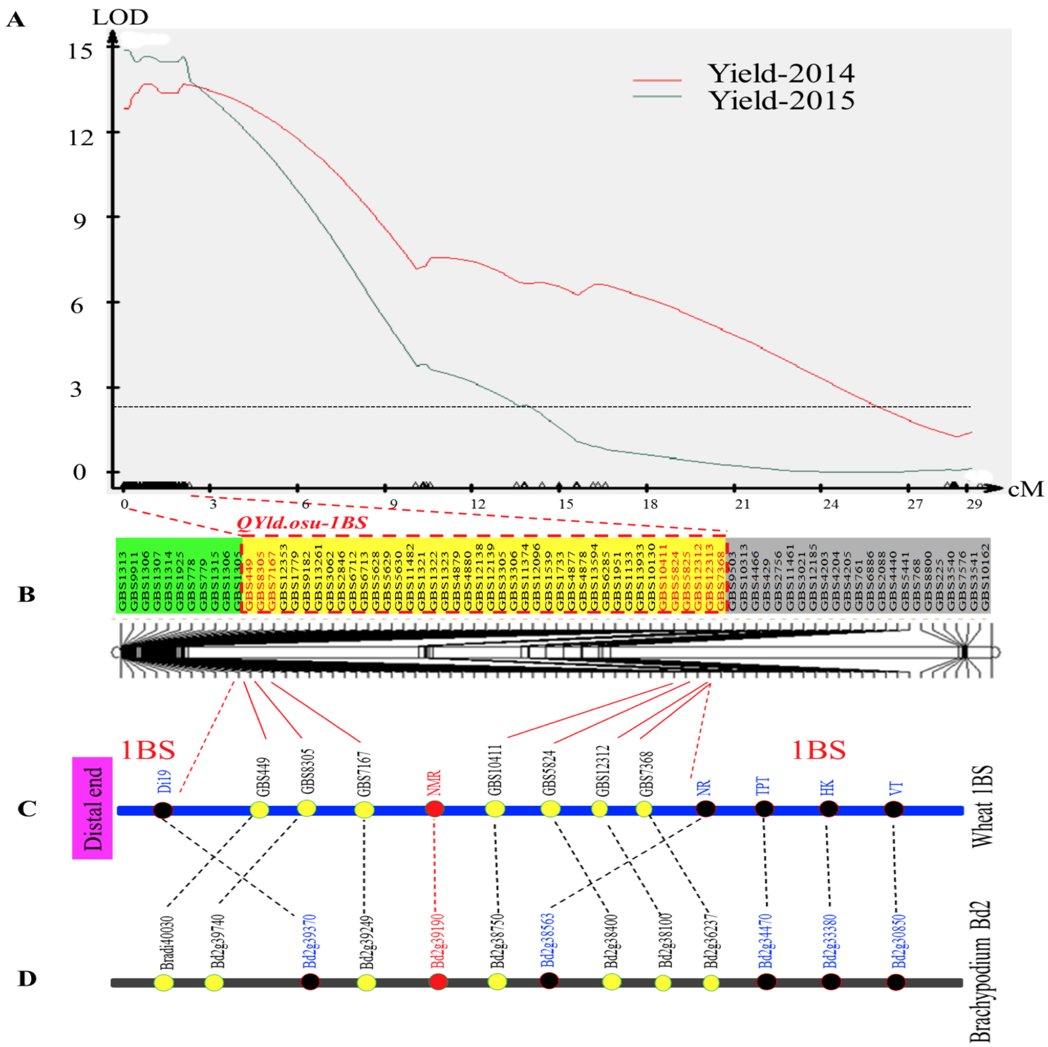


**Figure 8. Genetic effects of the quantitave trait locus, QTL, *QYld.osu-1BS* for grain yield, measured in 2014 and 2015, in the Duster x Billings DH population (A). Genotyping-by-sequencing, GBS, markers mapped under the peak of the QTL on the short arm of chromosome 1B are shown in panel B. Six genes from this genomic region were sequenced based on the order of genes in the wheat and Brachypodium genomes (C and D). Logarithm of the odds, LOD, threshold for significance was 2.5 for the presence of the QTL.**

includes genes involved in nitrogen metabolism pathways, including three enzymes involved in ammonium assimilation–glutamine synthetase, glutamate synthase and glutamate dehydrogenase. In Arabidopsis, several MADS-box genes, e.g., ANR1, AGL14, AGL16, AGL19, AGL21 and SOC1, have been reported to be involved in plant response to nitrogen fertilizer. The orthologous gene *TaANR1* had the highest identity to ANR1, AGL16 and AGL21.

Two pieces of evidence were found to confirm that *TaANR1* was also regulated by nitrogen in wheat. First, a natural mutant of *TaANR1* was found to have a significant genetic effect on wheat development and growth. When conserved primers for homoeologous *TaANR1* genes were designed to test expression profiles, the Jagger *TaANR1a* transcripts were found predominantly in roots of Jagger HRW wheat, but PCR products with different sizes were observed in the root cDNA samples of cultivar 2174 (Figures 9A and 9B). Sequence analysis indicated the cDNA products with the single band from Jagger represented a mixture of homoeologous *TaANR1* transcripts from chromosomes 2A and 2D. The cDNA products of the upper band were from *TaANR1* on chromosome 2D, and the cDNA products of the lower band were from *TaANR1* on chromosome 2A, but the 84 base pair, bp, exon 6 was missing from the *TaANR1b* gene in 2174. In order to determine if the missing exon 6 in the corresponding *TaANR1* cDNA of 2174 was caused by an exon-skipping event or any deletion event at the gDNA level, the gDNA products of this gene were cloned and sequenced. Results showed the lack of exon 6 in cDNA was due to a 23-bp-deletion event that included 10 bp at the 5' end of intron 5 and 13 bp of exon 6 in the gDNA sequence of 2174. This included the AG splice site at the 5'-end of intron 5, resulting in the loss of the full exon 6 in its mRNA and 28 amino acids in its protein.

Based on this 23-bp indel, a polymorphic chain reaction, PCR, marker for *TaANR1* was developed (Figure 9C). When phenotypic data from a population of 2174 x Jagger progeny lines was used to map *QNue.osu-5A* and then analyzed for genetic effects of *TaANR1*, a minor repressive effect of *TaANR1a* was observed for heading date. The Jagger and 2174 alleles differed in heading date effect by 5.2 days for plants grown in commercial soil and 3.9 days in Kirkland soil (Figure 9D). The results indicated the Jagger *TaANR1a* gene functioned as a minor repressor of heading in wheat. The natural *TaANR1b* mutant allele was found in 13 of 69 wheat accessions from across the U.S., but 12 of the 13 *TaANR1b* wheat cultivars were common to the southern Great Plains. Further study will be performed to test how *TaANR1* responds to nitrogen and what proteins interact with *TaANR1* in the nitrogen pathway.

In addition to markers for newly identified *QYld.osu-1BS* and *TaANR1*, perfect markers for 12 genes, including *VRN-A1*, *PPD-D1* and *VRN-D3* for reproductive development; *Pm3* for powdery mildew; *Lr34* for rust diseases; *TaXA21* for multiple diseases; *TaOPR1* in 2174 for Hessian fly; *TaPI-A1* in Duster for Hessian fly; and *TaALMT1* for acidic soils were used to genotype germplasm and advanced breeding lines. Molecular markers for translocated fragments that carry genes for resistance, including *VPM1* for multiple diseases, *Wsm1* for wheat streak mosaic virus and *Cmc4* for curl mites, also were used to genotype parental lines for performing crosses in the VDP. These genes are being pyramided to accelerate the breeding of winter wheat varieties for Oklahoma.

## Drought and Heat Tolerance Mechanisms

**Gopal Kakani**
Plant and Soil Sciences

Rapid and more efficient selection protocols are needed at the plant and canopy levels to develop wheat varieties better adapted to the combined effects of drought and heat

