Partners in Progress
WHEAT

Wheat Research at OSU 2017

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-1050

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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 Oklahoma Cooperative Extension Service 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 2016-2017. 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.

Working Steadfast, Moving Ahead

Partners in Progress WHEAT

In previous publications of *Partners in Progress* I have expressed the importance of the steadfast work provided by our Wheat Improvement Team at OSU. The 2017 wheat harvest is complete, and the OSU variety trial yield data has been collected and recorded. The continual addition of wheat varieties being made available to the general public makes following this data more important each year as growing environments and weather conditions tend to change.

To address this need, the OSU Small Grains Variety Testing Program evaluates yield potential and quality characteristics of approximately 20 commercially released wheat cultivars and two to four candidate cultivars at approximately 19 locations throughout Oklahoma. In addition, the program evaluates 40 to 50 cultivars and experimental lines at five regional test sites to ensure that statewide tests are filled with the best adapted cultivars. Data collected includes grain yield, disease resistance, response to fungicide application, adaptability to no-till production systems, high temperature sensitivity to germination, plant height, first hollow stem and heading data.

This year we are proud of three new variety releases out of the OSU public wheat research program which include, Smith's Gold, Spirit Rider and Lonerider. Each one of these varieties satisfies the critical need with end quality characteristics any miller or baker would be eager to work with. When it comes to dough strength and higher protein contents, the WIT continues to focus on these important aspects that buyers are looking for. We also continue to focus on **Graze*n*Grain** systems with many of our varieties. You will find more discussion about these new varieties on page 34.

The release of new varieties with different available attributes continues to make us more competitive in the marketplace, not only with yield benefits, but also with quality. The importance of creating varieties for maximum yield potential to make the producer more profitable is the main goal. However, it is also important to note the technologies funded to help release varieties focusing on better end-use value for the milling and baking industries. End-use quality attributes are highly regarded by selections released through the OSU breeding program. This is extremely important when focusing on consumer needs.

With the breeding program at OSU, we examine and study the end-use quality characteristics beneficial to our foreign and domestic customers. Therefore, we are working to capture more market share for the farmer using varieties created with our breeding program. Quality starts with the seed placed into the soil. To have a good product for the end game we must remember good quality also has to start from the beginning. We encourage soil testing that is available through your local county Extension office. We also encourage producers to look at the importance of nitrogen applications for increased protein levels. Exporters and domestic grain companies are looking for higher protein wheat that has better attributes for baking. By focusing on some of these factors in an operation, it can help ensure good decisions are being made to deliver high-quality wheat. The OWC and the OWRF, along with OSU's WIT and DASNR, continues to work on items beneficial to both the producer and the buyer. We move ahead by making great strides with the wheat research and Extension program at OSU, and want to thank the producers for the support to keep these programs at the front of technology discovery and transfer. The OSU WIT prepares for planting by spending numerous hours on research with sustained effort. The WIT is motivated by desire, with a determination and commitment to excellence, in pursuit of making our wheat producers successful, and therefore 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

2016-2017 progress made possible through OWRF/OWC support

- Claimed the top six varieties for planted acreage in Oklahoma, according to an OWC-sponsored survey conducted by USDA-NASS in 2017 (WIT).
- Released three hard red winter varieties as an upgrade for Gallagher (Smith's Gold), an intensive-management option for northern Oklahoma with commensurate standability (Spirit Rider) and a proven high-yielding solution for areas the WIT infrequently reaches, the western Plains (Lonerider) (WIT).
- Placed these candidates under preliminary or extended seed increase by Oklahoma Foundation Seed Stocks (WIT), five of which provide at minimum moderate resistance to wheat streak mosaic and 16 are moderately resistant or resistant to four of the six diseases most frequently evaluated since 2014 (stripe rust, leaf rust, tan spot, powdery mildew, wheat soil-borne mosaic, or WSBM and wheat spindle streak mosaic, or WSSM) (Carver, Hunger).

OK12716	OK Rising/OK98G508W-2-49
OK13209	OK Bullet/TX00D1390//Shocker
OK12DP22004-016	Everest/OK08328//OK09634
OK13621	Billings/TX00D1390
OK12206-127206-2	Y98-912/OK00611W//OK03716W
OCW05S616T-2	Babax+Lr42/Fannin//KS00F5-11-2
OK13P016	Billings/Duster
OK14319	NE01533/OK02125//Duster
OK13625	Billings/Fannin sib
OK14P212	OK01307/Duster//OK06822W
OK168512	Overley+/Fuller//2*CSU exptl.
OK168513	Overley+/Fuller//2*CSU exptl.
OK12612	N02Y5078/OK05741W
OK11P139	TX94V6920/TAM 303//OK Bullet
OK12912C-138407-2	N91D2308-13/OK03926C//OK03928C
OK128084C	N91D2308-13/OK04902C//OK05907C
OK11709W-139122-1	OK02523W/OK00608W//OK00611W
OCW04S717T-6W	CIMMYT seln/KS exptl.//KS91W047

- Reported consistently good quality attributes for TAM 114 and Ruby Lee and relatively poor bread baking potential for LCS Wizard and TAM 204, following complete end-use quality analysis of the 2016 wheat variety performance tests (Marburger, Carver).
- Evaluated 1,443 wheat experimental lines for field reaction to the wheat soil-borne mosaic/wheat spindle streak mosaic complex, of which 45 percent originated with WIT and the remainder from USDA-ARS cooperative nurseries, WIT collaborators in eastern Europe and from private industry (Hunger).
- Added a second layer of disease evaluation to the 652 WIT lines pre-designated for WSBM/WSSM screening, by testing further for leaf rust, powdery mildew and tan spot seedling reactions, and to differentiate between WSBM versus WSSM susceptibility (Hunger).
- Conducted first-time evaluation of advanced WIT lines for reaction to leaf rust in both seedling and adult plant stages, allowing detection of a form of resistance that was heretofore unobtainable without significant and timely field infections of leaf rust.

- Procured novel wheat germplasm from across the globe, including research partners in Hungary, Romania and Turkey (Hunger, Carver).
- Determined tan spot appears consistently earlier in Oklahoma wheat fields than Septoria/Stagonospora leaf and glume blotch, with localized distribution of tan spot isolates, extensive long-distance movement of inoculum and frequent genetic recombination (Hunger).
- Discovered a new and highly effective powdery mildew resistance gene, *Pm59*, with flanking molecular markers to facilitate introgression into WIT germplasm (Xu).
- Developed a new bird cherry-oat aphid, or BCOA, screening protocol, independent of the protocol developed by WIT members Giles and Zarrabi, to discover two new accessions with exceptional BCOA resistance (Xu).
- Validated rearing procedures for BCOA colonies to ensure reliable phenotyping results for germplasm evaluation and selection (Giles, Zarrabi).
- Confirmed tolerance to BCOA feeding in two F_5 populations from the OSU variety development pipeline, clearing the way for subsequent yield and quality testing of OSU's first set of experimental lines selected directly for BCOA resistance (Giles, Zarrabi).
- Discovered a potentially novel greenbug resistance gene, *Gb595379*, resident to a Kansas experimental line which offers wider resistance to greenbug biotypes than genes currently deployed (Xu).
- Discovered dinucleotide DNA (GA)n repeats present among genes in the leaf development pathway, a feature that may be used to develop genome-wide markers for functional genes controlling leaf size in wheat breeding populations (Yan).
- Developed a single primer set designed to amplify individual *SBEII-A, SBEII-B* and *SBEII-D* genes to accelerate breeding of high-amylose wheat with improved dietary fiber content (Yan, Powers).
- Identified, through genome-wide functional gene analysis, genes on chromosome 1BS and genes in the genomic region between 594 and 596.5 million basepairs of chromosome 3B may be worthy selection targets for improving yield under drought stress (Chen).
- Discovered promising reliability for a genomic selection strategy targeting sedimentation volume adjusted for protein content, with even greater reliability than protein content itself (Chen).
- Discovered a wide range of genetic variability in the OSU variety development pipeline to tolerate conditions of nitrogen stress (Arnall).
- Demonstrated candidate variety OK13209 to maintain relatively higher wheat protein levels even under significant nitrogen stress (Arnall, Carver).
- Provided stakeholders first-hollow-stem projections throughout Oklahoma generated by the web-based first-hollow-stem estimator tool located on the Oklahoma Mesonet Ag Weather page, as well as nine updates on current first-hollow-stem measurements collected at three Oklahoma sites (Marburger).
- Increased WIT web-based and social media presence, with team websites and social media receiving about 500,000 hits last year (Marburger).
- Conducted more than 30 wheat variety tours for over 600 attendees, providing stakeholders with current information on released and candidate varieties (Marburger).
- Evaluated 17 fungicide x fungicide rate combinations for control of wheat foliar diseases in field trials (Hunger).
- Provided in-season wheat disease updates to wheat growers, consultants, Extension educators and researchers via an electronic format (Hunger).
- Confirmed absence of Karnal bunt in 26 Oklahoma wheat grain samples to allow Oklahoma wheat to move without restriction into the export market (Hunger).

After 19 years of uninterrupted service, WIT is one of the longest-running research teams serving 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 came in the form of HRW wheat varieties, either as an upgrade for Gallagher (Smith's Gold), or an intensive-management option for northern Oklahoma with commensurate standability (Spirit Rider), or a proven high-yielding solution for areas the WIT infrequently reaches, the western Plains (Lonerider).

WIT scientists who received funding from the OWRF in 2016-2017 and reported their findings were **David Marburger**, information exchange; **Bob Hunger**, wheat pathology research and development of disease-resistant germplasm; **Xiangyang Xu**, pest resistance discovery and introgression; **Kris Giles**, bird cherry-oat aphid, or BCOA, resistance discovery; **Charles Chen** and **Liuling Yan**, gene discovery and genomic technology; **Brian Arnall**, nitrogen-use efficiency; 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 leaf rust and BCOA, plus a much needed boost in better selection protocols for adult-plant leaf rust 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 then eventually manipulated through a process called genomic selection. WIT broke ground with this technology for yield in 2016; this year attention on yield was maintained while opening a new door on quality traits.

Locally adapted germplasm with BCOA or WSM resistance is in the hands of WIT scientists; making this germplasm commercial-ready is achievable and all that lies ahead. WIT has also 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 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
Plant and Soil Sciences

Year in and year out, WIT is committed to providing timely information to stakeholders in

Oklahoma and across the southern Great Plains. During spring 2017, more than 30 wheat variety tours were held across the state with over 600 in attendance. These tours provided producers with the most current information about wheat varieties and their characteristics, as well as showcasing advanced experimental lines in the pipeline. Additionally, WIT has worked to significantly increase its web-based and social media efforts over the past few years. Since its creation in late 2012, the blog osuwheat.com has been used to deliver technical information and updates in a concise, timely manner. In five years, the site has generated more than 89,400 page views from over 54,300 visitors, with 11,900 of those views coming from clientele outside the United States. Views totaled 14,593 in 2016-2017 alone. Other information outlets included the wheat.okstate.edu website with 20,291 page views, YouTube channel, Facebook page with 51,050 reaches, and a Twitter account (@OSU_smallgrains) with 297,324 impressions. Other WIT members provide an additional web presence via their own pages and Twitter accounts, such as the one managed by Arnall, @OSU_NPK and Carver, @osuwit.

The first-hollow-stem estimator developed for the Oklahoma Mesonet in 2014 has been a success. This online tool, found in the Agriculture section at the site 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

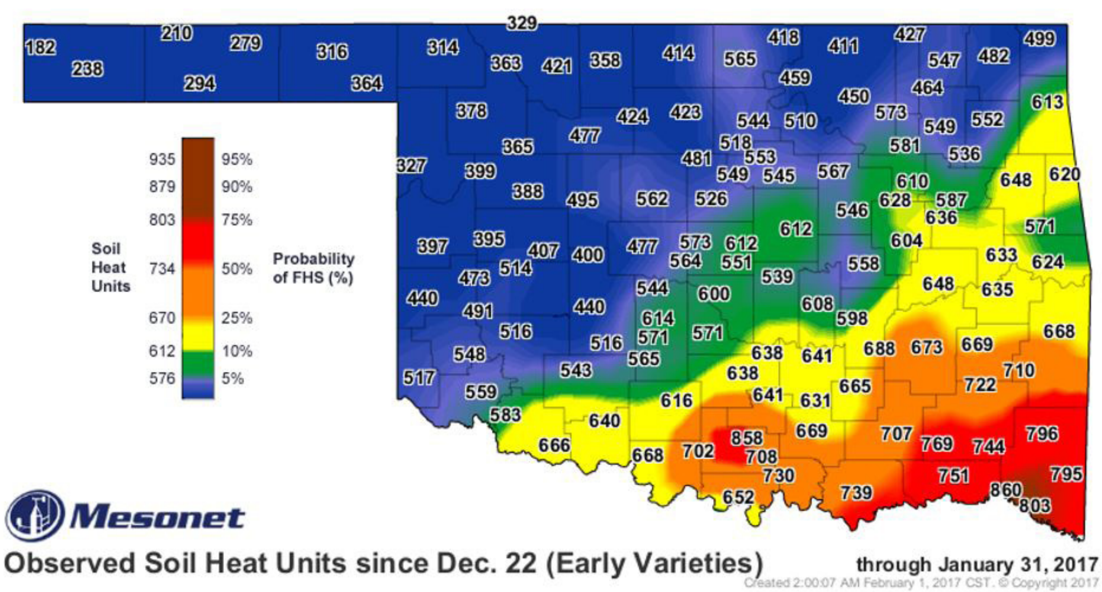

Figure 1. Screenshot of the Oklahoma Mesonet first-hollow-stem estimator as found on Jan. 31, 2017, indicating moderate to very low probabilities of the first-hollow-stem growth stage occurring for early-classified varieties in Oklahoma wheat fields, with moderate probabilities occurring approximately two weeks earlier than normal.

variety performance tests, the estimator allows Oklahoma wheat producers to make well-informed and timely decisions for removing cattle from wheat pastures. This tool proved to be invaluable this past year as this critical growth stage for cattle removal was reached approximately two weeks earlier than normal for many producers across the state.