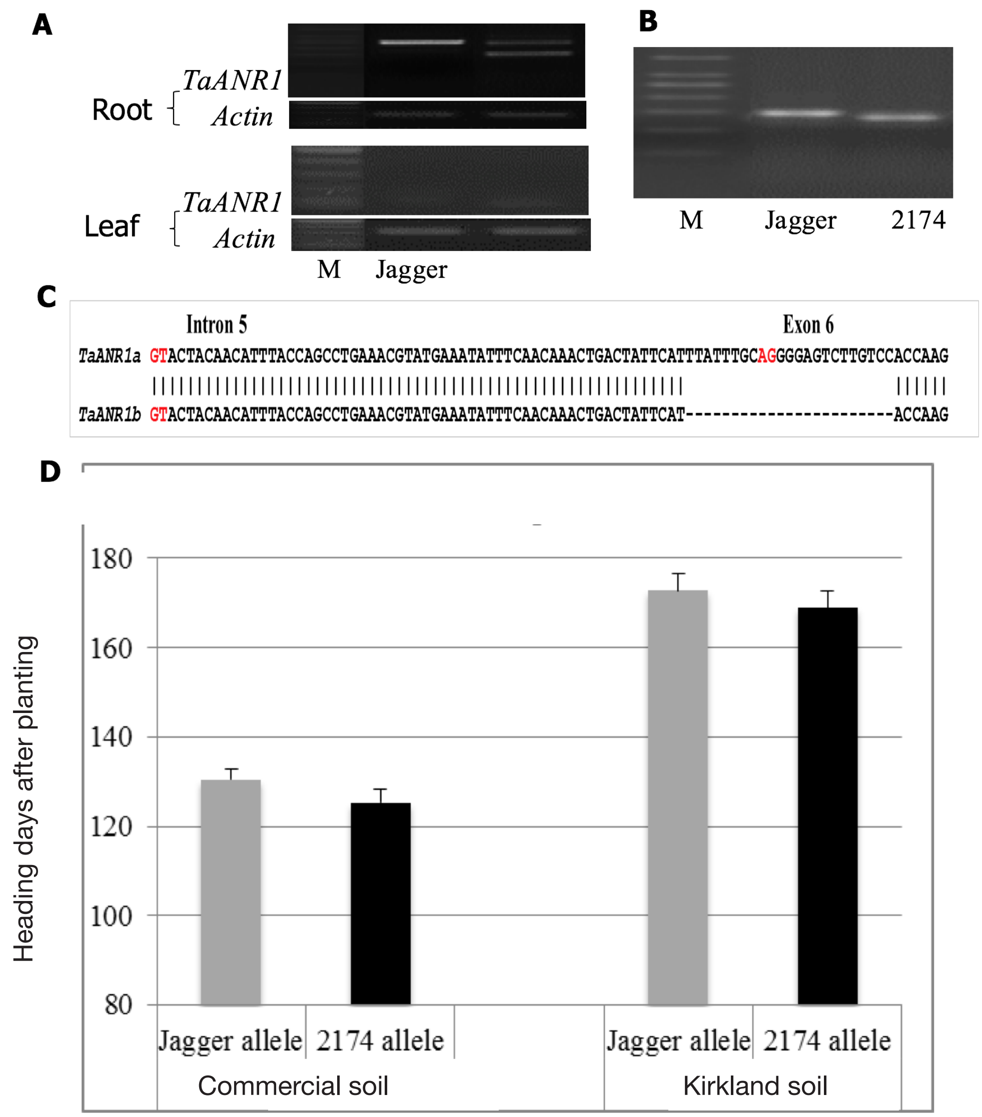


**Figure 9. Wheat orthologue of Arabidopsis nitrate regulated 1, TaANR1, with expression profiles shown in root and leaf tissue (A, B). Design of a polymerase chain reation, PCR, marker for TaANR1 is feasible given (C). The Jagger and 2174 alleles of TaANR1 differed in heading date effect by 5.2 days for plants grown in commercial soil and 3.9 days in Kirkland soil (D).**

stress. This project was commissioned to characterize the variation that may exist for key yield-determining physiological traits in the same Duster x Billings DH population evaluated by Chen and Yan. In past OWRF-supported research, this project showed that higher leaf area index, LAI, and a lower canopy-temperature increase under water-stress and high-temperature conditions may ensure higher grain-filling rates and higher yields.

In 2016, this line of research was conducted in much finer detail to eventually identify DH lines with improved drought and heat resistance. Experiments were conducted in four stages, each representing a target set of environmental conditions: 1) optimum growing conditions, 2) high-temperature stress, 3) drought stress and 4) combined high temperature and drought stress.

Different morpho-physiological parameters, including photosynthetic pigments; tiller number; plant height; photosynthesis rate; transpiration rate; stomatal conductance; intercellular $CO_2$ concentration; electron transport rate; fluorescence; instantaneous water use efficiency, IWUE; membrane thermal stability; carbohydrate remobilization; spike photosynthetic rate; and spike and stem weights were recorded depending upon the specific objective of each study. Gas exchange parameters of leaves and spikes were measured with a portable photosynthesis and fluorescence system. A defoliation treatment was imposed in the drought study to determine the contribution of stem carbohydrate remobilization to grain yield.

Results from screening under stress-free conditions showed significant differences among 100 DH lines for plant height, tiller number and leaf area (Figure 10). Similarly, the DH lines varied in gas exchange and fluorescence parameters, where stomatal conductance and IWUE explained most of the variability in the population under heat stress (Figure 11). Leaf photosynthetic rate, stomatal conductance, transpiration rate, and intercellular $CO_2$ concentration increased in response to elevated temperatures, whereas IWUE decreased. IWUE was least affected in progeny DH263 under heat stress. In the drought study, the DH progeny showed similar responses to different defoliation treatments. Partial defoliation increased the average spike weight (Figure 12), demonstrating more carbohydrate remobilization from stems for grain filling under drought. Changes in stem weight with defoliation were reflected in the change in spike weight (Figure 13), which in turn increased with spike photosynthetic rate (Figure 14). The progeny DH236 showed greater carbohydrate remobilization and spike photosynthesis under drought stress and it performed well under irrigated conditions.

In conclusion, plant height, tiller number, leaf size, IWUE and spike photosynthetic rate were most informative in this population. Progeny with greatest propensity for heat and drought tolerance are considered to be DH136, DH210, DH236, DH248, DH257 and DH263.

## Wheat Breeding and Variety Development

**Brett Carver**
Plant and Soil Sciences

### *Stripe rust déjà vu*

That same old nemesis, stripe rust, returned once again to take pole position among all diseases in the VDP. By far it was the disease that demanded the heaviest amount of selection pressure in wheat breeding nurseries. In other words, for an experimental line to be advanced in the OSU wheat variety development pipeline, it first had to show acceptance in stripe rust resistance level. One reason is stripe rust potentially impacts wheat production

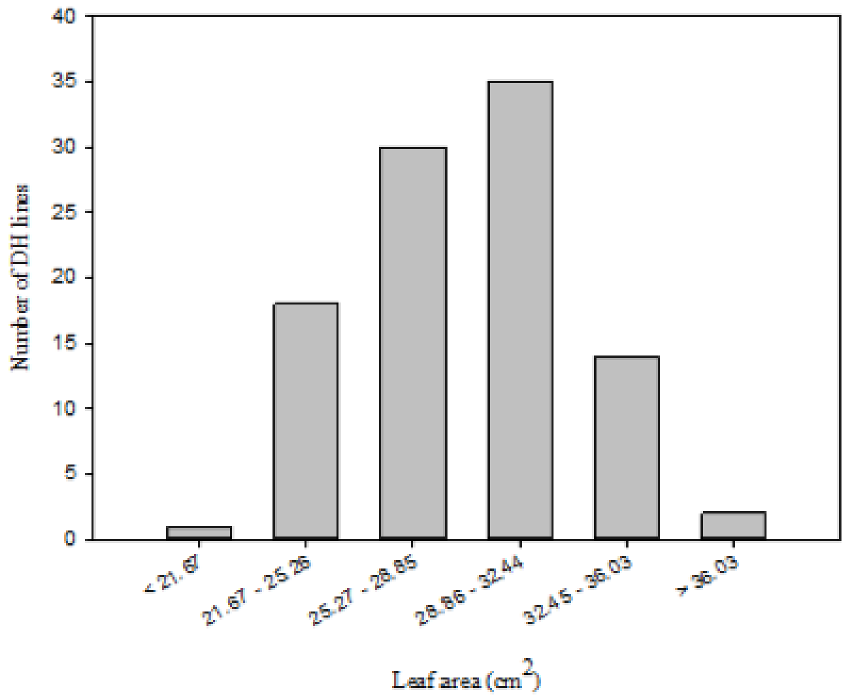


**Figure 10. Frequency distribution of 100 Duster x Billings doubled haploid lines into phenotypic classes based on area of the top most fully expanded single leaf. Plant height and leaf area were positively correlated.**

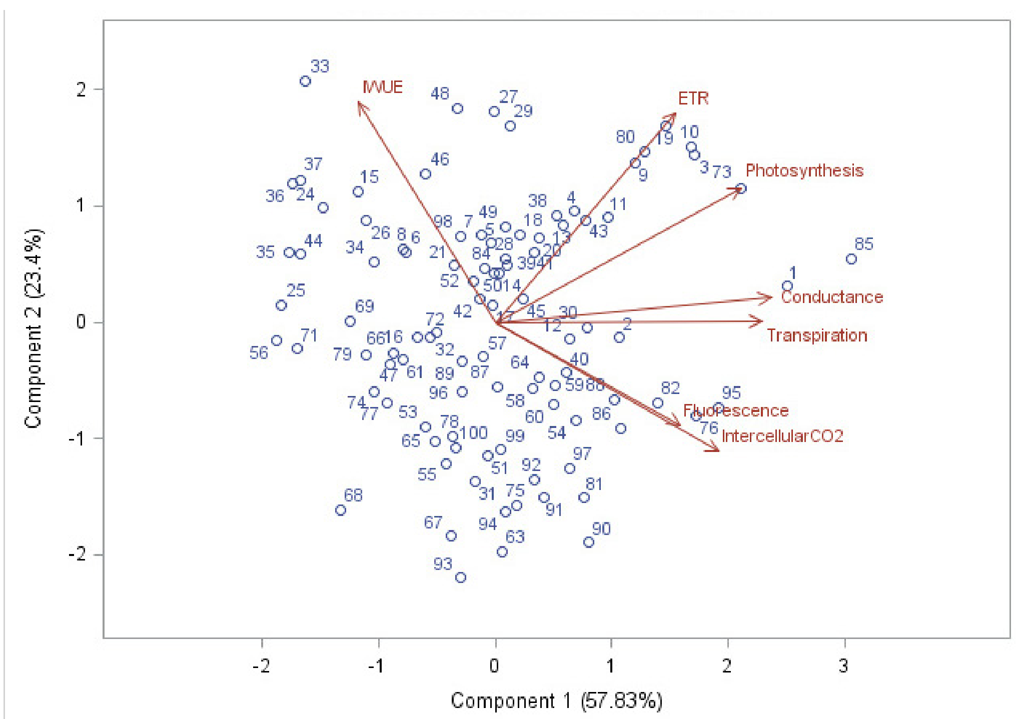


**Figure 11. Biplot of the eigenvectors for the first two principal component scores for several physiological traits measured under heat stress conditions. Individual Duster x Billings doubled haploid progeny are represented by each arbitrarily assigned number from 1 to 100.**

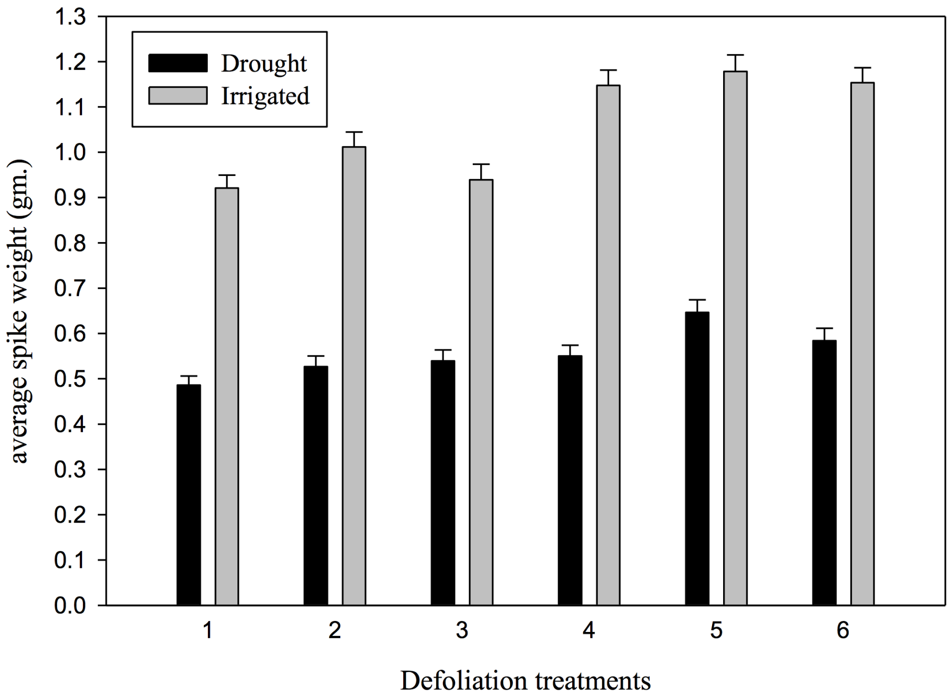


**Figure 12. Average spike weights of 33 Duster x Billings doubled haploid progeny for two irrigation regimes and six defoliation treatments: 1) spikes covered with no leaves, 2) spikes covered with all leaves, 3) spikes uncovered with no leaves, 4) spikes uncovered without flag leaf, 5) spikes uncovered with only flag leaf and 6) spikes uncovered with all leaves (control).**

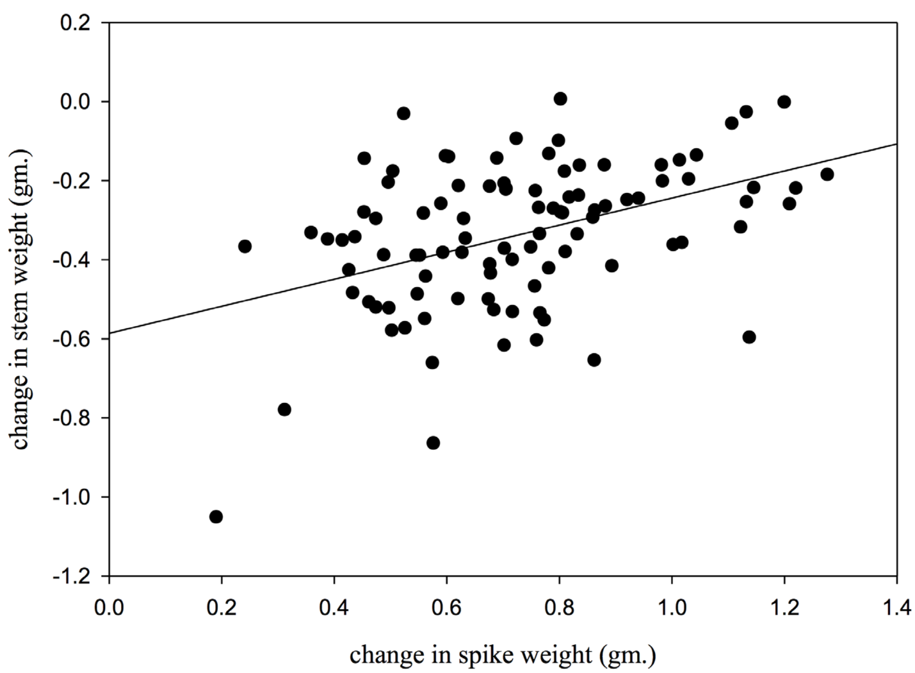


**Figure 13. Scatterplot showing the relationship between changes in spike and stem weights (final weight at harvest minus initial weight at anthesis) among 100 Duster x Billings doubled haploid lines. $R^2$=0.18, $p<0.05$.**

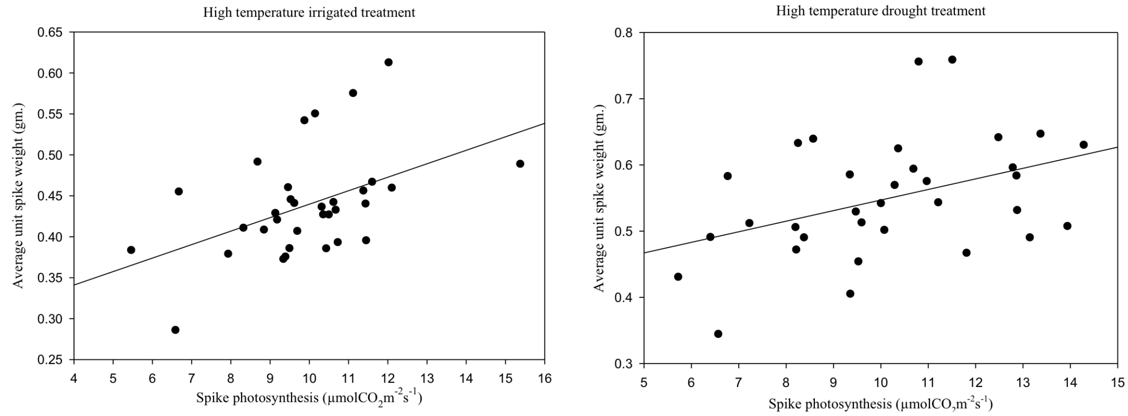


**Figure 14. Relation between average unit spike weight and spike photosynthetic rate in the high temperature irrigated treatment and the high temperature and drought treatment among 33 Duster x Billings doubled haploid lines.**

in every county of our state. From Okmulgee to Goodwell, WIT was present to collect the data that is now in the books and reflected in the selections advanced forward for 2016-2017.

Stripe rust ratings were first collected March 15, 2016 at Altus, three weeks before heading commenced in that part of the state. The last stripe rust rating occurred on May 20 at Goodwell, three weeks after heading commenced in the Panhandle. Infections prior to heading on juvenile plants elicit a different response or set of symptoms than what might be more familiar signs of stripe rust during the adult plant stages (Figure 15). WIT's breeding strategy has expanded to include selection for resistance before and after flowering, in most part due to favorable environmental conditions in Oklahoma in 2015 and 2016. Keep in mind what might be considered favorable to breeders may not be so desirable to wheat producers. A key driver in this strategy shift is that OSU varieties typically will show highly effective stripe rust resistance after flowering, such as Gallagher, but often are challenged by stripe rust before flowering, such that overall plant vigor is stunted and yielding ability is suppressed.

WIT saw immediate positive results in 2016 after taking action following the stripe rust epidemic of 2015. Prior to 2015, advanced lines crept through the pipeline without adequate vetting for stripe rust resistance, simply because selection pressure could not be applied during the drought years leading up to 2015. In contrast, advanced lines tested in 2016 mostly were resistant, with a low frequency of intermediate lines, and thus the rate of yield loss per step increase in susceptibility was proportionally lower in 2016 (Figure 16).

WIT continued to turn to other cooperators for assistance in stripe rust evaluation under field conditions, including scientists located in Manhattan, Kansas, with USDA-Agricultural Research Service, and in Pullman, Washington, with Washington State University. This collaboration ensures constant selection pressure for stripe rust

**Figure 15. Symptoms of stripe rust infection on Iba wheat before flowering (left) and after flowering on an unknown experimental line (right).**

resistance in years the disease is not present in Oklahoma, such as 2013 and 2014. In Washington, pressure from the disease far exceeds what is observed commonly in Oklahoma, yet the results from 2016 were highly encouraging. Two advanced lines that will be advanced as candidate cultivars produced atypically favorable ratings in Washington: OK11D25056 and OK13209. Effective resistance in Washington nearly always carries over to effective resistance in Oklahoma.

### *Biggest influencers*

Second to stripe rust resistance were several other traits that attracted WIT's attention. Those were recovery from spring freeze damage at Lahoma in March to April 2016; resistance to leaf rust either under early April infection at Stillwater or under a more typical infection period during mid-May at Lahoma; and straw strength. The latter will attract even greater attention moving forward as WIT sets its sights on varieties better adapted to eastern Oklahoma where

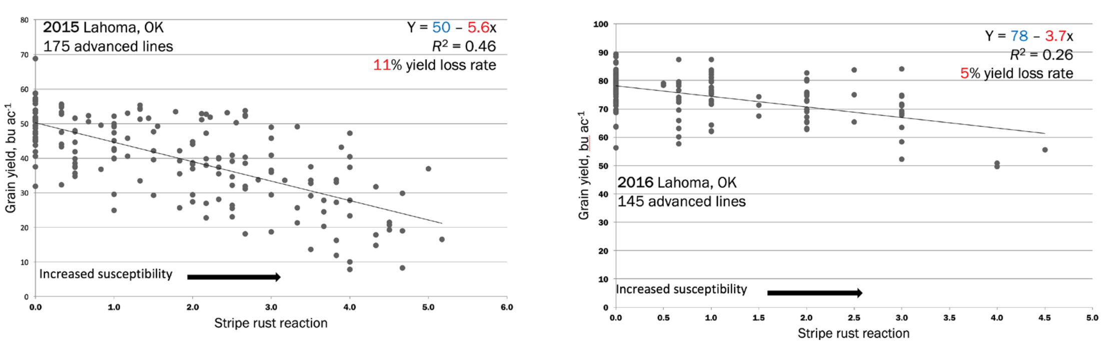


**Figure 16. Grain yield versus stripe rust ratings for advanced lines tested in 2015 and 2016 at Lahoma, where infection was naturally severe. Grain yield declined linearly with stepwise increases in susceptibility, but at different rates between 2015 and 2016. Reactions greater than 3.0 were considered susceptible in either year, and the frequency of susceptible reactions was lower in 2016 than 2015.**

straw strength is a prerequisite to grain yields that can often approach 100 bushels per acre. Straw strength is a trait WIT must improve upon if its cultivars are to find acceptance in high-yielding environments.