Fourteen 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 three experimental lines OK10126, OK11D25056 and OK12DP22002-042 as Spirit Rider, Smith's Gold and Lonerider, respectively, in spring 2017. In addition to collecting valuable information for experimental lines, the team increased its knowledge of leaf rust susceptibility and resistance among current varieties. While stripe rust was the predominant disease for the past two years, leaf rust was the key disease in 2017. The presence of leaf rust during 2017 was abnormal compared to previous years as it developed sooner and persisted through grain fill, while also reaching a wider geographic area. 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 leaf rust reaction were a driver of yield differences statewide in 2017, as shown in Table 1. However, it was not the only driver, as statewide yield of Bentley was no different than Gallagher, though Gallagher is known to have much stronger resistance to leaf rust. Likewise, the mean yield of Duster was intermediate, even though its 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,

Table 1. Mean yield and leaf rust ratings for 12 wheat varieties tested at all sites in the 2016-2017 Oklahoma wheat variety performance tests.

Developer	*Variety*	*Grain yield*[a] bu/ac	*Leaf rust rating*[b]
WestBred	WB-Grainfield	52 a	S
OSU	Iba	50 b	I
OSU	Gallagher	49 bc	R
OSU	Doublestop CL Plus	48 bc	R
Limagrain Cereal Seeds	LCS Chrome	48 bc	MR
OSU	Ruby Lee	48 bc	I
OSU	Bentley	47 cd	S
OSU	Duster	47 cd	R
Limagrain Cereal Seeds	LCS Pistol	45 de	MS
Texas AgriLife	TAM 204	44 e	MS
OSU	Endurance	44 e	MR
Colorado State Univ.	LCS Mint	41 f	S

[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 2017. R=resistant; MR=moderately resistant, I=intermediate; MS=moderately susceptible; S=susceptible.

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 3,900 times during summer 2017 with over 10,200 individual page views. The print version of the small grains variety performance tests was published in mid-July and distributed to more than 8,000 *High Plains Journal* subscribers throughout Oklahoma and the southern Great Plains.

Subsamples from the wheat variety performance tests were measured for grain protein, and for the first time, results were posted within a couple days after analysis during summer 2017. 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 2017, grain subsamples from the Lahoma and Chickasha locations were again saved for milling and flour quality analysis, and these results will be published in 2018. 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

An important component to developing improved OSU wheat varieties is knowing their reaction to common diseases in Oklahoma. Diseases evaluated in 2017 included the wheat soil-borne mosaic/wheat spindle streak mosaic, or WSBM/WSSM, complex, leaf rust, powdery mildew, tan spot and barley yellow dwarf, or BYD. Table 2 presents the number of lines evaluated for reaction to these diseases over the last nine years, and Table 3 presents the number of lines evaluated from 1983 through 2017.

Field evaluations, such as those done routinely for the WSBM/WSSM complex, provide the most reliable indication of disease reaction. However, given the large number of lines in the OSU wheat breeding program, evaluation of lines in greenhouse/growth chamber, or GH/GC, settings allows for testing of many more lines than possible in the field. Additionally, evaluation in a GH/GC setting allows for consistent and reliable disease pressure and presence, which can be lacking in the field. A combination of field and GH/GC evaluations is used to determine the most complete assessment of a disease reaction. Such evaluations would not be possible without funds provided by the OWRF.

OWRF funding also allowed for expansion of disease evaluations, including attempting to establish field nurseries to determine reactions to tan spot and Septoria tritici blotch, or STB, and developing a post-vernalization GH/GC test to identify adult plant resistance to leaf rust.

While tan spot reactions in a GH/GC setting have been informative and facilitates identification of lines with resistance, field evaluation would serve to confirm the GH/GC testing. Additionally, evaluating for reaction STB in a GH/GC setting has not

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

		Disease[a]						
Year	*Testing location*	*WSBM/WSSM*	*LR*	*YR*	*PM*	*TS*	*STB*	*BYD*
2009	Field	1,500						
	GH/GC[b]		400		400	400		
2010	Field	1,500						
	GH/GC		400		400	400	400	
2011	Field	1,400						
	GH/GC		324		67	262	262	
2012	Field	1,030			65			573
	GH/GC		427		618	170	105	
2013	Field	2,410			197	95		150
	GH/GC		347		150	277	277	
2014	Field	1,700			21		705	
	GH/GC		466		141	411		
2015	Field	1,500					75	160
	GH/GC		385		115	385		
2016	Field	1,421		385			145	145
	GH/GC		385			385		
2017	Field	1,523						
	GH/GC		331		331	331		
Total	Field & GH/GC evaluations	13,984	3,465	385	2,484	3,137	1,595	2,064

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

proven reliable because infection of known control varieties and lines has not been sufficiently consistent. Over the last several years, efforts have been made to establish field nurseries to evaluate the reaction of advanced lines to these leaf spotting diseases. To date, disease in these field nurseries has not been sufficient to result in a reliable evaluation for either disease. However, efforts will continue and use of supplemental watering will be used to enhance disease in the spring.

Expansion also occurred this past year with evaluation of advanced lines for reaction to leaf rust as seedlings and as adult plants (post-vernalization). Results of this testing are presented in Table 4. Six lines appear to have adult plant resistance to leaf rust as indicated by a susceptible reaction in the seedling test and a moderately resistant to resistant reaction in the adult plant test. Testing for adult plant resistance is being expanded this year to confirm that this offers a viable procedure to identify lines with adult plant resistance to leaf rust.

Since 2011, novel wheat germplasm has been formally exchanged under material transfer agreement with national wheat breeding programs in

Table 3. Summary of experimental lines evaluated for reaction to specific diseases from 1983 through 2017. Data do not include ratings collected in breeder trials or Extension trials.

Disease	*Year evaluations started*	*Evaluation location*[a]	*Number of lines evalated*
WSBM/WSSM[b]	1983	GH/GC	500
		Field	34,461
Leaf rust	1983	GH/GC	21,691
		Field	3,500
Powdery mildew	2000	GH/GC	2,845
	2011	Field	670
Tan spot	2003	GH/GC	2,986
	2014	Field	45
Septoria tritici blotch	2004	GH/GC	1,200
	2014	Field	215
Barley yellow dwarf	2011	GH/GC	0
		Field	505
Spot blotch/common root rot	2014	GH/GC	25
		Field	0
Total	1983-2017	GH/GC	29,247
		Field	39,396
	1983-2017	GH/GC + field	68,643

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

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

Hungary and Romania. Typically, five to 10 advanced lines are obtained from each country with an equivalent number from OSU provided to them. After appropriate quarantine mandated by the USDA-APHIS-PPQ, this germplasm is used in crossing with wheat lines adapted to Oklahoma with the purpose of introgressing novel and useful traits into OSU's wheat variety development pipeline. A similar program was restarted with Turkey in 2017. Expansion of OSU germplasm in this manner is a constant and necessary goal.

A similar effort is being made to develop wheat varieties with improved resistance to wheat streak mosaic, or WSM. This virus disease can be devastating to wheat, as observed throughout the central and northwestern U.S. in 2017. Cultural control methods, including elimination of volunteer wheat for at least two weeks before seedling wheat emerges and a later planting date, can be moderately effective in managing WSM. Relatively few HRW varieties are currently adapted to the central plains, which have moderately effective resistance to either the virus or to the wheat curl mite that transmits the virus, plus possess the expected level of end-use quality. WIT efforts to accelerate incorporation of resistance to WSM and its mite vector have intensified during the last several years , as will be elaborated in Carver's report.

A survey conducted in 2016 showed the incidence of tan spot, caused by the fungus *Pyrenophora tritici-repentis*, was greater than the incidence of leaf spots caused by the fungi *Septoria* and *Stagonospora* (Figure 2). Subsequent research evaluated the

Table 4. Comparison of seedling versus adult plant testing for reaction to leaf rust. Entries in bold indicate likely adult plant resistance.

Entry	*Seedling rating (pre-vernalization)*	*Adult plant rating (post-vernalization)*
Chisholm	S	S
Duster	R	R
Gallagher	MR	R
Iba	R	R
Doublestop CL+	S	S
Bentley	R	R
SY Monument	MR	R
Stardust	S	S
OK12716	S/MS	S
Smith's Gold	**MS**	**MR**
OK11D25005	MS	S
Lonerider	R	R
OK12D22004-016	MS/MR	R
OK13209	R	R
OK128084C	S	S
OK12912C-138407-2	**S**	**R**
OK11P139	MS/MR	R
OK11208	**S**	**MR**
OK12621-138232-2	**S**	**R**
OK11999W-139144-6W	MR/MS	MR
OK11755W-139129-3W	S	MS
OK11709W-139122-1W	R	R
OCW04S717T-6W	R	R
OK12206-127206-2	**MS**	**MR**
OK13621	MR	R
OK12D22002-077	**MS/S (segregating)**	**R**
OK13P803W	S	S
OK13P016	MR	R
OK11625-128226-2	MS/MR	S
OK14319	R	R

genetic relatedness between isolates of *P. tritici-repentis* collected from different fields. Results indicate there is a low but significant genetic differentiation among field populations (Figure 3). This suggests local distribution of isolates, extensive long distance movement of inoculum and frequent genetic recombination. This information has implications to the epidemiology of these leaf spotting diseases, but more importantly, lays a foundation for working with the toxins produced by *P. tritici-repentis* and evaluating for resistance to tan spot. That work currently is underway.

Fungicides were evaluated again in 2017 for their efficacy in wheat foliar disease management in Oklahoma, though powdery mildew was the only disease at sufficient levels to be rated (Table 5). Fungicide testing was

FIELD	LOCATION	PTR LIKE	PYCNIDIA	SINGLE SPORE PTR ISOLATES	MOLECULAR ID PTR ISOLATES
A	Altus	62	58	51	43
B	Apache	90	11	78	63
C	Scheiber	51	5	46	21
D	Talala	31	2	30	0
E	Pawnee	4	8	4	1
F	Stillwater	57	19	50	39
G	Kildare	44	50	36	18
H	Walters	21	6	17	11
I	Olustee	40	-	40	34
J	Alva	68	7	47	41
K	Afton	17	1	15	9
L	Banner Road	17	3	16	12
M	Lahoma	63	-	47	19
TOTAL		565	190	477	311

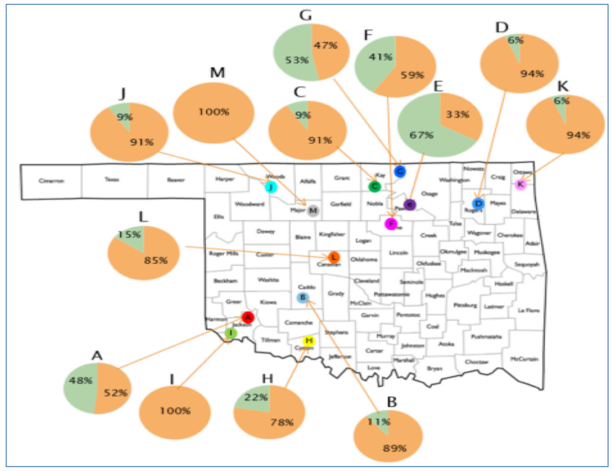

Figure 2. Occurrence of tan spot (PTR) and pycnidial (most likely Septoria/Stagonospora) isolates obtained during spring 2016 from Oklahoma wheat fields (mostly no-till fields).

A	B	C	F	G	H	I	J	L	M	
0.000										A
0.049	**0.000**									B
0.068	0.087	**0.000**								C
0.008	0.070	0.063	**0.000**							F
0.094	0.099	0.036	0.063	**0.000**						G
0.059	0.072	0.026	0.076	0.031	**0.000**					H
0.069	0.068	0.042	0.062	0.040	0.000	**0.000**				I
0.033	0.052	0.053	0.051	0.052	0.047	0.009	**0.000**			J
0.021	0.047	0.029	0.050	0.064	0.032	0.062	0.055	**0.000**		L
0.031	0.042	0.044	0.076	0.084	0.031	0.010	0.032	0.040	**0.000**	M

Stat	Range	Differentiation
PhiPT	>0.05	Not significative
PhiPT	0.05 - 0.15	Low
PhiPT	0.15 - 0.25	Moderate
PhiPT	0.25 - 1	High

Figure 3. Genetic relationship between isolates of the tan spot fungus isolated from different fields (different colors) in Oklahoma. Field identification is consistent with Figure 2. Combinations highlighted in light tan indicate populations from different fields that show low but significant genetic differentiation.

conducted near Stillwater using the variety Ruby Lee, which is susceptible to powdery mildew, stripe rust and leaf rust but resistant to the WSBM/WSSM complex. Rainfall was abundant during July through October (15.15 inches). November through December was much drier (1.27 inches), but the rainfall prior to November was sufficient to sustain the wheat in this trial. Moisture was plentiful through the subsequent winter and spring, with 19.22 inches falling during January through April (9.94 inches in April). Harvest in June was not impeded by wet conditions, but storms in April and May led to severe lodging that impacted yield across the trial. Symptoms indicative of BYD were scattered in the trial but no stunting was observed, so this disease likely did not impact yield to a significant extent. Powdery mildew was the primary disease and was observed on lower to middle leaves in mid-March through mid-April, reaching a severity of nearly 80 percent. Stripe rust and leaf rust, although severe across much of Oklahoma (especially leaf rust), did not reach a ratable level in this trial.

No indication of phytotoxicity by any fungicide treatment was observed. Yield varied from 33 bushels per acre (nontreated check) to 42 bushels per acre, and test weight varied from 58

Table 5. Effect of foliar fungicides on severity of powdery mildew, or PM, yield and test weight, or TW, of Ruby Lee wheat in Stillwater for 2016-17.