Introgression of WSM resistance into the variety development pipeline continued in 2016 with success. WIT's strategy remains focused on a three-pronged approach of selecting for molecular markers either in close linkage with or inherently part of genes *Cmc4*, *Wsm1*, *Wsm2* and other unnamed genes. Adapted segregating populations and fixed lines have resulted from this work. WIT's only chance at reliable field validation of advanced lines is provided courtesy of USDA-ARS collaborators in Lincoln, Nebraska who conducted a field screening for WSM resistance under natural conditions (Figure 17). Virus symptoms from this test often are severe and reveal dramatic differences, even among lines carrying one of the genes listed above. The 2016 screen was so severe that Mace separated from other WSM-resistant cultivars like TAM 204, Oakley CL and Snowmass as having the highest resistance. Encouraging to WIT was the advanced line OK12612, which showed WSM resistance equivalent to Mace. This line has the pedigree N02Y5078/OK05741W and likely will serve as a locally adapted and preferred donor of WSM resistance, rather than relying on other less adapted external sources. Until this year, WIT had no such donor that could be confidently placed in the same resistance category as Mace. This Nebraska cultivar appears to be a better source of resistance for Oklahoma, because WSM resistance is expressed at a higher temperature than that conferred by the alternative gene *Wsm2*. The goal is to combine *Wsm1* with *Cmc4* (curl mite resistance) in the same genetic background with minimal impact of yield-reducing genes linked to *Wsm1*.

The report on page 7 has information about breeding efforts devoted to other diseases.

### *Changes ahead*

Wheat cultivar development by WIT follows a general track through four essential stages (Figure 18). The kinds and number of crosses performed establish the foundation and ceiling,for future success. Second to that stage in importance, however, are the population development and line selection stages which span six years. Imagine a filter through which potentially millions of genetic combinations will pass and a small proportion ultimately generates fixed genetic lines for eventual testing. WIT has employed such a specially designed filter, called the ***Grazen**Grain* breeding system, to invoke selection for multiple characteristics applicable to both grain-only and dual-purpose management systems. Since 1997 this system has been centered at the Expanded Wheat Pasture Research unit at Marshall for population development, and at Stillwater and Lahoma for subsequent line selection. While this selection system remains in place and continues to work very well, the filter used in this system may not be best for developing lines for far western Oklahoma.

For about 10 percent of the more than 1,000 crosses made per year, WIT is growing the segregating bulk

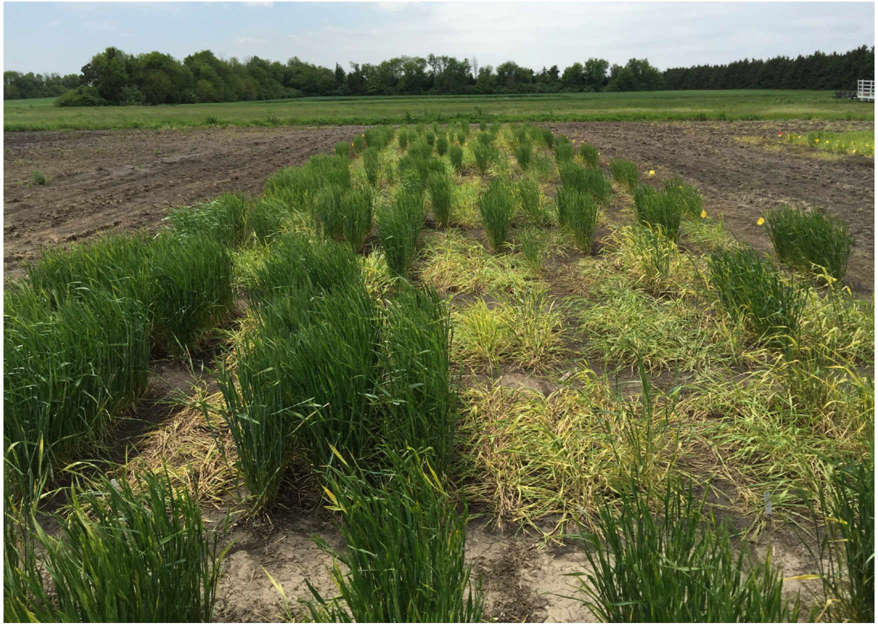

Figure 17. Mite-transmitted virus screen conducted by the U.S. Department of Agriculture - Agriculture Research Service scientists at the USDA-ARS Agricultural Research and Development Center near Mead, Nebraska in 2016. Wheat streak mosaic-susceptible lines exhibit severe yellowing and stunting. Photo provided by G. Hein and R. Graybosch.


Figure 18. Oklahoma State University pureline wheat breeding follows a typical flow of germplasm over a period of about 11 years from the initial cross to cultivar release. Population development in a grazed dual-purpose system near Marshall is one of the components that differentiates the OSU breeding program from other public and private programs.

populations at Oklahoma Panhandle Research and Extension Center under near-dryland conditions, whereby irrigation is provided only if needed to perpetuate the crop. Independent subsets of the same populations are also cycled through Marshall, so this process can be considered running a smaller but highly targeted breeding program inside a larger and expansive breeding program. Progeny extracted from populations grown and selected at OPREC are more likely to be specifically adapted to High Plains climatic and edaphic conditions than those extracted from populations grown at Marshall. WIT finished its third year and first complete cycle of population development in 2016. For what is believed to be the first time in OSU history, wheat headrow families will be evaluated at OPREC some 275 miles from OSU-Stillwater to begin the line selection process (Figure 19). The primary motivation is to move the impact of the OSU wheat breeding program farther west without physically having to move the program.

### *Busting barriers for hard white wheat*

The last OSU release of a HW cultivar occurred in 2008 following the development of OK Rising. Though it was yield-competitive with HRW cultivars grown at that time, OK Rising failed to take traction with seed producers for reasons mostly tied to marketing and not to genetics. Times have truly changed in the past eight years. Demand for hard white wheat has grown in domestic mills in the Great Plains, with no decline in the consistently high demand from export grain markets. Mexico wants HW wheat, and always has. The U.S. school lunch program needs HW wheat, and probably always will. Who will provide it?

Cultivar choices of HW wheat have not kept stride with this uptick. HW cultivars today largely are limited to public wheat breeding programs in western Kansas and to a lesser extent, Colorado. For HW production to be successful in Oklahoma, cultivars will need to be better locally adapted and adapted to the main body of the state rather than strictly to the Panhandle region as the trend was with earlier OSU HW releases (Intrada and Guymon).

**Figure 19. Single 3-foot rows, called headrows because each originated from a single head in the previous generation, are shown two weeks after emergence at the OPREC in October 2016. Each row represents a genetically unique experimental line and forerunner to a released cultivar.**

At minimum, HW cultivars in Oklahoma should yield as well as the leading HRW cultivars, possess resistance to the WSBM/WSSM complex and have some degree of tolerance to low soil pH and to preharvest sprouting. Preferably, resistances to other diseases would strengthen appeal and help drive HW adoption, such as effective resistance to powdery mildew, tan spot, stripe rust or leaf rust. Stardust, officially released by the Oklahoma Agricultural Experiment Station in February 2016, meets all of the minimum criteria and most of the preferred criteria except leaf rust resistance.

A tribute to its grandparent OK Bullet, Stardust carries the added bonus of straw strength. Beyond the field and into the mill, Stardust carries another bonus: naturally high flour yield. White wheat offers the inherent benefit to millers of potentially higher flour extraction rates (1 to 3 percentage points). Stardust already has a naturally high ceiling for flour extraction, giving millers a head start on margin expansion by making normal roller mill adjustments for HW grain.

Stardust can be grown statewide but is best adapted to northern regions of Oklahoma. The most opportune area for grain production resides in north-central Oklahoma and south-central Kansas. One fitness trait key to production in this region is preharvest sprouting tolerance. Controlled spike sampling at physiological maturity in 2016 confirmed Stardust has indeed broken a significant trait barrier for OSU HW wheat by showing a level of preharvest sprouting tolerance equivalent to or better than some HRW cultivars (Figure 20). This does not imply that Stardust will not show at least some sprout damage if harvest is delayed significantly into late June or early July due to excessively wet conditions.

Owing to its moderate resistance to tan spot, Stardust appears to be better suited for high-residue management systems than Duster or its HRW derivatives, Gallagher and Iba. One primary note of caution for diseases concerns leaf rust, for which a fungicide application may be needed to protect against severe or prolonged leaf rust infection and possibly stripe rust pressure. Resistance genes present in Stardust do not provide full protection to current virulent races. Other favorable attributes of Stardust are above-average test weight and kernel size, early maturity and a high level of tolerance to low pH soils (Figure 21).

Stardust should be used foremost for its grain production. Adaptation to a dual-purpose system is supported by its observed ability to rapidly accumulate fall vegetative biomass, regenerate vegetative biomass upon removal, and recover from forage removal at time of grazing termination. Limitations of adaptation to this system, however, should not go unheeded. Those include an early first hollow stem date that requires grazing termination earlier than dual-purpose standards such as Duster and Endurance, and the potential to show susceptibility to barley yellow dwarf especially in the event of fall infestations of its insect vector.

### *By the numbers*

The moving parts of a plant breeding program, including this one, can be likened to a musical canon in which essentially the same music is being played or sung starting at different times. Likewise, the same fundamental breeding procedure is followed starting with a new set of hybridizations each year. A freeze frame of the breeding program at any point in time reveals different parts of the process in motion, as shown in Figure 22.