Treatment number Fungicide[a]; rate	*GS applied[b]*	*Date applied*	*PM (%)[c] March 28*	*PM (%)[c] April 12*	*Yield (bu/A)*	*TW (lb/bu)*
1 Not-sprayed check	---	---	29	73	33	60
2 Tilt; 4 oz/A	10.5	April 11	29	76	36	60
3 Folicur (generic); 4 oz/ A	10.5	April 11	26	63	38	60
4 Quadris; 8 oz/ A	10.5	April 11	33	76	37	60
5 Trivapro; 9 oz/ A FB[d] Miravis; 11.5 oz/ A	6 FB 10.5	March 10 FB April 11	3	36	42	60
6 Priaxor; 2 oz/ A FB Nexicor; 7 oz/ A	6 FB 10.5	March 10 FB April 11	9	43	40	60
7 Nexicor; 3.5 oz/ A FB Nexicor; 7 oz/ A	6 FB 10.5	March 10 FB April 11	1	13	40	58
8 Aproach @ 3 oz/ A FB Aproach Prima 6.8 oz/ A	6 FB 10.5	March 10 FB April 11	2	21	41	59
9 Nexicor; 9 oz/ A	10.5	April 11	30	65	38	60
10 Aproach Prima; 6.8 oz/ A	10.5	April 11	33	63	38	60
11 Aproach; 6 oz/ A	10.5	April 11	29	70	38	60
12 Trivapro; 13.7 oz/ A	10.5	April 11	29	63	39	60
13 Alto; 4 oz/ A	10.5	April 11	26	76	36	60
14 Absolute Maxx; 4 oz/ A	10.5	April 11	29	69	37	60
15 Absolute Maxx; 5 oz/ A	10.5	April 11	30	65	36	60
16 Prosaro 421 SC; 5 oz/ A	10.5	April 11	30	63	37	60
17 Prosaro 421 SC; 6.5 oz/ A	10.5	April 11	30	76	37	59
LSD (*P*=0.05)			11	17	2	1

[a] Plus 0.125% Induce (volume by volume) for treatments 14-17; plus 0.25% Induce (volume by volume) for treatments 5-13.

[b] GS=Growth Stage. Reported according to Feekes' scale, where GS 6=first node detectable at base of main tiller; GS 10.5=heads completely emerged but not yet flowering.

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

d FB=followed by.

to 60 pounds per bushel. These results indicate a significant yield increase was obtained following fungicide treatment in a year when disease pressure was limited almost exclusively to early season powdery mildew. Additionally, highest yields were associated with treatments receiving two fungicide applications (numbers 5 to 8 in Table 5), with the first application being in the early season, followed by a second application when heads were fully emerged. However, the average yield increase for applying fungicide twice compared to a single application at heading was 3.5 bushels per acre. This yield increase, although statistically significant, is just approaching the breakeven point when the price of wheat is at $4 per bushel. If only generic fungicides are used, which are substantially less expensive, two applications should be considered.

Finally, timely electronic updates on the status of wheat diseases were provided to wheat producers, Extension educators and others involved with wheat. The 2017 Oklahoma wheat crop was tested for the presence of Karnal bunt. Results from 26 samples in 12 counties were used to certify that 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.

Pest Resistance Discovery and Introgression

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USDA-ARS
Wheat, Peanut and Other Field Crops Research Unit

This part of WIT is dedicated to using multiple tools from several disciplines, including wheat pathology, wheat entomology, molecular genetics and wheat pre-breeding, to diversify and fortify the germplasm base on which WIT's variety development pipeline depends.

Novel Bird Cherry-oat Aphid resistance sources

A primary challenge for breeding BOCA-resistant cultivars is that traditional aphid screening methods cannot be used. A new BCOA screening protocol was developed that differs slightly from the one described by Giles and Zarrabi. Using large cages to ensure continuous infestation, a key reaction parameter is the interval between infestation and initiation to wilt signified by IIW. In the experimental population TA3516/Bainong418, heritability was estimated to be 73 percent, exceeding other parameters reported in the literature (16 to 37 percent). The hypothesis is that IIW represents the combined effects of antibiosis, antixenosis and tolerance, and can be used as a surrogate for these resistance components in wheat breeding.

Thus, IIW was used further to evaluate BCOA reaction in over 4,000 wheat accessions from worldwide collections, varying from 14 to 36 days after infestation. Two landraces, Osiris and Ghund Hosa, still grew well when experiments were terminated at 36 DAI. Thus, both are good candidates as novel BCOA resistance sources. Osiris and Ghund Hosa will be mated to create a mapping population of sister lines suitable for QTL analysis of IIW and ultimately gene discovery for IIW.

From BCOA to other aphids

With the support of OWRF, several novel biotic stress resistance genes were identified: *Gb595379* for greenbug resistance, *Dn10* for Russian wheat aphid, or RWA, resistance and *Pm59* for powdery mildew resistance. *Gb595379* was discovered in a reselection from KS95WGRC33 (PI 595379), a publicly available experimental line with the pedigree KS93U69*2/TA2397 exhibiting high resistance to greenbug biotype E. TA 2397 is an *Aegilops tauschii* Coss accession collected near Sisiar in Afghanistan. WIT subsequently mapped *Gb595379* on the long arm of chromosome 7DL (Figure 4).

Greenbug resistance genes *Gb3* and *Gb7* were previously mapped on 7DL, with estimated genetic distances of 8.9 and 29.8 centimorgans to Gb595379, respectively (Figure 4). Previous studies also suggested that *Gb3* and *Gb7* confer resistance to greenbug biotype E. Thus,

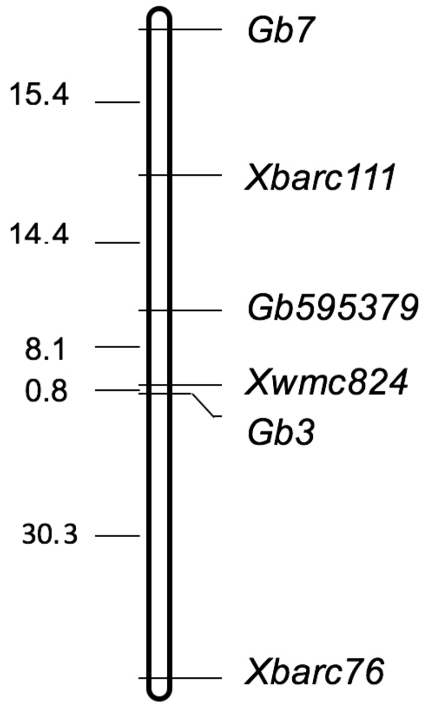

Figure 4. A linkage map of chromosome 7DL containing genes *Gb595379, Gb3* and Gb7. The genomic locations of *Gb3* and *Gb5* were inferred based on previous studies.

WIT used six additional biotypes, B, C, F, G, H and I, to test *Gb595379*, *Gb3* and *Gb7*. Results indicated that biotype B is virulent to *Gb3* and *Gb7*, but avirulent to *Gb595379*, indicating that *Gb595379* is a different gene from *Gb3* or *Gb7*. In addition, *Gb595379* and *Gb3* confer resistance to biotype C which is virulent to *Gb7* (Table 6). In 2018, allelism tests will determine whether *Gb595379* is a novel gene or a new allele of known genes. Fine mapping of the *Gb595379* gene will identify molecular markers that can be more efficiently used in marker-assisted selection for greenbug resistance.

A gene for RWA resistance, *Dn10*, was identified in PI 682675, a single-plant selection from Iranian landrace PI 624151, which exhibits high resistance to RWA biotype 2. In 2017, progeny with the pedigree PI 682675/ Zhengyou 6 were used to map the RWA2 resistance gene in PI 682675. Mapping results indicated that PI 682675 carries a dominant resistance gene, *Dn10*, flanked by SSR markers *Xgwm437* and *Xwmc488* on chromosome 7DL (Figure 5). Physical mapping showed that *Dn10* resides in chromosome bin 7DL 0.1-0.77, whereas *Dn2401* and *Dn616580*, that also confer resistance to RWA2 were physically mapped to the short arm of chromosome 7D, 7DS. Allelism tests suggested that *Dn10* was located about 16.7 cM from *Dn2401* and 20.9 cM from *Dn626580*. *Dn10* is thus a new RWA2 resistance gene that can be used by WIT to replace the rye-derived *Dn7*

Table 6. Responses of greenbug resistance genes Gb585379, Gb3 and Gb7 to greenbug biotypes B, C, F, G, H and I.

Biotype	*Gb595379*	*Gb3* (Largo)	*Gb7* (W7984)	Control (Custer)
B	R[a]	S	S	S
C	R	R	S	S
F	S	S	S	S
G	MR[b]	S	S	S
H	S	S	S	S
I	R	R	R	S

[a] R, MR and S represent resistant, moderately resistant and susceptible reactions, respectively.

[b] Some leaves (mainly first leaves) showed damage when the experiment was terminated. Additional tests are needed to confirm results.

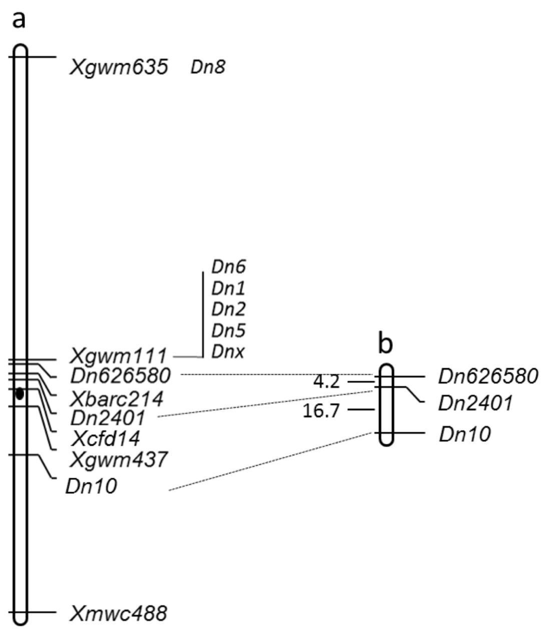

Figure 5. A comparative map of chromosome 7DL containing genes *Dn1, Dn2, Dn5, Dn6, Dn8, DnX, Dn626580, Dn2401* and *Dn10* based on a) literature and mapping results from this study, and b) a map inferred from allelism tests. Currently, only *Dn10, Dn2401, Dn626580* and *Dn7* confer resistance to Russian wheat aphid biotype 2, the dominant and most virulent biotype in the USA.

gene, which is currently present in Oklahoma germplasm but associated with undesirable end-use quality.

In the Great Plains, powdery mildew isolates virulent to resistance genes widely used in this region, such as *Pm3a*, were previously identified. A potentially unique and powerful powdery mildew resistance gene was further characterized in Afghanistan landrace PI 181356 using progeny with the pedigree PI 181356/OK1059060-126135-3. Genetic analysis indicated that PI 181356 carries a new dominant gene, designated *Pm59*, in the terminal region of the long arm of chromosome 7A (Figure 6). *Pm59* was mapped to an interval between sequence tag site markers *Xmag1759* and *Xmag1714*, with genetic distances of 0.4 cM distal to *Xmag1759* and 5.7 cM proximal to *Xmag1714*. Physical mapping suggested that *Pm59* resides in the distal bin 7AL 0.99-1.00 (Figure 6). *Pm59* confers resistance to powdery mildew isolates collected from the Great Plains and the state of Montana, and can be used to breed powdery mildew-resistant cultivars in Oklahoma. *Xmag1759* will be used by WIT to introgress *Pm59* into OSU germplasm.

BCOA Resistance Discovery

Kris Giles
Ali Zarrabi
Entomology and Plant Pathology

A BCOA-phenotyping assay developed specifically for WIT was well described in previous reports and

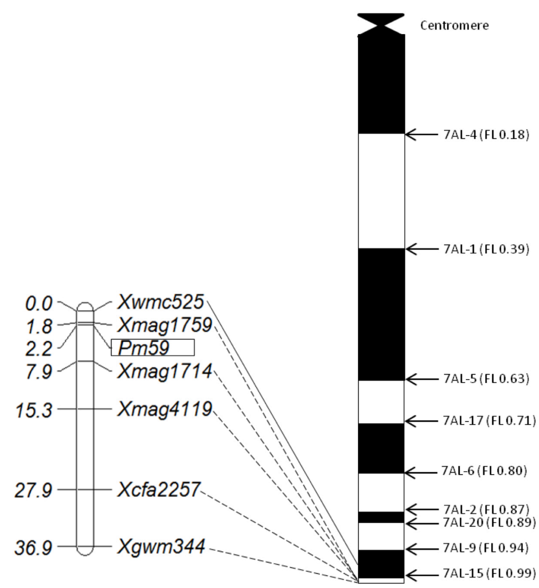

Figure 6. Linkage (left) and physical (right) maps of *Pm59*. Marker names are shown on the right side of the linkage map, and genetic distances in centimorgans on the left side. Each molecular marker flanking *Pm59* is connected to its appropriate physical bin. The breakpoint of each Chinese Spring deletion line is shown with an arrow, and the corresponding fraction length value is given in the corresponding parentheses.

relies on aphid colony sources that most conservatively estimate wheat seedling plant injury. OSU's source colony is produced within environmental chambers at the Controlled Environment Research Lab under crowded plant conditions and high aphid densities that induce significant feeding stress. Aphids from the source colony are small relative to field-collected BCOA, but they feed consistently on source plants.

In 2017, an alternative BCOA colony was established within environmental chambers in an effort to reduce plant and aphid crowding and optimize rearing conditions for this aphid. Aphids from this alternative colony were larger (similar to wild-type aphids), produced significantly more offspring and were demonstrated to initiate more feeding attempts on wheat seedlings. However, despite their smaller size and apparent reduced fitness, aphids from OSU's source colony fed on wheat seedlings for a longer duration, and caused significantly more injury to wheat seedlings. These results are meaningful and validate that our source colony rearing procedures and phenotyping assay allows for the most conservative interpretation of plant injury and identification of resistant germplasm sources.

Also in 2017, 23 segregating F_5 populations were pulled from several hundred F_5 populations in the variety development pipeline to select for plants with the least plant injury following source colony feeding. Six populations were identified with a significant proportion of individual F_5 seedling plants similar to the resistant check. Individual resistant plants were isolated, and results were validated by testing the F_6 progeny of about 10 percent of the selected F_5 resistant plants, totaling 43 F_6 plants. Two OSU populations identified as 162056 055 and 162052 038 were rated at fair to excellent for tolerant resistance compared with the susceptible and resistant checks (Figure 7).