### *Candidate variety lineup*

Following the 2016 harvest and after thorough consideration of all advanced lines under breeder-seed increase in 2016, WIT submitted breeder seed of nine new HRW candidates for grow-out and on-farm evaluation by Oklahoma Foundation Seed Stocks in 2016-2017 (Table 8). Another 13 candidates already were under foundation seed increase in 2016. Of those, nine were retained, for

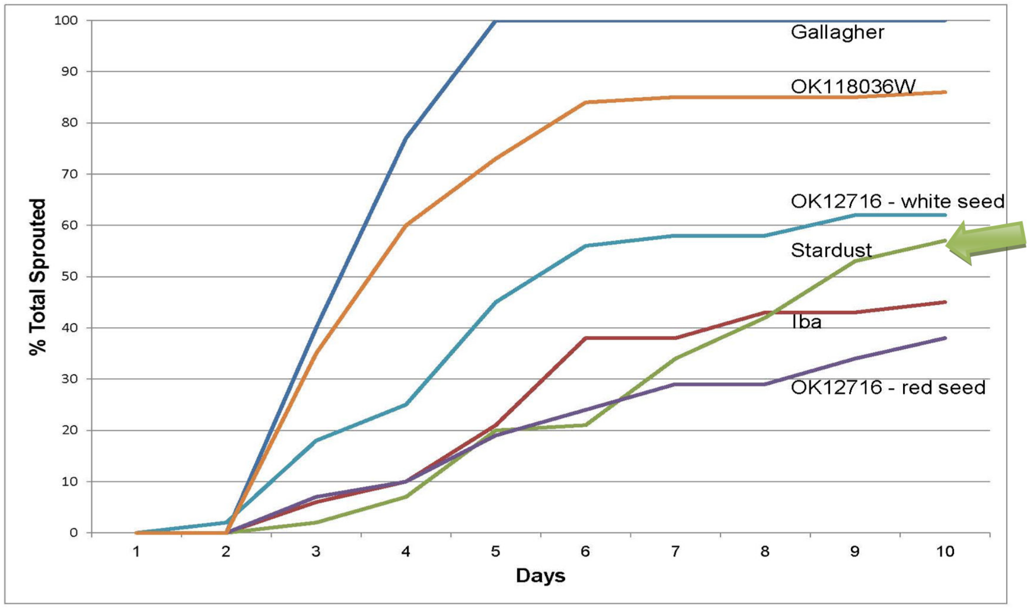


**Figure 20. Cumulative percentage of sprouted kernels when subjected to optimal germination conditions over a 10-day period. Kernels were harvested at a maturity-equivalent stage for all cultivars (physiological maturity) grown at Stillwater in 2016.**

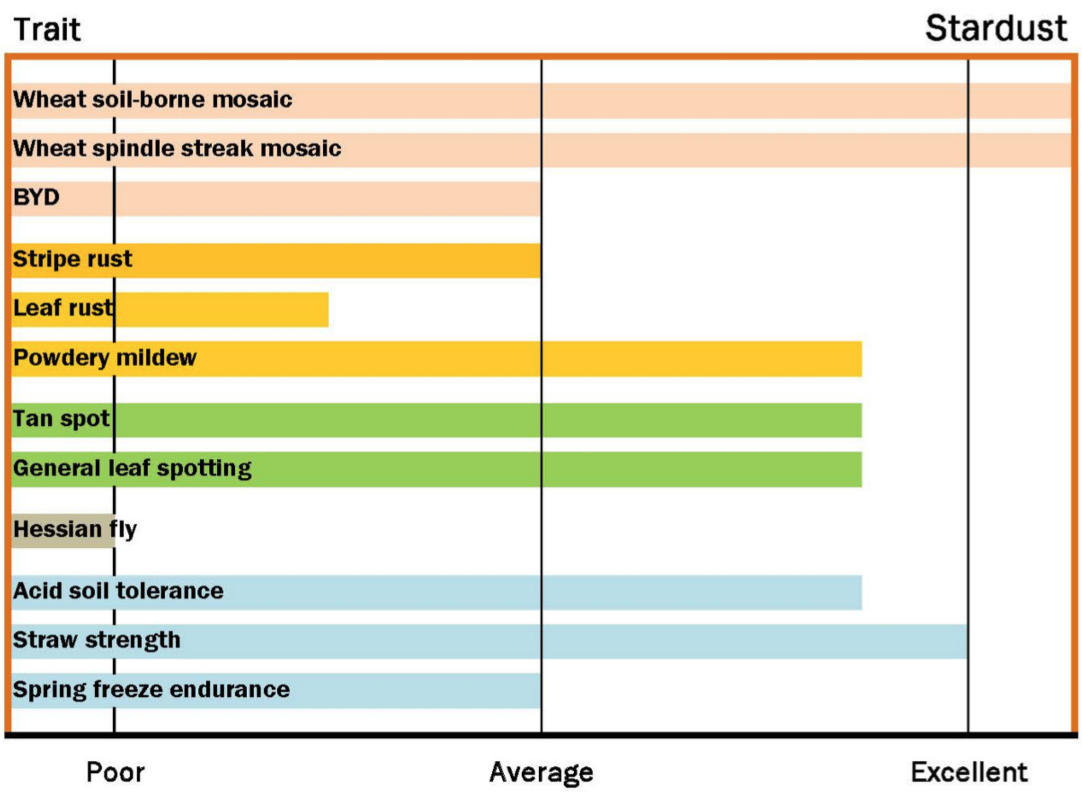


**Figure 21. Trait descriptions for Stardust, as reported at time of release by the Oklahoma Agricultural Experiment Station in February 2016.**

which five candidates are shown as the first five entries in Table 8.

Not listed in Table 8 is OK09915C-1, a single-plant selection from Doublestop CL Plus that held a 3-bushel-per-acre yield advantage over the parent variety across 40 replicated breeder trials since 2014. It also exhibited better stripe rust protection than Doublestop CL Plus and more uniform resistance to the Great Plains biotype of Hessian fly. Otherwise, the two are phenotypically similar. Nearly 850 bushels of foundation seed of OK09915C-1 were produced in 2016. From this point forward, OK09915C-1 will be used to perpetuate breeder, foundation and certified seed of Doublestop CL Plus. Two new Clearfield Plus candidates under foundation seed increase in 2016-2017 are OK12912C-138407-2 and OK128084C. After final testing in breeder trials, OAES and KSU variety trials, and BASF qualification trials, a release recommendation will be forwarded to OAES for one of the two candidates during the latter half of 2017.

Subsequent to preparation of this report, WIT will prepare release proposals for three candidates (OK11D25056, OK12DP22002-042, and OK10126) for OAES consideration in early 2017. The DH, OK12DP22002-042 led the other 37 entries in the 2016 Southern Regional Performance Nursery, SRPN, program by a statistically significant and extraordinary margin of 3 bushels per acre. Among 19 locations from Texas to Nebraska, OK12DP22002-042 placed in the top three yielding positions at Bushland, Texas; Goodwell, Oklahoma; Colby and Hays, Kansas; Ft. Collins, Colorado; and Lincoln, Nebraska. OK12DP22002-042 also was first among OSU elite lines for statewide grain yield in breeder trials in 2014 and 2015. It is short statured with very high straw strength (Table 9), making it a perfect candidate for high-rainfall or irrigated conditions where yields might be maximized. However, drought tolerance makes OK12DP22002-042 well suited for dryland production. The lack of WSBM/WSSM resistance pushes its target region to western Oklahoma, but its best SRPN performance was in High Plains environments from Texas to Colorado. It is almost unprecedented for OSU to release a WSBM-susceptible variety, but exception may be warranted in this case since the line is naturally best fit for western Oklahoma where WSBM bears less concern. A significant part of the high yield potential of OK12DP22002-042 comes from its exceptional kernel weight, exceeding a mean of 39 milligrams in samples collected statewide in 2016, more than 10 percent greater than Doublestop CL Plus.

The third highest-yielding entry in the 2016 SRPN was another OSU DH OK11D25056, owing 50 percent of its parentage to Gallagher, 25 percent to TAM 110, and 25 percent to 2174. This HRW experimental line combines resistance to Hessian fly and biotype E greenbug (Table 9) and was produced in cooperation with AgriPro-Syngenta. OK11D25056 is widely adapted and shows excellent leaf hygiene, except in the presence of WSM or under conditions of physiological leaf spotting. It is highly effective against current races of stripe rust and appears to offer

| | | |
|---|---|---|
| **2,316** | The number of segregating populations cycled through the ***Graze*** n***Grain*** ™ breeding system at Marshall, Lahoma and Altus in 2016. About 30 percent of these populations were sufficiently inbred to allow extraction of experimental lines for eventual testing and selection. One segregating population usually generates 96 experimental lines. |  |
| **49,427** | The number of first-generation $F_5$ experimental lines planted in 3-foot headrows. This number is about average for the variety development program. Selection pressure was very intense in 2016 to avoid advancing lines with undesirable disease resistance. Less than 2,000 of these lines were advanced for observation in conventional plots in 2016–2017. |  |
| **2,133** | The number of second-generation fixed lines dedicated to our centerpiece breeding nursery, the Dual-Purpose Observation Nursery and key turning point for lines born of the ***Graze*** n***Grain*** ™ breeding system. Only those progeny superior for grazing persistence and grain-only yield potential are advanced for statewide yield testing. Of those lines, 14 percent were hard white. |  |
| **745** | The number of doubled haploid lines produced outside of, and which short-circuit, the conventional ***Graze*** n***Grain*** ™ system. The first HRW doubled haploid experimental line to reach candidate cultivar status, OK11D25056, is a progeny of Gallagher. If released, it will go into commercial seed production just four years after Gallagher's release. The normal breeding cycle from parent to progeny release is about 10 |   |
| **2** | Number of consecutive years in which OSU experimental lines in the Hard Winter Wheat Evaluation program of the Wheat Quality Council were recognized with superior milling and baking quality. The WIT will roll out a new brand of genetics that showcase this level of milling and baking quality, tentatively called ***Gold*** n***Grain*** . |  |
| **2 of 3** | Two OSU advanced lines ranked in the top 3 (first and third places) in the 2016 Southern Regional Performance Nursery when averaged across the entire southern and central Plains. At the top was the short-statured, HRW doubled haploid, OK12DP24002-042, which will be positioned for western Oklahoma and the High Plains if approved for release in early 2017. The pedigree is Billings/OK08328. | USDA |
| **3** | The number of candidate cultivars in the queue for possible release in February 2017. These are OK10126, OK11D25056 and OK12DP24002-042. This does not include a possible fourth—a beardless tri-purpose line —that may follow in summer 2017 pending producer evaluation. |  |
| **1 and only 1** | The OSU WIT is the only program in the U.S. that focuses on adaptation to the wheat/stocker cattle enterprise without losing sight of what steers wheat prices. Quality does matter. |  |