Moving forward, the goal is to advance the most desirable plant selections for subsequent seed increase and field testing, and to use them immediately in crossing schemes designed to improve variety performance in early planted management systems.

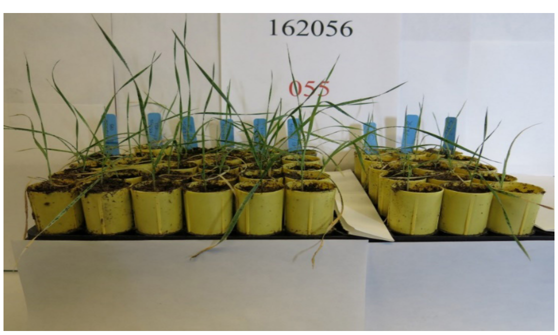

Figure 7. Two segregating populations from the OSU variety development program producing an unusually high frequency of BCOA-tolerant plants. Population on the left is from a complex pedigree featuring CIMMYT and OSU germplasm. Population on the right has the pedigree, KS06O3A~58-2/OK10408//Bentley.

Gene Discovery and Genomic Technology

Liuling Yan
Carol Powers
Plant and Soil Sciences

How can barrelclover help wheat?

Wheat varieties in the southern Plains are often used in a dual-purpose system, requiring production of leaf tissue for cattle grazing before stem elongation and grain development. Larger leaves may produce more biomass for grazing, but even in the absence of grazing, juvenile wheat plants with larger leaves may produce an improved photosynthetic canopy source to more effectively drive the transition from vegetative to reproductive tissue formation in grain-only wheat. The leaves in wheat plants are the primary organs that capture energy from sunlight for photosynthesis, producing carbohydrates that are eventually used, along with other nutrients, for development, growth and reproduction.

The leaf shape of wild-type common wheat is best described as linear, with parallel margins, and elongated. The genetic basis of the leaf shape in wheat is unknown. In the Australian forage crop species *Medicago truncatula*, also called barrelclover or barrel medic, the leaf shape is naturally ovate, or egg-shaped, and wider at the base. This leaf shape is controlled by gene *STENOFOLIA*, or *STF*, a member in the plant-specific *WUSCHEL-related homeobox*, or *WOX*, gene "superfamily." When *STF* is mutated by inserting a transposable element, leaf shape is dramatically altered. Cell proliferation at the adaxial–abaxial boundary is significantly reduced, leading to a major decrease in lateral leaf growth and the disappearance of the marginal serrations on the leaf. Similarly, mutation of *LAM1*, the orthologue of *STF* in tobacco plants, causes leaves to have a narrow, elongated morphology, both resembling the narrow, linear leaves of common wheat.

Given that the loss of *STF* can change wild-type ovate *Medicago* leaves so that they resemble narrow wheat-like leaves, the above findings raise the intriguing question of whether *STF* can be expressed in wheat to produce wider and thus larger leaves in this monocot. We expressed the *STF* gene from *M. truncatula* in the OSU wheat variety, 2174. The most striking difference between the transgenic and non-transgenic siblings was widened leaves, particularly at the juvenile stage (Figure 8A). This finding indicates that the key role of *STF* in the determination of leaf width was maintained when expressed in an unrelated monocot species. In addition, two other traits, flowering time and leaf greenness, were modified in the transgenic (*STF+*) wheat plants.

In an effort to better understand the mechanism for leaf widening in wheat, the transcriptomic and proteomic profiles of *STF+* plants revealed DNA and protein targets of the expressed STF protein. The STF protein was directly bound to the $(GA)_n$ DNA motif present in numerous genes in wheat (Figure 8B). Among the genes known to affect leaf development in wheat, the *KNOTTED1*-type, or *KN1*, homeobox, *KNOX1*, genes (*TaKN1*) and Bell1-type homeobox genes (*TaBEL1*) were indeed found to share the common structural feature of $(GA)_n$ repeats in their proximal promoters or other regulatory regions. In addition, STF protein was found to interact with multiple proteins in wheat, such as

*Ta*SUB1 (Figure 8C). SUB1 in plants is a temperature-sensitive receptor-like kinase that plays a role in coordinating cell proliferation and differentiation during leaf development.

An important message from this study is that the DNA and proteins targeted by *STF* may be involved in leaf development, suggesting a network of genetic and biochemical factors regulating leaf morphology and size. In addition, dinucleotide repeat DNA $(GA)_n$ repeats present among genes in the pathway can be used as genome-wide markers for functional genes controlling leaf size in wheat breeding applications.

It's not all about wheat protein

While wheat gluten gets most of the media attention, the real focus might best be turned to the primary component of wheat flour – starch. The amount and kind of starch present in a wheat kernel is largely determined by the ratio of amylose and amylopectin. Wild-type wheat starch consists of 25 to 30 percent amylose, which is synthesized by granule-bound starch synthase, GBSS, also called the waxy protein, and 70 to 75 percent amylopectin, which is regulated by a series of starch branching enzymes, specifically SBEII. Though wheat flour with reduced amylose content produces higher swelling volumes and high

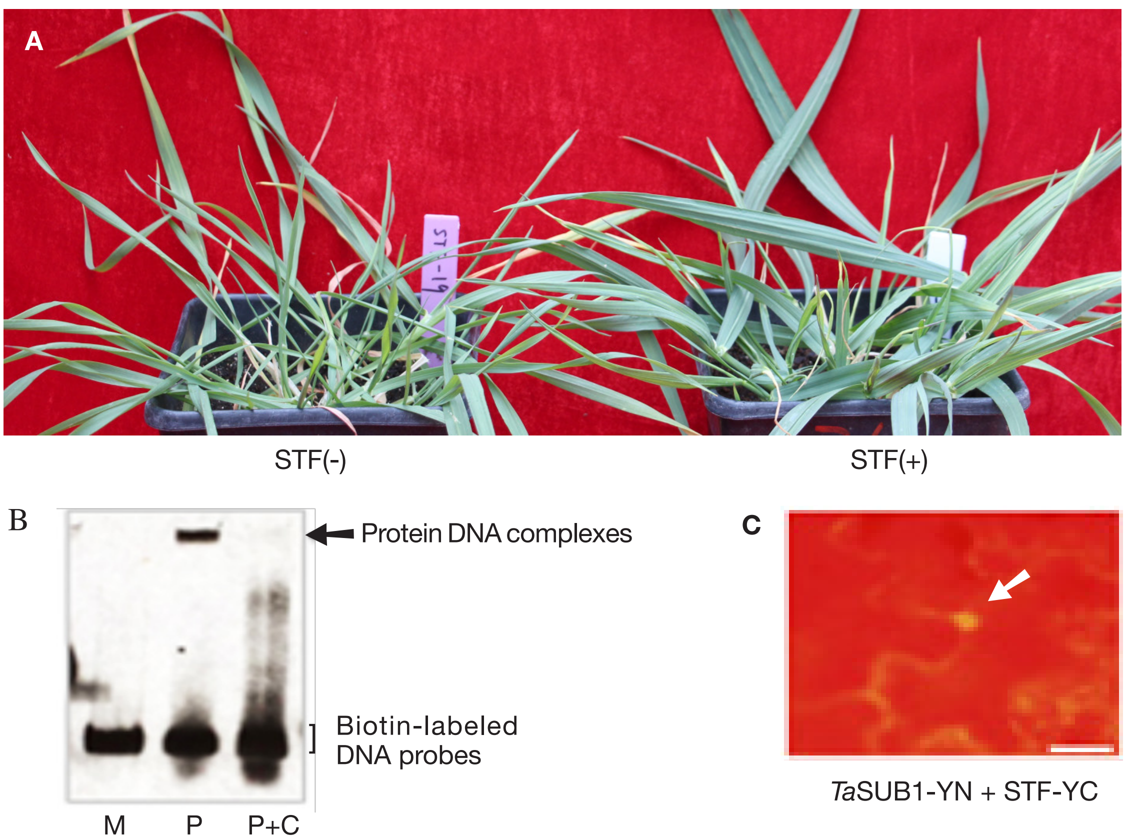

Figure 8. STF in transgenic wheat. (A) Comparison of leaf size in transgenic wheat STF(+) and the wild type STF(-). (B) Interactions of STF protein and $(GA)_n$ DNA motif repeated elements. M indicates a protein VRNA1 with a MBP tag. P indicates the STF protein that was added to EMSA reactions, P+C displays the STF protein and 100X protein competitors that were added to the EMSA reactions. (C) Interactions of STF and SUB proteins. STF in a pEG202-YC vector was transformed with SUB in a pEG201-YN vector into the leaves of *Nicotiana benthamiana* plants.

peak pasting viscosities desirable for improved noodle quality, elevated amylose content is considered a healthier source of starch for the human diet due to an associated increase in dietary fiber content. High-amylose starch is more resistant to hydrolysis, which among other benefits has the potential to reduce risk of colorectal cancer. No commercial wheat variety is available with increased amylose content, but that status may change as private entities pursue patented varieties with non-GM starch compositional changes for commercial wheat production.

In 2013, WIT obtained mutant lines, in which three genes for starch branching enzyme SBEII isoforms, namely *SBEII-A* on chromosome 2A, *SBEII-B* on chromosome 2B, and *SBEII-D* on chromosome 2D, were mutated using a non-transgenic approach. It was reported that amylose content increased about 85 percent in a spring wheat breeding line with the three *SBEII* mutants present. Though progress has been slower than expected, breeding populations were developed since 2013 to introgress all combinations of the *SBEII* genes into a predominately Gallagher background. WIT's ultimate objective is to incorporate the complete set of *SBEII-A, SBEII-B* and *SBEII-D* genes into a single line adapted to the southern Great Plains, but effective and discriminatory markers for all genomes was lacking.

In 2017, multiple sequence alignment revealed specific locations of mutations in *SBEII-A, SBEII-B* and *SBEII-D*, relative to their respective wild-type gene. On the basis of the specific domain of the three homoeologous gene DNA sequences, one primer set has now been designed to amplify individual *SBEII-A, SBEII-B* and *SBEII-D* genes and distinguish between the mutant and the wild type form of each gene. The diagnostic PCR markers will accelerate incorporating these three genes into a single winter wheat line adapted to Oklahoma. Marker-assisted selection has already been initiated in 2017.

Gene cloning – yield and Hessian fly resistance

Among approximately 1,000 Duster x Billings $F_{2:3}$ progenies, 19 families were found to have crossovers in the *QYld.osu-1B* region, a quantitative trait locus, or QTL, associated with a significant yield increase in the population. The recombinant lines were planted in the field in fall 2017 to test grain yield and to genotype six PCR markers in the internal region of *QYld.osu-1B*. Integration of phenotypes and genotypes will greatly reduce the region of *QYld.osu-1B* and eventually provide WIT with a valuable marker tool to select for this QTL.

In the same mapping population, this project identified new crossovers in the *TaHf-A1* region, containing a key Hessian fly resistance gene unique to Duster. Progeny plants of the new recombinant lines were phenotyped for biotype GP resistance, in collaboration with Dr. M. Chen at USDA-ARS, Manhattan. *TaHf-A1* has been narrowed down to a 180 kb region. Candidate genes in the region for *TaHf-A1* will be validated for future deployment in breeding populations.

Genotyping in the VDP

A few molecular markers were used to genotype breeding lines in the OSU VDP in 2017, strictly as a supplement to the primary genotyping work performed by the USDA-ARS Hard Winter Wheat Genotyping Laboratory, Manhattan, Kansas. Local work was dedicated to characterizing 65 Duster-derived lines for *QYld.osu-1B*, but the genotyping results were inconclusive due to imperfect markers and the very large QTL region as mentioned above. Other molecular targets included *Lr34* among 23 DH lines segregating for multiple leaf rust resistance genes, and *SBEII-B* in a F_2 population of 180 plants derived principally from Gallagher.

Discovery and Predictability of Yielding Ability

Charles Chen
Karyn Willyerd
Biochemistry and Molecular Biology

Duster and Billings are two leading winter wheat varieties for both yield and end-use quality in the southern Plains. After intercrossing these two varieties, a DH population of 282 lines was generated hereafter called Buster, providing a segregating population in which genetic mechanisms responsible for important and economic phenotypes can be disclosed in detail. Since the last report in 2016, a new release of the Chinese spring wheat reference genome, IWGSC RefSeq v1.0, was released with annotation details. The previously reported single nucleotide polymorphism, or SNP, dataset for Buster, built from genotyping-by-sequencing and exome capture technologies, was re-anchored and filtered for 50 percent missing data to generate 213,940 SNPs in build Buster_hmp_v1.0. To study the importance of these SNPs for grain yield, genome-wide association studies and QTL mapping were performed to identify genomic regions associated with traits of interest.

Genome-wide association mapping, commonly used to identify SNPs responsible for variation in phenotypes such as yield, revealed the impact of genotype-environment interactions on yield stability. Genetic effects associated with low rainfall totals in 2014 and 2015 growing seasons were demonstrated by similar association profiles, while yield associations in 2016 with more abundant rainfall during key developmental stages produced a profile with considerably higher magnitude of significance for sub-genomes of chromosome two (Figure 9). Genetic response to environmental perturbations clearly reflected the impact on by-year yield expression, with 85 SNPs demonstrating significant differential response to growing seasons based on a single-locus analysis. After removing year and plot effects using the Best Linear Unbiased Prediction Model a polygenic nature of genetic associations governed variation in grain yield. Eighty significant SNPs were localized on 14 chromosomes, including co-localization of significant associations with the previously identified yield QTL on chromosome 1BS, *QYld.osu-1B* (see Gene cloning – yield and Hessian fly resistance, page 19) detected in low precipitation years 2014 and 2015 (Figure 9).

With the addition of capture technologies, WIT narrowed this QTL region on chromosome 1BS originally reported by Yan's lab. A QTL region spanning 84.2 cM was identified from 2014 yield data, with 225 significant SNP markers. Two QTL regions were identified in 2015 spanning 32.55 and 0.9 cM, with 55 and 31 markers, respectively. In the non-drought year,

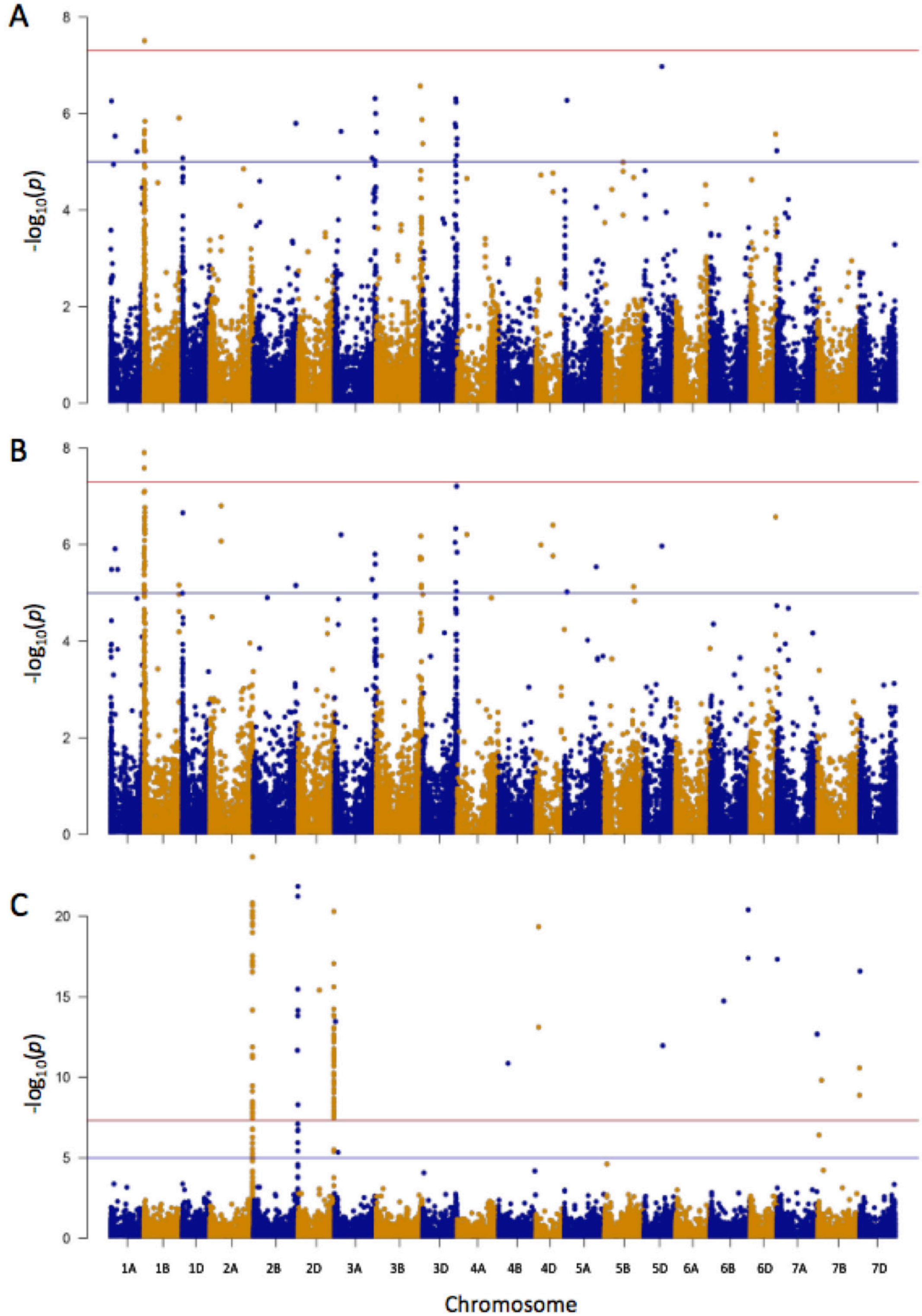

Figure 9. Genome-wide association study for yield in harvest years (A) 2014, (B) 2015 and (C) 2016 from 56,376 SNPs and 240 individuals. Data was filtered for less than 10 percent missing data ratio and more than 1 percent minor allele frequency from Buster_hmp_v1.0.

2016, the QTL spanned 2.21 cM, with 16 significant markers (Figure 10). The 1BS QTL explained 28 percent and 26 percent of the phenotypic variation observed in low precipitation years 2014 and 2015, yet only explained 9 percent of the variation in 2016 where more consistent precipitation was observed (Table 7). The QTL peaked consistently at 4.66 cM, where six SNP markers are located, three of which are located within annotated gene sequences and three close to other genes. Haplotypes of the SNP markers based on physical linkage revealed a total of 542 genes in the 2014 QTL region, 230 in 2015 and 47 in 2016. Stability of this QTL across three years differing widely in abiotic stress suggests its importance in grain yield. Decreased magnitude of the *QYld.osu-1B* correlated with increased rainfall. The SNPs surrounding the peaks at 25 cM and 75 cM were of particular interest for investigating genetic responsiveness

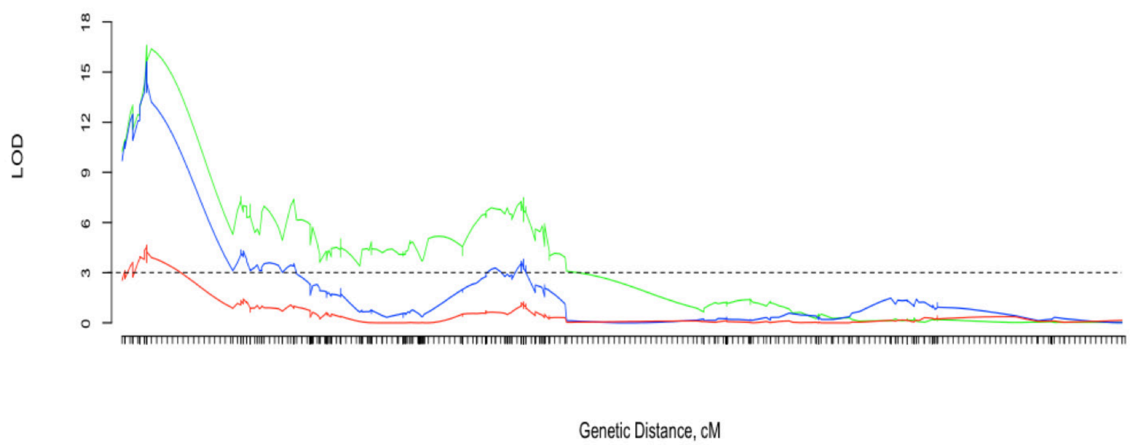

Figure 10. QTL for grain yield in chromosome 1BS, identified by Yan as *QYld.osu-1B.* Data processing removed uninformative SNP markers from Buster_hmp_v1.0 for genetic map construction with 5,443 SNPs from 235 individuals. LOD threshold for significance was 3 for the presence of the QTL.

Table 7. Summary of QTLs detected for grain yield in the Duster/Billings DH population.

Year	*Chromo-some*	*Position cM*	*Genomic Region*	*LOD*	*PVE*	*Effect Size*
2014	1B	4.66	Chr1B: 4,222,625 - 622,471,382	16.6	27.8	-0.527
	2A	180.83	Chr2A: 734,872,036 – 735,261,782	3.75	7.1	-0.266
	2D	80.24	Chr2D: 73,207,210 – 74,936,173	3.4	6.5	-0.255
		86.45	Chr2D: 75,260,724 – 79,066,699	3.95	7.5	-0.273
	5A	7.29	Chr5A: 8,710,394 – 9,475,995	3.91	7.4	-0.273
		15.26	Chr5A: 7,620,544 – 8,056,453	3.44	6.5	-0.256
2015	1B	4.66	Chr1B: 4,222,625 – 476,879,614	15.62	26.4	-0.513
		76.07	Chr1B: 473,496,554 – 480,327,429	3.8	7.2	-0.268
	3B	181.65	Chr3B: 593,921,171 – 596,599,347	3.04	5.8	0.24
2016	1B	4.66	Chr1B: 6,477,296 – 9,711,621	4.65	8.7	-0.297
BLUP	1B	4.66	Chr1B: 4,222,625 – 563,778,606	22.76	36.0	-0.288

to drought conditions. Yield QTLs in other chromosomes that were only present in low precipitation years 2014 and 2015 also will be examined.

Supported by three years of field assessment, a drought tolerant Buster genotype, DH169, and a drought susceptible Buster genotype, DH173, were selected for a pilot RNA sequencing, or RNAseq, study to investigate transcriptional variation in response to field drought conditions (Figure 11). Analysis of *de novo* transcriptome assemblies of individual genotypes revealed 4-fold or higher differential expression among 3,242 putative genes (DH169) and 3,589 (DH173) in response to controlled water stress. Heatmaps of assembled putative genes were generated from normalized expression matrices and centered to the mean to visualize values of gene expression under drought and control conditions for individual genotypes (Figure 12). A closer look of genes with values greater than ±4 revealed five genes in DH169 and 82 genes in DH173 exhibiting high levels of transcriptional variation in response to drought stress. Significant blast hits of these genes to the annotation of Chinese spring wheat revealed homology to genes mostly related to photosynthetic activity. Further investigation into these putative genes in drought tolerant and susceptible genotypes is underway to identify important targets as future molecular tools.

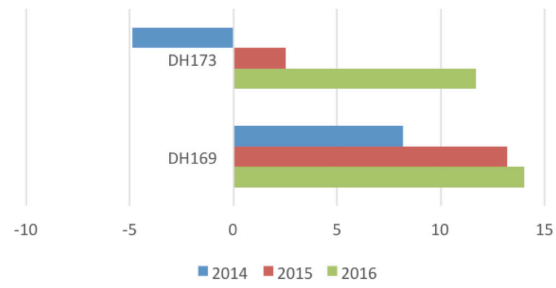

Figure 11. Grain yield of selected DH lines over three field seasons normalized to the mean of the population. DH169 is high yielding in all three years, whereas DH173 is susceptible to drought.

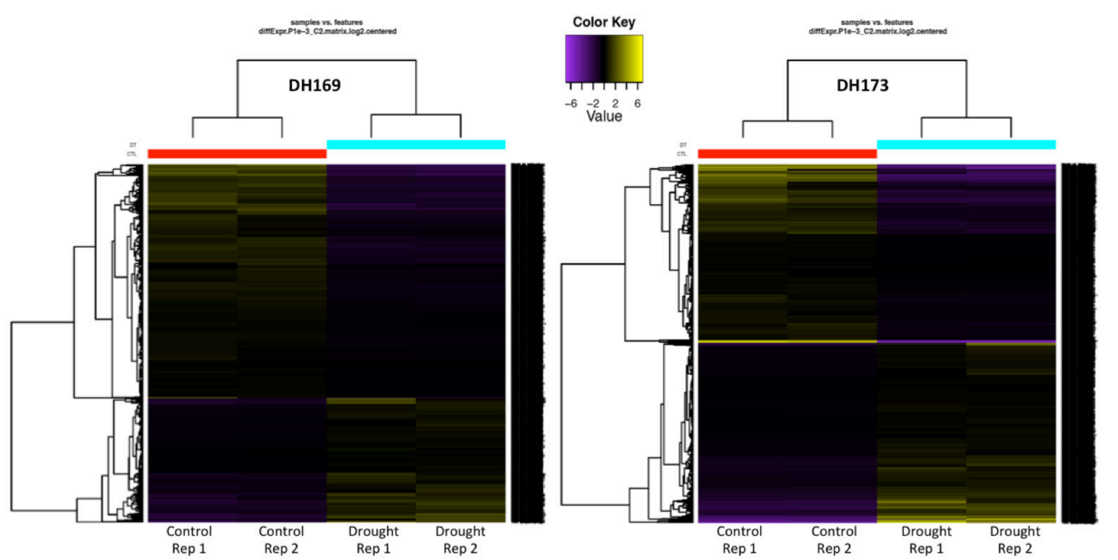

Figure 12. Heat maps produced from analysis of RNA sequencing data on two DH genotypes divergent in response to water stress: drought tolerant, DH169, and drought susceptible, DH173.

To further encourage data re-usability, WIT has integrated data sets and the newly released genome sequence and annotation information from IWGSC (https://wheat-urgi.versailles.inra.fr) into an interactive genome browser called Jbrowse. Utilization of this tool permits simple and user-friendly visualization of SNP polymorphism with other functional genomic components. As an example, visualization of one of the six SNPs identified at the peak of *QYld.osu-1B* shows its location within an annotated gene with variation of SNP presence in drought tolerant and susceptible DH lines (Figure 13). Cross-referencing this kind of genomic knowledge to mine exploitable genetic variation, WIT envisions a greater degree of genomic discovery effort to determine presence or absence in various genetic elements, SNPs, transcripts as well as microRNA and other variants from experimental lines and varieties sequenced in the future.