**Figure 22. The OSU wheat improvement program, by the numbers, for the 2015-2016 crop season.**

**Table 8. Oklahoma State University candidate varieties placed under seed increase in fall 2016 with Oklahoma Foundation Seed Stocks.**

| *Candidate*[a] | *Pedigree* | *Increase status* | *Feature traits* |
|---|---|---|---|
| OK11D25056 | Gallagher/OK05511 | Pre-release | Greenbug + Hessian fly resistance; ***GoldnGrain*** |
| OK10126 | OK Bullet/OK98680 | Pre-release | Lodging-resistant 3-year winner at Goodwell, OK |
| OK12DP22002-042 | Billings/OK08328 | Pre-release | Lodging-resistant yield topper - 2016 SRPN[b]; WSBM-S[c] |
| OK10430-2 | CS+1V/2*Endurance sibling | Pre-release | Awnletted, forage + grain ideotype; high early vigor |
| OK12912C-138407-2 | N91D2308-13/OK03926C//OK03928C | Year 1 or 2 | Doublestop upgrade for three diseases, straw strength |
| OK128084C | N91D2308-13/OK04902C//OK05907C | Year 1 | Like OK12912C but early; lacks PM/freeze tolerance |
| OK13209 | OK Bullet/TX00D1390//Shocker | Year 1 | Stout on stripe rust; central corridor and northeast Olahoma |
| OK12DP22004-016 | Everest/OK08328//OK09634 | Year 1 | Very short and early; ***GoldnGrain***™ |
| OK13621 | TX00D1390/Billings | Year 1 | Broad disease package; ***GoldnGrain***™ |
| OK13625 | Billings/Fannin sibling | Year 2 | High N-use efficiency and very early; ***GoldnGrain***™/organic |
| OK12D22002-077 | Billings/OK08328 | Year 1 | -042 sibling but WSBM[e] resistant; targeted downstate |
| OK14319 | NE01533/OK02125//Duster | Year 1 | Targeted for northeast Oklahoma; low pH/grazing tolerant |
| OK12206-127206-2 | Y98-912/OK00611W//OK03716W | Year 1 | All-around best beardless – agronomic and quality |
| OK15115 | Pete/OK Bullet//TX03A0148 | Year 1 | Backup beardless; strong straw and disease package |

[a] OK12716R/W not shown
[b] SRPN=Southern Regional Performance Nursery
[c] WSBM-S=wheat soil-borne mosaic-susceptible
[d] PM=powdery mildew
[e] WSBM= wheat soil-borne mosaic

better protection than Gallagher when infection occurs before heading. This difference is noteworthy, because Gallagher has shown some weakness to severe stripe rust infections recently, even though its resistance during later grain-fill stages is exceptional. Interestingly in controlled-environment conditions, Gallagher has shown moderate tolerance to BCOA.

Another HRW candidate, OK10126, has parentage from OK Bullet and an OSU experimental line derived from a Ukrainian selection and Mesa. OK10126 will be targeted toward grain-only management systems, because earlier planting tends to expose its weakness to late winter freezes. Otherwise, OK10126 is an outstanding grain producer in the presence of several problem diseases, such as stripe rust and tan spot (Table 9). It shows outstanding straw strength under intensively managed conditions, perhaps unrelated to the presence of an infrequent semidwarfing gene called *Rht8*. OK10126 also has the distinction of being the top-yielding entry for the past three years in the Goodwell irrigated variety trial conducted by OCES. Like OK12DP22002-042, straw strength of OK10126 is exceptional.

Pending final evaluation of 2016–2017 performance, a fourth candidate, OK10430-2, may be petitioned for OAES release sometime in summer 2017. This line offers the dual-purpose reliability of its recurrent parent, a

**Table 9. Trait ratings (1 to 5 scale) for Oklahoma State University candidates under Foundation Seed increase in 2016–2017.**

| | *Trait category*[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Candidate* | *DP* | *HF* | *YR* | *LR* | *TS* | *PM* | *V* | *AST* | *SS* | *BQ* | *Weaknesses* |
| OK11D25056 | 2 | 1 | 2 | 3 | 4 | 1 | 1 | 2 | 2 | 1 | |
| OK10126 | 3 | 5 | 2 | 3 | 3 | 4 | 2 | 2 | 1 | 2 | April freeze |
| OK12DP22002-042 | 2 | 2 | 3 | 2 | 5 | 2 | 5 | 1 | 1 | 2 | Pre-harvest sprouting |
| OK10430-2 | 1 | 5 | 3 | 1 | 4 | 2 | 2 | 1 | 3 | 4 | Shattering |
| OK12912C-138407-2 | 2 | 2 | 2 | 2 | 3 | 2 | 1 | 1 | 1 | 1 | |
| OK128084C | 3 | 3 | 1 | 3 | 2 | 4 | 1 | 1 | 1 | 1 | April freeze |
| OK13209 | 2 | 5 | 1 | 2 | 3 | -- | 2 | 2 | 1 | 2 | Shattering |
| OK12DP22004-016 | 4 | 2 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | Grazing recovery |
| OK13621 | 1 | 5 | 1 | 3 | 4 | 1 | 1 | 2 | 2 | 1 | |
| OK13625 | 4 | 5 | 2 | 1 | 2 | 2 | 1 | 1 | 3 | 1 | Winter injury |
| OK12D22002-077 | 3 | 1 | 1 | 3 | -- | 2 | 1 | 2 | 1 | 2 | |
| OK14319 | 2 | 1 | 2 | 1 | 2 | -- | 1 | 1 | 1 | 1 | April freeze |
| OK12206-127206-2 | 1 | 1 | 1 | 2 | 2 | -- | 1 | 1 | 2 | 1 | |
| OK15115 | 2 | -- | 2 | 1 | 2 | -- | 3 | 3 | 1 | 1 | |

[a] Trait categories are abbreviated as DP, dual-purpose capability (forage and grain combined); HF=Hessian fly; YR=stripe rust; LR=leaf rust; TS=tan spot; PM=powdery mildew; V=wheat soil-borne mosaic/wheat spindle streak mosaic complex; AST=acid-soil tolerance; SS=straw strength; and BQ=baking quality. Values ≤2 are considered very desirable; those ≥4 are undesirable. No value (--) indicates inconsistent or insufficient data for postulation.

closely related sibling of Endurance, but with higher yield potential and a more aggressive fall forage growth pattern that would be appealing to forage and dual-purpose wheat producers. It also produces an awnletted spike that would appeal to those wanting to graze out or produce hay.

# Wheat Variety Trials

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The 2016 Oklahoma wheat production is estimated to be approximately 136.5 million bushels, which is about 38 percent greater than our 2015 production (Table 10) and 287 percent greater than production in 2014. Although the estimated harvested acres is lower than the estimate for 2015, the statewide average yield is projected at 39 bu/ac, and this is a 13 bushels per acre (50 percent) increase compared to 2015 (Table 10). Based on these numbers, this is the largest wheat production for the state since 2012, and the average yield ties the state record.

**Table 10. Oklahoma wheat production for 2014 and 2015 as estimated by the U.S. Department of Agriculture, National Agricultural Statistics Service, July 2016.**

| | *2015* | *2016* |
|---|---|---|
| Harvested acres | 3.8 million | 3.5 million |
| Yield (bu./A) | 26 | 39 |
| Total bushels | 98.8 million | 136.5 million |

The 2015–2016 wheat growing season was unlike most years in Oklahoma, characterized by periods of plentiful rainfall and near optimal growing conditions at critical times. Most wheat was sown into soil with adequate moisture, allowing it to emerge rapidly. The sufficient rainfall and mild temperatures allowed for good fall growth and bumper forage yields. Plants in many nongrazed fields were abnormally large and phenologically advanced going into winter, causing some concern about winterkill. With mild temperatures continuing into the winter months, this concern proved to be largely unfounded and most plants moved to spring green-up without injury.

Similar to 2014 and 2015, January and February were dry months for the southern Great Plains, and the ample forage growth quickly wicked moisture from the soil. As the wheat crop was coming out of dormancy, there was considerable concern the dry conditions would reduce yield potential. Fortunately, rain fell during early- to mid-March as the crop was greening up. This also helped provide grazed wheat the extra boost it needed to recover from grazing injury.

As the wheat crop progressed from greenup to flowering, rain continued to fall, but warmer-than-normal temperatures moved the crop along quickly, and at the time, most thought harvest would come earlier than normal. With the transition into grain fill, temperatures stayed at more ideal levels, favoring kernel filling.

Most wheat was mature in southwestern Oklahoma and in the central part of the state by the end of the May. Widespread rainfall at the end of May delayed most producers from beginning harvest until the first week in June. Dry weather during June allowed much of the wheat crop to be harvested quickly. Unfortunately, some areas of southwestern Oklahoma were plagued by regular and heavy rainfall events that delayed harvest toward the end of the month. Overall, harvest was nearly finished in the state by the end of June.

Yields throughout Oklahoma were very good overall, with field averages of 30 to 60 bushels per acre being the norm. Field averages in the range of 60 to 90 bushels per acre were not uncommon, and there were even isolated cases of fields averaging more than 100 bushels per acre. Some producers expressed they would never see yields this high again in their lifetime, and let's hope they are wrong. Test weights throughout harvest remained at or above 60 pounds per bushel for early-harvested fields and did not drop much below the upper 50s toward the end of harvest. This was a welcomed change from the low test weights of 2015.

Other than bird cherry-oat aphids and wheat curl mites, there were few widespread insect problems in 2015–2016. Aphids were not really a concern for most producers until numbers ballooned in mid-March. As a result, it was not hard to find barley yellow dwarf, BYD, as flag leaves and heads started to emerge. While there was quite a bit of purpling associated with BYD, there was not as much stunting as sometimes observed with early-season transmission of the virus. Wheat streak mosaic, WSM, was not as widespread as in 2015, but it still was a significant issue for many producers in 2016. The favorable growing conditions likely reduced the impact of both BYD and WSM, and yield reductions were not as severe as they might have been in a more drought-stressed environment.