More precise target identification is important in a genetically complex crop such as wheat. Together with information on transcriptional variation under conditions of water stress and information on SNP variants established from genome-wide analysis, the ability to pinpoint genetic components related to yield response to drought stress will enable gene target identification for possible breeding applications. Furthermore, this data set will be used

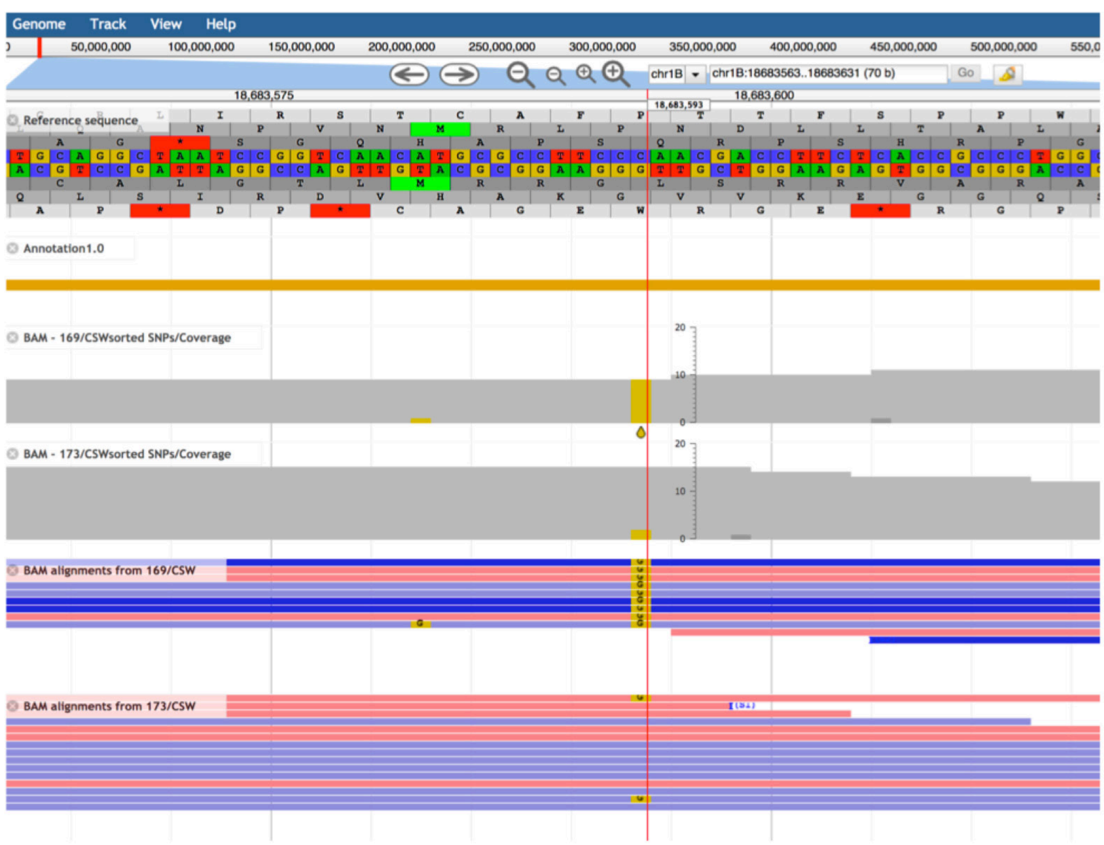

Figure 13. Jbrowse, a genome browser, visualization and identification of SNPs in annotated genes and their presence or absence in sequenced genotypes of interest in the Duster/Billings DH population. Tracks for transposable elements, long non-coding RNAs, microRNAs and untranslated regions were integrated.

next to similarly investigate other key traits related to grain quality and disease resistance.

Exploring further with genomic selection – yield and quality

In 2017, WIT continued to test the effectiveness of genomic selection, or GS, using the Duster/Billings DH lines as a model population, but this time with the newly developed genomic information. In total 15 phenotypes and eight GS algorithms were tested, of which grain yield, wheat protein content, kernel weight, adjusted sedimentation value (an indirect measure of protein quality relative to loaf volume) and four GS algorithms were used to illustrate the results. Meaningful differences were found when GS performance was evaluated by the two-generation cross-season validation algorithm (Figure 14), rather than the commonly used cross-validation algorithm (Figure 15). Most notable was the overinflated prediction accuracy from cross-validation; nearly a 50 perent reduction in GS accuracy for grain yield can be expected when a more realistic cross-season validation is used. The upward bias in GS accuracy was most discernible for wheat protein prediction. Despite the variability in growing seasons, adjusted sedimentation provided the most predictable phenotype, averaging 0.54 predictability for within-year cross-validation (Figure 15) and 0.45 in all cross-season predictions (Figure 14).

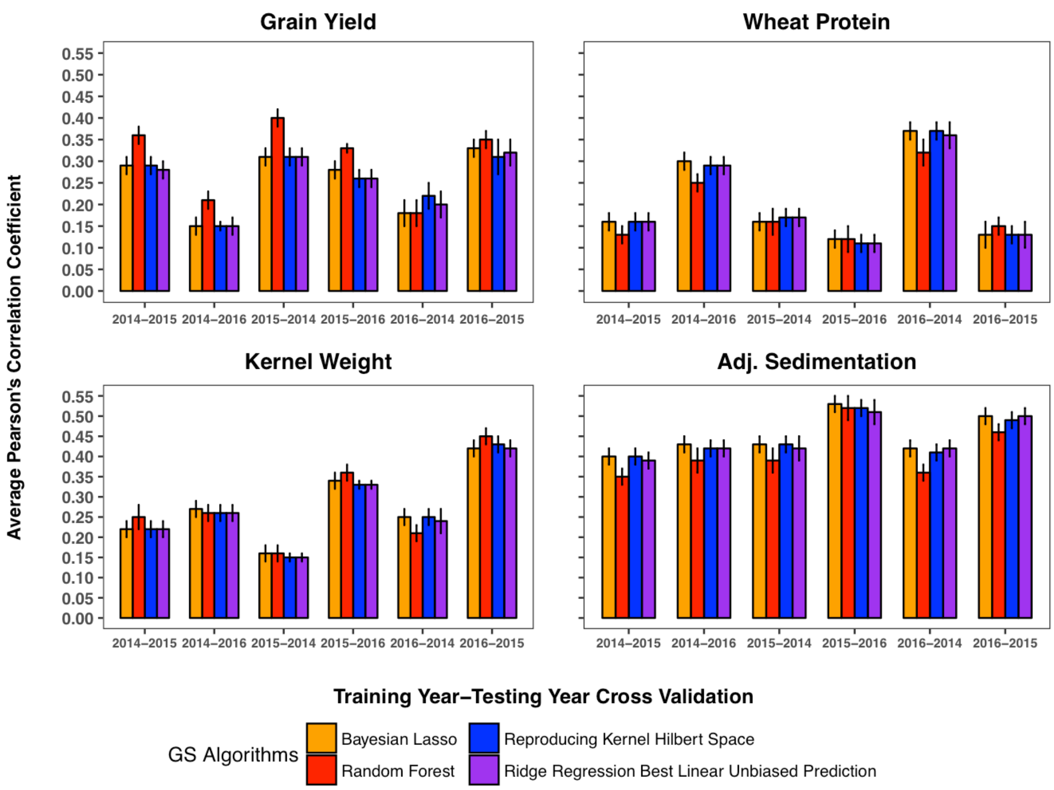

Figure 14. Average Pearson's correlation coefficient as an indication of genomic selection prediction accuracy for cross-year validation of grain yield, wheat protein, kernel weight and adjusted sedimentation value. The error bar represents one standard deviation. Horizontal axis represents the relationship between training and testing population, that is, the year before and the year after the dash indicates harvest year of training and testing populations, respectively.

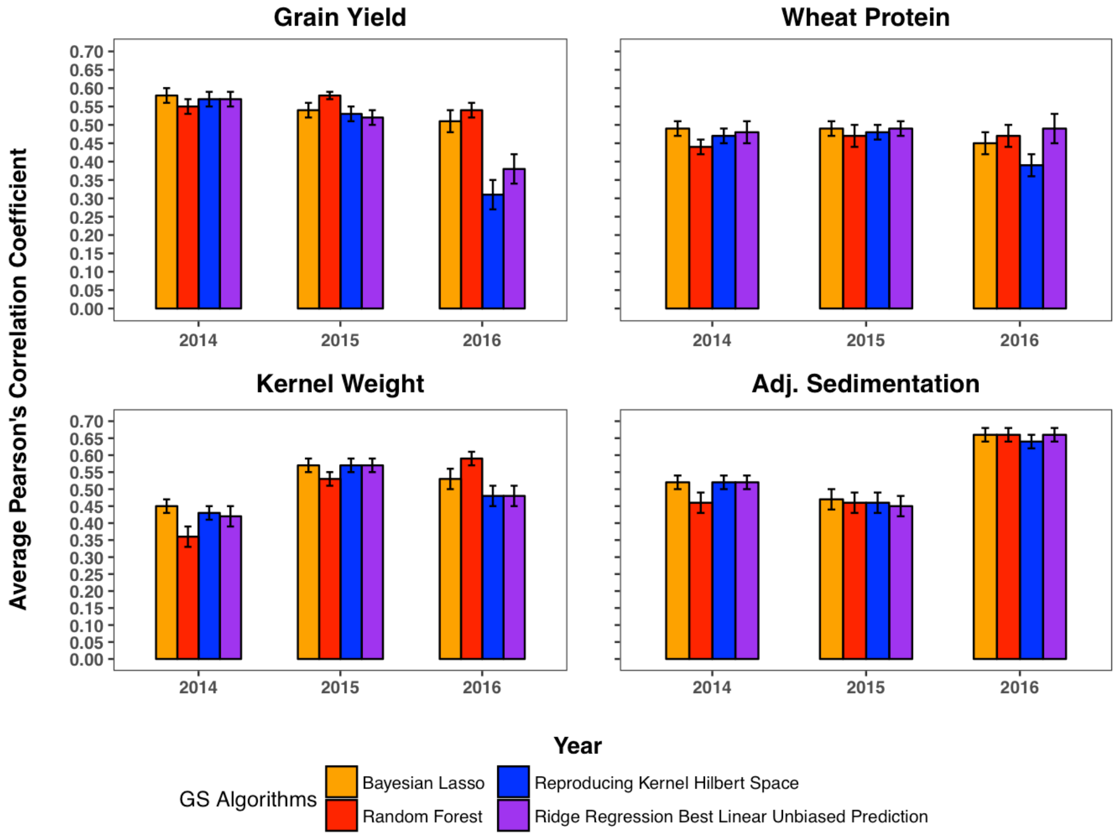

Figure 15. Average Pearson's correlation coefficient as an indication of genomic selection prediction accuracy for within-year cross-validation for grain yield, wheat protein, kernel weight and adjusted sedimentation value. The error bar represents one standard deviation.

Perhaps not so coincidentally, WIT has relied increasingly over the past five years on adjusted sedimentation values to filter out under-performing lines for dough strength.

Further, in Figure 14, considerable variability in predictability was observed for the relationship between training and testing populations. For example, grain yield data trained in year 2014 predicted with an average of 32 percent accuracy for 2015 across all GS algorithms, but this accuracy diminished by one-half when predicting 2016 grain yield data. For kernel weight, a key component of grain yield, data trained in 2015 predicted with an average of 35 percent accuracy for 2016, whereas data trained in 2014 could only result in 25 percent accuracy for 2016 in the best scenario. This lack of stability of GS predictability across growing seasons reflects the fluctuation in winter wheat growing conditions in the region, also emphasizing the importance of GE interactions when considering GS as forming part of the breeding pipeline. To account for the differential genomic effects due to severe environmental variability in the southern Plains, WIT has developed a multivariate prediction algorithm capable of modeling phenotypic variance based on the source of genome responsiveness, genetics and the interaction of environmental variation with genomic background. With the capacity to model the intricate GE effect between 2014, 2015 and 2016 field seasons shown in Figure 16, an accuracy of 65 percent may be achieved for grain yield prediction, exceeding accuracies in cross-validation using commonly used algorithms that fail to include environmental variation. Finally, the input genotypic information used in GS algorithms can also be a factor for GS predictability. Suggested by the comparisons in Figure 16, including SNPs derived from functional genomic components such as the use of expressed microRNA as templates in exome capture techniques can result in more predictable outcomes.

Nitrogen-use Efficiency at the Genetic Level

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Plant and Soil Sciences

In fall 2016, and for the fourth consecutive year, wheat breeding nurseries were established at the OSU southwest agronomy farm at Tipton to differentiate among 175 advanced lines in several breeding nurseries at a nitrogen level approximating 25 percent of the optimum rate. Eighty of those lines were also tested at the full nitrogen rate for direct comparison. Yields at the full nitrogen rate were reduced and yield differences were compressed due to a higher incidence of symptoms resembling, but not confirmed as, strawbreaker disease.

Continued advanced line testing at Tipton has demonstrated superiority of Doublestop CL+ for yielding ability at the 25 percent nitrogen rate. For example in 2017, yields across three nurseries averaged 32 bushels per acre for Doublestop CL+ versus 24 bushels per acre for Gallagher ($P<0.001$). This 30 percent yield advantage of Doublestop CL+ is unbiased by differences in

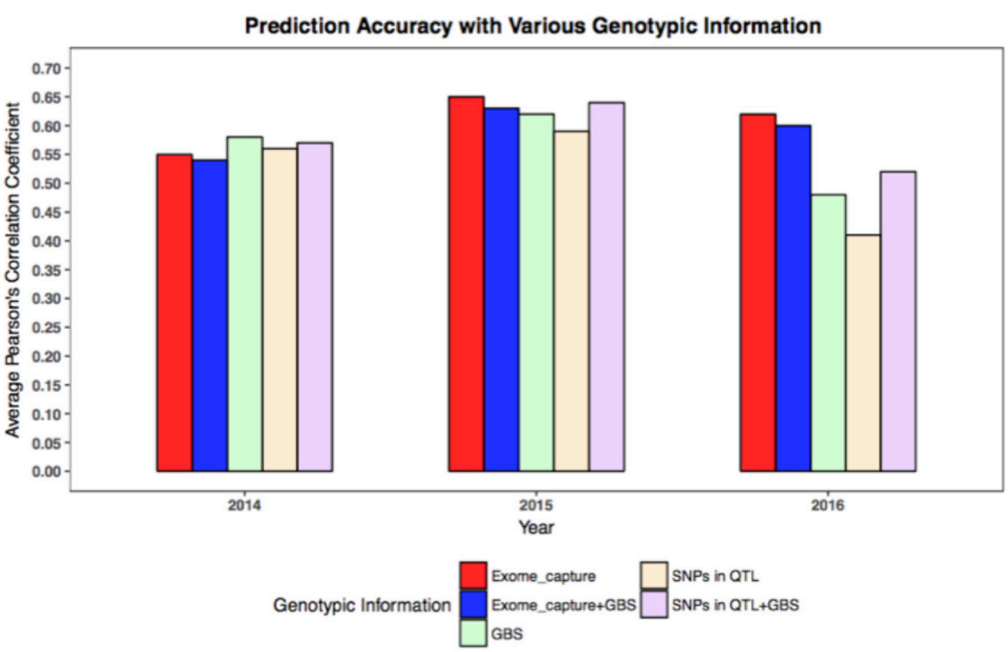

Figure 16. Genomic selection performance using a multivariate model to account for GE interactions. Prediction of grain yield was performed with training information derived from all three field seasons (2014-2016). GS performance was also evaluated with genotypic information from different combinations of SNP profiles, including genotyping-by-sequencing, exome capture sequencing and SNPs identified in QTL mapping.

disease reaction, but presumably a reflection of differential tolerance to limited nitrogen availability throughout the growing season. At this time, WIT has no genetic understanding of the nitrogen-use efficiency, or NUE difference between Doublestop CL+ and Gallagher. Relative to the complete range of genotypes evaluated since 2014 at Tipton, varietal rankings in tolerance at the 25 percent nitrogen rate generally have occurred in this order: Doublestop CL+ > Bentley > Gallagher=Duster > Stardust.

Experimental lines which placed in the top-yielding statistical group in each nursery in 2017 (about 38 to 45 bushels per acre), and which showed minimal difference in yield between nitrogen treatments, where tested simultaneously, are listed below with their pedigree. These lines have already been prioritized for future cycles of selection and are considered equivalent or superior to Doublestop CL+ for NUE. Those listed in boldface are discussed further in the Wheat Breeding and Variety Development report on page 31 as candidate varieties moving forward.

After four successful years of testing, WIT's observations may be summarized as follows. A sandy soil texture and depletion of residual nitrogen in the rooting zone in a continuous wheat system have enabled control of nitrogen supply and thus minimal spatial variation in plant response across the nitrogen-limited area. Less spatial variation leads to reduced experimental error. A standardized yardstick for experimental error, called coefficient of variation, C.V., rarely exceeds 14 percent in the nitrogen-limited area for replicated trials with fewer than 40 entries per block. This level of C.V. is no different than expected for yield trials conducted at full nitrogen fertility. All of this adds up to one scientific convenience: breeder observations based on overall plant vigor, color, spike density and spike size can be made as routinely as disease ratings. Varieties used as checks also demonstrate consistency in ranking across experiments for a given year, or even across years. Further, the ability to statistically differentiate varietal yields at the 10 percent level makes the application of genomic selection an intriguing possibility, given the predictive success already in using genome-wide association mapping to characterize drought tolerance (see Discovery and Predictability of Yielding Ability on page 20). Differentiation based on traditional yardsticks for end-use quality have been more problematic, given that wheat protein levels typically

OCW05S616T-2	Babax+Lr42/Fannin//KS00F5-11-2
OK1059018-129332-5	Billings/Duster
OK12D-Blgs/Dst-DH106	Billings/Duster
OK12D-Blgs/Dst-DH169	Billings/Duster
OK13209	OK Bullet/TX00D1390//Shocker
OK149132C	CO06054/ OK06029C (Clearfield Plus)
OK15828	KS05HW15-1/N03Y2016//OK05312 (tentatively classified WSM-resistant)
OK15620	(Parula/2*PASTOR)/Duster//T158
OCW03S580S-8WF	G991502/BULK SELN 00F5-11-2 (soft red winter)

average below 10.5 percent at the 25 percent nitrogen rate, practically too low to produce an interpretable mixogram.

This work was expanded in 2017 to include more stepwise increases in nitrogen rate with far fewer varieties. WIT's objectives were twofold: 1) to ascertain any difference in apparent NUE in Smith's Gold relative to one of its parents, Gallagher, and 2) to confirm observations at Tipton that experimental lines OK13209 and OK12D22002-077 not only are nitrogen responsive but also tolerate low nitrogen better than Gallagher. OK13209 remains a candidate variety under Foundation Seed increase, whereas OK12D22002-077 was intended to provide a Lonerider replica but with WSBM/WSSM resistance. OK12D22002-077 has since been terminated due to low resistance to leaf rust and BYD in 2017.

Experiments were conducted near Stillwater at the Lake Carl Blackwell Research ranges and near Lahoma at the North Central Research Station. The study consisted of four cultivars (Gallagher, Smith's Gold, OK13209 and OK12D22002-077) at four rates of preplant nitrogen (30, 60, 90 and 120 pounds nitrogen per acre). All varieties were planted at a seeding rate of 67 pounds of seed per acre. At LCB, the plots were no-tilled into standing wheat stubble, while at Lahoma the plots were no-till drilled into fallow soil. Stand establishment at LCB was superb, whereas a dry seed bed at Lahoma resulted in extremely reduced stands. Observations were taken on stand and will be taken into account during final analysis. However, those measurements will not be discussed in this report. At both locations a post-emergence herbicide application of zidua, axial and metribuzin was utilized as a broad spectrum weed management strategy. At no time was weed competition a problem for these locations. In addition to herbicide, both locations were managed with a two-pass fungicide program. At jointing, Quilt was applied with an insecticide while Approach was applied at flag leaf emergence. While leaf rust was noted in the planted area surrounding the trial at each location, no disease was observed within the trials.

Grain yield from LCB showed a strong response to nitrogen fertilizer across all varieties, with a 30 to 40 bushels per acre difference between the lowest and highest nitrogen treatments (Figure 17). It should be noted in an adjacent study which received top-dress nitrogen Gallagher exceeded 90 bushels per acre. This, along with visual symptomology, indicates the 120 pounds nitrogen pre-plant rate was still below the optimum nitrogen rate. Also at LCB, a significant increase in protein was observed with increasing nitrogen rates across all varieties. As was hypothesized, variety did impact protein level. Figure 17 demonstrates how OK13209 produced greater wheat protein content than Gallagher, even at the lowest level of nitrogen input, but with similar yields.

Unfortunately the poor stand establishment at Lahoma resulted in a data set with a significantly higher level of variability (Figure 18). While trends were evident in the data, it will take further investigation to better understand the results. Though analysis of dough quality is ongoing at the time of report submission, OK13209 exhibited higher mixing tolerance at the lowest nitrogen rate, but did not maintain this advantage relative to

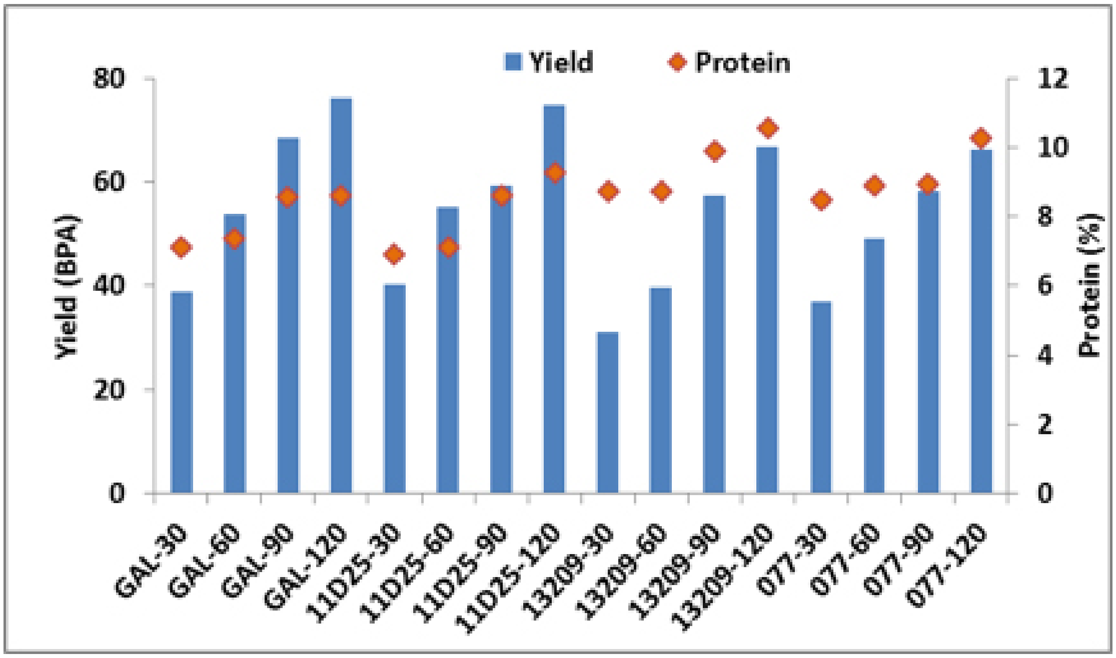

Figure 17. Yield in bushels per acre (BPA) and wheat protein in percentage units from the 2016-2017 Varietal Nitrogen Use Efficiency study conducted at the Lake Carl Blackwell Research farm near Stillwater. GAL = Gallagher; 11D25=Smith's Gold; 13209=OK13209; 077=OK12D22002-077 (Lonerider sib). N-rates in pounds per acre indicated as 30, 60, 90 and 120.

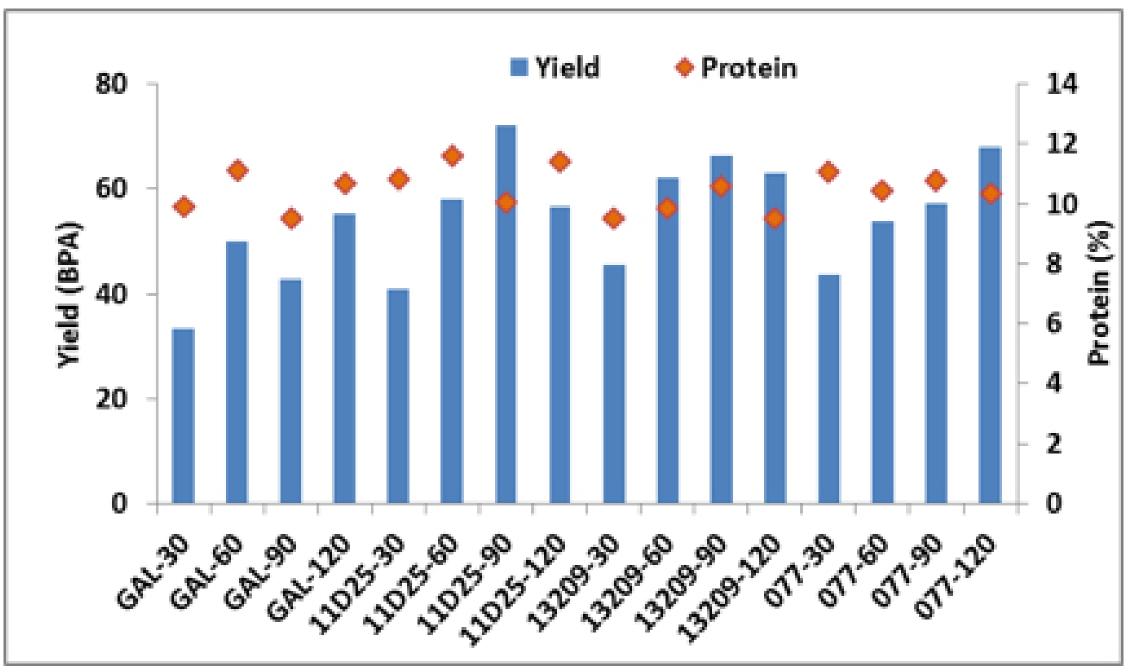

Figure 18. Yield in bushels per acre (BPA) and wheat protein in percentage units from the 2016-2017 Varietal Nitrogen Use Efficiency study conducted at the North Central Research Station near Lahoma. GAL = Gallagher; 11D25=Smith's Gold; 13209=OK13209; 077=OK12D22002-077 (Lonerider sib). N-rates in pounds per acre indicated as 30, 60, 90 and 120.

Smith's Gold as nitrogen rate increased. As expected, an overall wheat protein level of 9.5 percent across both locations and nitrogen rates makes differentiation for dough quality more challenging, and especially since all varieties included in the trial normally possess acceptable milling and baking quality.

In summary, the data from the first year of this project is encouraging. The results from LCB and Lahoma aligned with those from Tipton to suggest a tendency for OK13209 to maintain protein levels even at sub-optimum nitrogen levels. Also positive was the ability of OK13209 to reach yield levels similar to that of Gallagher and Smith's Gold.

Moving forward, the study will be continued in 2018, except OK12D22002-077 will be replaced by Lonerider. Information became available immediately following its release in 2017 that Lonerider's dough quality may decline sharply at lower protein levels. To support an undergraduate research project, height measurements and GreenSeeker readings will be collected weekly to determine if the rate of vegetative growth is linked to NUE and grain quality.

Wheat Breeding and Variety Development

Brett Carver
Plant and Soil Sciences

Return of the orange dragon – leaf rust

Much like the 2015 and 2016 harvest years when stripe rust consumed WIT's attention in germplasm evaluation and selection decisions, it was a different form of rust, leaf rust, which took center stage in 2017. Leaf rust in the Great Plains took on epidemic proportions in 2017 due to its longevity of infection and severity of damage. Not since 2007 did leaf rust dominate selection decisions from top to bottom in the breeding program. For any experimental line or population to be advanced in the OSU wheat variety development pipeline following the 2017 harvest, it had to first show acceptance in leaf rust resistance level. Not having this level of selection pressure for 10 years left the breeding pipeline in a vulnerable position as WIT reported previously, but the uninterrupted evaluation of advanced lines for seedling reaction to leaf rust by Hunger maintained a base level of protection in OSU germplasm.

Nevertheless, leaf rust severely limited grain yield and test weight of susceptible varieties with even an intermediate level of resistance, because the disease impacted the 2017 crop unusually early in its development, that is, before heading. WIT first collected leaf rust reactions on April 14, 2017, at Stillwater several weeks after onset of symptoms. As with stripe rust, leaf rust infections prior to heading on juvenile plants may elicit qualitatively different symptomology than with infection during the adult plant stages, typically early to mid-May in north central Oklahoma. Two varieties for which this was most evident in 2017 were Bentley and WB Grainfield (Table 8).