Similar to 2015, stripe rust was the major foliar disease impacting wheat production in 2016. The devastation caused by the 2015 stripe rust epidemic had many producers more open to the idea of applying foliar fungicide to susceptible varieties. Many fields throughout the state received at least one fungicide application, and anecdotal evidence from agricultural retailers indicates Oklahoma wheat acres treated with a foliar fungicide in 2016 more than doubled those treated in 2015. Variety trial results from Apache, Chickasha and Lahoma indicate producers were justified in spraying many of these acres. Grain yield of the popular variety Ruby Lee, for example, was increased by 68 bushels per acre at Chickasha when treated twice with a foliar fungicide. The results at Chickasha also show the power of genetic resistance to disease in varieties such as Billings which maintained an 83-bushels-per-acre grain yield without the assistance of a foliar fungicide. In addition to stripe rust, leaf rust was present, but it was at low levels in isolated areas and was not widespread throughout the state.

## Methods

Seed was packaged and planted in the same condition as it was delivered from the respective seed companies. Most seed was treated with an insecticide-plus-fungicide seed treatment, but the formulation and rate of seed treatment used was not confirmed or reported in this document.

Conventional till plots were eight rows wide with 6-inch row spacing and were sown with a Hege small plot cone seeder. No-till plots were seven rows wide with 7.5-inch row spacing and were sown with a Great Plains no-till drill modified for coneseeded, small-plot research. With the exception of dryland locations in the Panhandle, plots were planted 25 feet long and trimmed to 19 feet at harvest with the plot combine. Panhandle dryland locations were 35 feet long at planting and trimmed to 29 feet at harvest. Wheel tracks were included in the plot area for yield calculation, for a total plot width of 59 inches. Experimental design for all sites other than Apache and Lahoma was a randomized complete block with four replications. Apache and Lahoma were a split-block arrangement of a randomized complete block with four replications where whole plots were fungicide treated or nontreated, and subplots were wheat variety.

Conventional plots received 50 pounds per acre of 18-46-0 in-furrow at planting. No-till plots received 5 gallons per acre of 10-34-0 at planting. The Marshall dual-purpose trial, Union City, Walters and forage trials were sown at 120 pounds per acre. All other locations were sown at 60 pounds per acre. Grazing pressure, nitrogen fertilization and insect and weed control decisions were made on a location-by-location basis and reflect standard management practices for the area.

Plots were harvested with a Kincaid or Wintersteiger Delta small-plot combine. When sample size allowed for grain moisture measurement on individual plots, grain yields were corrected to 12 percent moisture. Grain moisture at all sites generally was below 11 percent, and maximum and minimum grain moisture for all plots at a location typically ranged no more than 2 percent. Balko plots were not harvested due to severe hail damage in early May. Kingfisher plots were harvested but not reported due to harvest equipment malfunctions. The Keyes plots also were harvested, but data are not reported as the coefficient of variation exceeded 25.

### *Additional information on the web*

A copy of this publication, as well as additional variety information and more information about wheat management can be found at:

**Website:** wheat.okstate.edu

**Blog:** osuwheat.com

**Twitter:** @OSU_smallgrains

**Facebook:** @osusmallgrains

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J.B. Stewart, Keyes
Rodney Mueggenborg, Kingfisher

***Participating Seed Companies***

**AGSECO, Inc.**
Steve Ahring
P.O. Box 7
Girard, KS 66743
800-962-5429
steve@delangeseed.com
agseco.com
Varieties: AG Robust, TAM 114

**Colorado Wheat Research Foundation–PlainsGold**
Kim Warner
4026 S. Timberline Road, Suite 100
Fort Collins, CO 80525
970-449-6994
kwarner@coloradowheat.org
coloradowheat.org
Varieties: Avery, Brawl CL Plus, Byrd

**Dyna-Gro Seed**
Ryan Klamforth
419-310-6370
dynagroseed.com
Varieties: Long Branch

**Kansas Wheat Alliance**
Daryl Strouts
1990 Kimball Ave.
Manhattan, KS 66502
785-320-4080
kwa@kansas.net
kswheatalliance.org
Varieties: 1863, Everest, Joe, KanMark, Larry, Oakley CL, Tatanka, Zenda

**Limagrain Cereal Seeds**
Drew Hendricker
2040 SE Frontage Road
Fort Collins, CO 80525
970-498-2218
drew.hendricker@limagrain.com
limargraincerealseeds.com
Varieties: LCS Chrome, LCS Mint, LCS Pistol, LCS Wizard, T158

**Monsanto/WestBred**
John Fenderson
1616 E. Glencoe Road
Stillwater, OK 74075
620-243-4263
john.m.fenderson@monsanto.com
westbred.com
Varieties: WB4303, WB4458, WB4515, WB4721, WB-Cedar, WB-Grainfield, Winterhawk

**Oklahoma Genetics Inc. (OGI)**
Mark Hodges
P.O. Box 2113
Stillwater, OK 74076
405-744-7741
okgenetics.com
Varieties: Bentley, Billings, Doublestop CL Plus, Duster, Gallagher, Iba, NF 101, OK Rising, Ruby Lee, Stardust

**Oklahoma Foundation Seed Stocks (Oklahoma State University)**
Jeff Wright
2902 W. 6th Ave.
Stillwater, OK 74074
405-744-7741
ofss.okstate.edu
Varieties: Endurance

**Syngenta Seeds**
Greg Gungoll
1517 Osage Ave.
Enid, OK 73703
405-714-2839
greg.gungoll@syngenta.com
agriprowheat.com
Varieties: SY Drifter, SY Flint, SY Grit, SY Llano, SY Monument, SY Razor, SY Wolf

**Watley Seed**
Andy Watley
Box 51
Spearman, TX 79081
806-659-3838
watleyseed@valornet.com
watleyseed.com
Varieties: TAM 112, TAM 204

**Wheat protein data are available in Extension Current Report CR-2135 Protein Content of Winter Wheat Varieties in Oklahoma-2016.**

# 2015-2016 Oklahoma Wheat Variety Performance Tests Summary

| Source | Variety | *Afton* | *Altus* | *Alva* | *Apache* | *Apache Fungicide* | *Buffalo* | *Cherokee* | *Chickasha* | *Chickasha IWM* | *Goodwell Irrigated* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grain yield (bu./A) | | | | | | | | | |
| KWA | 1863 | - | 44 | - | - | - | - | - | 73 | 84 | 73 |
| AGSECO | AG Robust | - | 44 | - | - | - | - | - | 80 | 94 | 63 |
| PlainsGold | Avery | - | 33 | 60 | - | - | 72 | 65 | 27 | 82 | 77 |
| OGI | Bentley | 42 | 48 | 61 | 77 | 80 | 82 | 71 | 54 | 84 | 83 |
| OGI | Billings | 46 | 35 | - | - | - | - | - | 83 | 94 | 91 |
| PlainsGold | Brawl CL Plus | - | 44 | 48 | - | - | 79 | 65 | 42 | 87 | 82 |
| PlainsGold | Byrd | - | 34 | 60 | - | - | 80 | 68 | 26 | 91 | 84 |
| OGI | Doublestop CL Plus | 40 | 39 | 56 | 61 | 68 | 73 | 62 | 56 | 75 | 66 |
| OGI | Duster | 43 | 51 | 58 | 39 | 49 | 73 | 68 | 56 | 67 | 87 |
| OSU | Endurance | 41 | 34 | 56 | 50 | 57 | 75 | 68 | 47 | 74 | 79 |
| KWA | Everest | 36 | 22 | - | - | - | - | - | 25 | 85 | 76 |
| OGI | Gallagher | 44 | 42 | 56 | 63 | 68 | 65 | 57 | 73 | 93 | 86 |
| OGI | Iba | 42 | 51 | 57 | 61 | 76 | 79 | 71 | 60 | 81 | 91 |
| KWA | Joe | - | 52 | - | - | - | - | - | 76 | 75 | 94 |
| KWA | KanMark | - | 44 | 55 | 57 | 76 | 73 | 59 | 61 | 87 | 83 |
| KWA | Larry | - | 48 | - | - | - | - | - | 77 | 84 | 88 |
| LCS | LCS Chrome | - | 55 | - | - | - | - | - | 75 | 84 | 88 |
| LCS | LCS Mint | - | 45 | 61 | - | - | 71 | 62 | 40 | 79 | 88 |
| LCS | LCS Pistol | 41 | 33 | 52 | 51 | 60 | 66 | 58 | 47 | 70 | 83 |
| LCS | LCS Wizard | 43 | 31 | 55 | 48 | 70 | 77 | 54 | 36 | 87 | 77 |
| Dyna-Gro | Long Branch | - | 49 | - | - | - | - | - | 52 | 55 | 90 |
| OGI | NF 101 | - | 23 | - | - | - | - | - | 49 | 77 | 73 |
| KWA | Oakley CL | - | 60 | - | - | - | - | - | 66 | 69 | 90 |
| OGI | OK Rising | - | 39 | - | - | - | - | - | 57 | 80 | 71 |
| OGI | Ruby Lee | 42 | 23 | 50 | 37 | 75 | 60 | 53 | 23 | 92 | 85 |
| OGI | Stardust | - | - | - | - | - | - | - | - | - | - |
| Syngenta | SY Drifter | 39 | 48 | - | 56 | 66 | - | - | 64 | 84 | 89 |
| Syngenta | SY Flint | 37 | 52 | 51 | 68 | 69 | 74 | 64 | 74 | 91 | 90 |
| Syngenta | SY Grit | - | 43 | - | - | - | - | - | 61 | 95 | 81 |
| Syngenta | SY Llano | 35 | 32 | - | 64 | 66 | - | - | 72 | 85 | 65 |
| Syngenta | SY Monument | - | 50 | 56 | - | - | 80 | 70 | 71 | 80 | 87 |
| Syngenta | SY Razor | - | 39 | - | - | - | - | - | 60 | 73 | 77 |
| Syngenta | SY Wolf | - | - | - | - | - | - | - | - | - | 85 |
| LCS | T158 | - | 55 | - | 64 | 68 | - | - | 71 | 89 | 75 |
| Watley | TAM 112 | - | 29 | 59 | - | - | 60 | 64 | 33 | 72 | 75 |
| AGSECO | TAM 114 | - | 42 | 49 | - | - | 76 | 54 | 72 | 90 | 87 |
| Watley | TAM 204 | 45 | 45 | 55 | 67 | 79 | 69 | 67 | 68 | 101 | 90 |
| KWA | Tatanka | - | 60 | - | - | - | - | - | 74 | 82 | 86 |
| WestBred | WB4303 | - | 44 | - | - | - | - | - | 62 | 103 | 80 |
| WestBred | WB4458 | 32 | 47 | - | 84 | 90 | - | - | 72 | 103 | 77 |
| WestBred | WB4515 | - | 47 | - | - | - | - | - | 70 | 91 | 79 |
| WestBred | WB4721 | - | 51 | - | - | - | - | - | 65 | 72 | 87 |
| WestBred | WB-Cedar | 33 | 37 | 51 | - | - | 63 | 39 | 69 | 96 | 74 |
| WestBred | WB-Grainfield | 43 | 49 | 57 | 74 | 88 | 86 | 74 | 60 | 75 | 85 |
| WestBred | Winterhawk | - | 52 | 55 | 62 | 78 | 77 | 74 | 60 | 90 | 84 |
| KWA | Zenda | - | 48 | - | - | - | - | - | 70 | 85 | 85 |
| **OSU Experimentals** | | | | | | | | | | | |
| | OK09915C-1 | 38 | 46 | 45 | 66 | 77 | 65 | 64 | 69 | 77 | 74 |
| | OK10126 | - | - | - | - | - | - | - | - | - | 94 |
| | OK1059060-3 | - | - | - | - | - | - | - | - | - | |
| | OK11231 | 31 | - | - | - | - | - | - | - | - | |
| | OK118036R/W | - | - | - | - | - | - | - | - | - | |
| | OK11D25056 | - | 55 | 47 | - | - | - | - | 75 | 84 | 84 |
| | OK12621 | - | - | 53 | - | - | - | - | - | - | 65 |
| | OK12716R/W | - | 67 | 53 | 67 | 72 | - | 76 | - | - | 96 |
| | OK12912C | - | - | 47 | - | - | 76 | 60 | 78 | 90 | 76 |
| | OK12DP22002-042 | - | - | - | - | - | - | - | - | - | 95 |
| **Mean** | | **40** | **44** | **54** | **61** | **72** | **73** | **64** | **60** | **84** | **82** |
| **Least significant difference (0.05)** | | **7** | **6** | **7** | **7** | **11** | **8** | **7** | **7** | **9** | **15** |

# 2015-2016 Oklahoma Wheat Variety Performance Tests Summary (cont'd)

| Source | Variety | *Homestead* | *Hooker* | *Kildare* | *Lahoma* | *Lahoma Fungicide* | *Lamont* | *Marshall Dual-Purpose* | *Marshall Grain-Only* | *Thomas* | *Union City* | *Walters* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grain yield (bu./A) | | | | | | | | | | |
| KWA | 1863 | - | - | - | 76 | 85 | - | - | - | - | - | - |
| AGSECO | AG Robust | - | - | - | 71 | 82 | - | - | - | - | - | - |
| PlainsGold | Avery | - | 53 | - | 42 | 84 | - | - | - | - | - | - |
| OGI | Bentley | 92 | 60 | 59 | 69 | 87 | 86 | 50 | 51 | 81 | 66 | 35 |
| OGI | Billings | 86 | - | 49 | 64 | 75 | 52 | 38 | 51 | 68 | 52 | - |
| PlainsGold | Brawl CL Plus | - | 59 | - | 67 | 90 | - | - | - | - | - | - |
| PlainsGold | Byrd | - | 43 | - | 37 | 88 | - | - | - | - | - | - |
| OGI | Doublestop CL Plus | 74 | 56 | 53 | 62 | 73 | 69 | 48 | 48 | 66 | 57 | 36 |
| OGI | Duster | 80 | 57 | 49 | 56 | 72 | 60 | 51 | 54 | 66 | 57 | 43 |
| OSU | Endurance | 73 | 60 | 48 | 57 | 77 | 63 | 51 | 47 | 69 | 66 | 27 |
| KWA | Everest | 64 | - | 57 | 55 | 75 | 64 | 40 | 30 | - | - | - |
| OGI | Gallagher | 92 | 42 | 48 | 66 | 80 | 61 | 48 | 57 | 75 | 63 | 40 |
| OGI | Iba | 88 | 47 | 61 | 65 | 76 | 69 | 51 | 58 | 70 | 62 | 32 |
| KWA | Joe | - | - | - | 82 | 92 | - | - | - | - | - | - |
| KWA | KanMark | 89 | 49 | 60 | 59 | 79 | 68 | 40 | 50 | 78 | 53 | 23 |
| KWA | Larry | - | - | - | 77 | 84 | - | - | - | - | - | - |
| LCS | LCS Chrome | - | - | - | 81 | 82 | - | - | - | - | - | - |
| LCS | LCS Mint | 76 | 56 | 41 | 65 | 88 | 73 | 25 | 42 | 77 | 73 | - |
| LCS | LCS Pistol | 78 | 54 | 41 | 54 | 72 | 58 | 41 | 39 | 69 | 57 | 31 |
| LCS | LCS Wizard | 74 | 48 | 59 | 52 | 80 | 71 | 32 | 28 | 64 | 53 | 30 |
| Dyna-Gro | Long Branch | - | - | - | 59 | 62 | - | - | - | - | - | - |
| OGI | NF 101 | - | - | - | 57 | 67 | - | - | - | - | - | - |
| KWA | Oakley CL | - | - | - | 79 | 81 | - | - | - | - | - | - |
| OGI | OK Rising | - | - | - | 54 | 67 | - | - | - | - | - | - |
| OGI | Ruby Lee | 65 | 42 | 67 | 51 | 83 | 52 | 29 | 25 | 52 | 53 | 25 |
| OGI | Stardust | - | - | - | 70 | 81 | 70 | - | - | - | - | - |
| Syngenta | SY Drifter | - | - | - | 63 | 72 | - | - | - | 69 | 50 | 24 |
| Syngenta | SY Flint | 87 | 46 | 47 | 69 | 77 | 54 | 45 | 57 | 63 | 58 | 43 |
| Syngenta | SY Grit | - | - | - | 75 | 89 | - | - | - | - | - | - |
| Syngenta | SY Llano | 75 | - | 44 | 64 | 70 | 46 | 32 | 52 | 37 | 50 | 24 |
| Syngenta | SY Monument | 88 | 40 | 53 | 74 | 83 | 72 | 53 | 62 | - | - | - |
| Syngenta | SY Razor | - | - | - | 77 | 76 | - | - | - | - | - | - |
| Syngenta | SY Wolf | - | 50 | - | - | - | - | - | - | - | - | - |
| LCS | T158 | - | - | - | 67 | 87 | - | - | - | - | - | 37 |
| Watley | TAM 112 | - | 36 | - | 43 | 83 | - | - | - | - | - | - |
| AGSECO | TAM 114 | - | 38 | - | 75 | 90 | - | - | - | - | - | - |
| Watley | TAM 204 | 91 | 62 | 64 | 70 | 85 | 82 | 31 | 45 | 75 | 60 | 31 |
| KWA | Tatanka | - | - | - | 71 | 84 | - | - | - | - | - | - |
| WestBred | WB4303 | - | - | - | 70 | 90 | - | - | - | - | - | - |
| WestBred | WB4458 | 88 | - | 59 | 73 | 84 | 76 | 38 | 51 | 62 | 50 | 27 |
| WestBred | WB4515 | - | - | - | 65 | 76 | - | - | - | - | - | - |
| WestBred | WB4721 | - | - | - | 78 | 85 | - | - | - | - | - | - |
| WestBred | WB-Cedar | 64 | 45 | 41 | 67 | 74 | 65 | 43 | 47 | 48 | 55 | 26 |
| WestBred | WB-Grainfield | 93 | 82 | 50 | 71 | 82 | 81 | 50 | 59 | 74 | 58 | 27 |
| WestBred | Winterhawk | - | 54 | - | 66 | 79 | - | - | - | - | - | - |
| KWA | Zenda | - | - | - | 80 | 82 | - | - | - | - | - | - |
| **OSU Experimentals** | | - | | | | | | | | | | |
| | OK09915C-1 | 77 | 50 | 49 | 66 | 71 | 70 | 47 | 48 | 66 | 57 | 41 |
| | OK10126 | - | - | 55 | - | - | 81 | - | - | - | - | - |
| | OK1059060-3 | - | - | 52 | - | - | 78 | - | - | - | - | - |
| | OK11231 | - | - | - | 53 | 66 | - | 29 | 40 | - | - | - |
| | OK118036R/W | - | 50 | - | - | - | - | - | - | - | - | - |
| | OK11D25056 | - | - | - | 74 | 83 | - | - | - | 75 | 60 | - |
| | OK12621 | - | - | - | - | - | - | 51 | 56 | - | 61 | - |
| | OK12716R/W | 84 | - | 50 | 73 | 88 | 68 | 50 | 59 | - | 72 | - |
| | OK12912C | 79 | - | 48 | 69 | 75 | 80 | 45 | 51 | - | 49 | - |
| | OK12DP22002-042 | - | 53 | - | - | - | - | - | - | - | - | - |
| **Mean** | | **81** | **51** | **52** | **66** | **80** | **68** | **42** | **48** | **67** | **58** | **32** |
| **Least significant difference (0.05)** | | **11** | **14** | **10** | **8** | **7** | **11** | **8** | **7** | **12** | **8** | **7** |

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