Despite the early and severe onset of leaf rust in 2017, Gallagher produced a resistant reaction in all breeding nurseries across the state throughout the principle stages of grain filling. Leaf rust sporulation was observed very late in grain filling on Gallagher flag leaves, but when leaf senescence had

Table 8. Leaf rust reaction of common hard red winter wheat varieties in Oklahoma following early infection in 2017 versus reactions in previous years with a typical infection timing.

	Leaf rust reaction as of 2017[a]	
Variety	*April infection (2017)*	*Typical May infection*
Lonerider	I	MR-R
Spirit Rider	MS	MR
Smith's Gold	MS	MR
Iba	I	MR
Bentley	VS	I-MR
Grainfield	VS	R
Doublestop CL+	R	R
Gallagher	R	R
Stardust	VS	S
Ruby Lee	I	I-MR
Duster	R	R

[a] R=resistant, MR=moderately resistant, I=intermediate, MS=moderately susceptible, S=susceptible, VS=very susceptible.

already commenced; thus damage was minimal. Gallagher carries one gene for leaf rust resistance, *Lr26*, present on the rye segment of the 1B-1R wheat-rye translocation. WIT feared this was the only gene present, as continued wide cultivation of Gallagher would apply selection pressure favoring virulent races to *Lr26*. Fortuitously, WIT discovered Gallagher must indeed carry additional gene(s) for leaf rust resistance, as backcross progeny with a genetic identity very close to Gallagher were observed to segregate for varying levels of leaf rust resistance in the presence or absence of *Lr26* (Table 9). These progeny were developed to introgress a major gene for dough strength, rather than evaluation for leaf rust. Capitalizing further on this opportunity, the hypothesis will be tested in 2017-2018 that another adult-

Table 9. Leaf rust ratings of eight backcross progeny of Gallagher collected in April 2017 at Lahoma.

*Gallagher backcross progeny line (3*Gallagher/Snowmass)*	*Lr26 presence*	*Leaf rust rating*[a]
OK15DMASBx7 ARS 8-59	+	MR
OK15DMASBx7 ARS 8-60	+	I
OK15DMASBx7 ARS 8-61	+	MR
OK15DMASBx7 ARS 8-62	+	R
OK15DMASBx7 ARS 8-65	+	MR
OK15DMASBx7 ARS 8-66	+	MS
OK15DMASBx7 ARS 8-67	—	R
OK15DMASBx7 ARS 8-70	+	R

[a] R=resistant (comparable to Gallagher), MR=moderately resistant, I=intermediate, MS=moderately susceptible.

plant resistance gene, namely *Lr77* inherited from Duster, is providing additional protection in Gallagher. The combination of *Lr26+Lr77*, which presumably is rare in current varieties grown in the Great Plains, should provide longer lasting protection than *Lr26* alone. On a related note, the source of adult-plant resistance to stripe rust in Gallagher remains unknown.

While selection pressure for stripe rust resistance was lighter in 2017, WIT continued to turn to other cooperators for stripe rust evaluations under field conditions, including scientists located in Manhattan, Kansas with USDA-ARS, and in Pullman, Washington with Washington State University. This collaboration ensures constant selection pressure for stripe rust resistance in years which the disease is not present in Oklahoma. In Washington, pressure from the disease far exceeds what is observed commonly in Oklahoma, yet the results from 2016 and 2017 were highly encouraging. Effective resistance in Washington nearly always carries over to effective resistance in Oklahoma.

Most candidates forwarded in 2017 to Oklahoma Foundation Seed Stocks for foundation seed increase possess a highly effective level of resistance to current races of stripe rust.

Genetic progress with other pests

Introgression of WSM resistance into the variety development pipeline continued in 2017, with commercial-ready germplasm now within sight. WIT's strategy remains focused on a multi-pronged approach of selecting for molecular markers in either 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, but now, five candidate varieties with putative WSM resistance were forwarded in summer 2017 for Foundation Seed production. WIT's best chance at reliable field validation of advanced lines is provided courtesy of USDA-ARS collaborators in Lincoln, Nebraska (Bob Graybosch and Gary Hein), who conduct a field screening for WSM resistance under field conditions. Virus symptoms from this test are often severe and reveal dramatic differences, even among lines carrying one of the genes previously listed. 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 for WIT, 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*. Our ultimate goal remains to combine *Wsm1* with *Cmc4* (curl mite resistance) in the same genetic background with minimal impact of yield-reducing genes linked to *Wsm1*.

Resistance to WSM also occurs in hard winter wheat without connection to a known causal gene. Even less common is to find WSM resistance when there is no obvious parental source. That was the case at Marshall, where an entire nursery of 2,100 early-generation populations was decimated by curl mite infestation and subsequent WSM damage, except for multiple check plots occupied by Joe (not surprising) and Doublestop CL+ (quite surprising; Figure 19).

Hessian fly is fast-becoming a deciding factor in variety adoption across central and southwestern Oklahoma, especially in concentrated areas of reduced tillage. WIT has always emphasized selection and molecular characterization of Hessian fly resistance, since the release of 2174 by OAES in 1997 under the direction of Ed Smith. This constant pressure well explains the frequency of resistance harbored by advanced lines forwarded for field testing in 2018. The most recent seedling assays conducted by Ming Chen, USDA-ARS, Manhattan, Kansas, indicates Hessian fly resistance is present in 35, 44 and 48 percent of the lines selected in 2017 for testing in the 2018 Oklahoma Elite Trials, OET1, OET2 and OET3 nurseries, respectively. The OET3 nursery contains the most advanced material and thus reflects more cycles of selection for Hessian fly resistance and many other traits. The likelihood of a candidate released for commercialization with Hessian fly

Figure 19. Left: Breeding nursery at Marshall on April 27, 2017 with contrasting plots of a WSM-susceptible population on the left and Doublestop CL+ check plot on the right. Disease symptoms of tiller loss and abortion, chlorosis and overall plant stunting were accentuated by heavy and prolonged winter grazing. Right: Broader view of the same nursery featuring three WSM-resistant populations segregating for Wsm1 and/or Wsm2 in the foreground.

resistance is about 50 percent. Twenty years ago in the pre-Duster era, the likelihood was less than 10 percent.

WIT's goal is to follow up that kind of success with discovery and deployment of BCOA resistance under the leadership of Xu, Giles and Zarrabi. Previously, aphid colonies were developed and maintained, and a reliable and repeatable screening assay was developed; in 2017, selection pressure was applied further back in the variety development pipeline to better ensure discovery and retention of resistant germplasm. The first cycle of fixed breeding lines awaits yield and quality testing following one generation of seed increase, and without further delay, crossing will commence with this valuable germplasm in 2018. This activity constitutes a major breakthrough in addressing a persistent direct (by plant injury) or indirect (by BYD transmission) hazard to wheat production in Oklahoma.

WIT's pipeline contains a 4-way valve

While the kind and number of crosses performed establish a trunk for the entirety of the variety development pipeline, a 4-way valve in the pipeline creates multiple flow paths distinguishable by unique breeding tactics (Figure 20). The principle flow path is through the **Graze*n*Grain**™ breeding system. Imagine a filter through which potentially millions of genetic combinations will pass through and a small proportion ultimately generates fixed genetic lines for eventual testing. WIT has employed such a specially designed filter with the incorporation of grazing pressure at key points in the flow path, to invoke selection for multiple characteristics relevant to both grain-only and dual-purpose management systems. From 1997 until 2017 this system was applied at the Wheat Pasture Center at Marshall for population development, and at Stillwater and Lahoma for subsequent line selection. Beginning in fall 2017, population development was moved to Okarche. While this selection system remains in place and continues to work very well, the filter used in this system may not be the best one for developing lines best adapted to the far western part of Oklahoma.

For about 10 percent of the 1,000+ crosses made per year, WIT

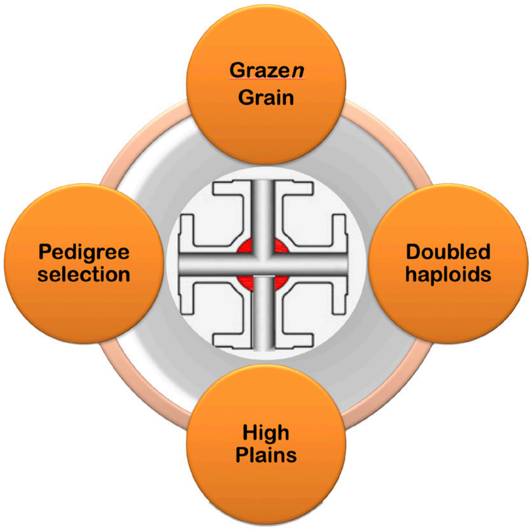

Figure 20. The OSU wheat variety development pipeline is, in practice, four pipelines of germplasm, each originating early in the breeding process, or one to three years after the cross.

is now growing the segregating bulk 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 the **Graze*n*Grain**™ breeding system, 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 or Okarche. WIT finished its fourth year of population development in 2017. For the first time in OSU history, wheat headrow families were successfully evaluated at OPREC in 2017 to begin the line development process (Figure 21). The primary motivation is to move the impact of the OSU wheat breeding program further west without physically having to move the program.

With increasing regularity, WIT is bypassing both the **Graze*n*Grain**™ and High Plains paths in favor of doubled haploids, a breeding tool to create inbred experimental lines within two years of executing the cross, using a specialized mating system and tissue culture. The production of doubled haploids has its disadvantages and limitations,

Figure 21. Single 3-foot rows, called headrows because each originated from a single head in the previous generation, are shown March 21 (left) and May 22 (right) 2017 at OPREC. Each row represents a genetically unique experimental line and forerunner to a released cultivar. The 2017 harvest marked completion of the first cycle of population advancement and line development strictly in the Oklahoma panhandle.

and thus only about 1 percent of the available crosses fit this tool. However, turning the 10-year breeding cycle over at a faster rate improves the potential rate of gain on a per-annum basis and puts a wheat improvement program on par with other breeding programs (for example, maize) where the cycle time is greatly shortened. Six percent of the experimental lines subjected to replicated yield and quality testing in 2017 were doubled haploids. This number will increase to about 15 to 20 percent over the next five years. Two released OSU varieties were developed as doubled haploids, Smith's Gold and Lonerider.

The fourth and final leg of the variety development pipeline is populated with experimental lines intensively selected for yielding ability using a modified pedigree-selection breeding method. Rather than advancing populations of plants through the early generation phase of years two through four following the cross, desirable families are selected for yield-determining characteristics, from which families are selected again the following generation. This repetitive process may continue until highly inbred lines are selected with the highest yield potential, prior to replicated yield and quality testing. In 2017, WIT reached a turning point in this selection process to advance several thousand experimental lines for seed increase and subsequent testing. Up to about 10 percent of the total pipeline is expected to originate via this path.

In summary, this 4-way valve adds breadth to the OSU wheat breeding program to address multiple needs of wheat producers from the panhandle to Green Country, while maintaining depth or sheer numbers of breeding lines from which to choose candidate varieties. Common to all branches of this pipeline is an emphasis on end-use or functional quality demanded by a complex milling and baking industry.

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 thus reveals different parts of the process in motion, as enumerated and discussed further in Figure 22.

Candidate variety lineup

Following the 2017 harvest and after thorough consideration of all advanced lines under breeder-seed increase in 2017, WIT submitted breeder seed of 10 new HRW and HW candidates for grow-out and on-farm evaluation by Oklahoma Foundation Seed Stocks, or OFSS, in 2017-2018. Another 13 candidates previously under Foundation Seed increase in 2017 were carried over to 2017-2018.

Subsequent to preparation of this report, WIT will prepare release documentation for two candidates, OK12716 and OK13209 in early 2018. One is not preferred over the other, because they are highly divergent in performance features. OK12716 exhibits wider adaptation with a higher yield ceiling, but lacks leaf rust resistance and possesses average baking quality. No other candidate in the pipeline since 2012 ranked higher for statewide grain yield. Both HRW and HW sib lines of OK12716 are currently

1,735	The number of segregating populations cycled through the ***Graze*** n***Grain*** ™ breeding system at Marshall, Lahoma, and Altus, OK in 2017. About 30% 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.	
59,463	The number of first-generation F_5 experimental lines planted in 3-foot headrows. This number was about 10% above-average for the variety development program. Selection pressure was very intense in 2017 to avoid advancing lines with leaf rust susceptibility. Less than 2,000 of these lines were advanced for observation in conventional yield plots in 2017-2018.	
1,832	The number of second-generation fixed lines dedicated to our centerpiece breeding nursery, the Dual-Purpose Observation Nursery (DPON), and key turning point for lines borne out 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. 7% of these lines were HW.	
3,069	Doubled haploid lines produced outside of, and which short-circuit, the conventional ***Graze*** n***Grain*** ™ system. The normal breeding cycle from parent to progeny release is about 10 yrs. The use of doubled haploid lines reduced that cycle to 7 yrs. This portion of the line-evaluation program accounts for about 10% of the total testing pipeline each year.	
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 (2015, 2016). *OSU once again maintained one of the highest average ranks in overall quality scores for its submissions in 2017, but the awards committee saw fit to recognize another breeding program.	WHEAT QUALITY COUNCIL
23	Record number of candidate varieties advanced for seed increase by Oklahoma Foundation Seed Stocks in summer 2017.	
1 and only 1	One wheat team, one wheat variety development program, in the USA 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 2016-2017 crop season.

under Foundation Seed increase. OK13209 provides one of the best HRW combinations of resistance to leaf rust and stripe rust; it is highly competitive for yield in the central wheat corridor of Oklahoma but has performed poorly in the panhandle and northward into Kansas. OK13209 exhibits above-average end-use quality and protein content.

Another pair of candidates, OK12DP22004-016 and OK13621, offers promise for contract production of exceptional end-use quality, but similarities end there. The former is widely adapted across Oklahoma and is the shortest candidate to originate from this program in the past 20 years. In addition to contract production, OK12DP22004-016 appears highly suited for intensively managed environments where grain yield and reliance on standability are maximized. OK13621 produces a dough with unparalleled strength compared with any other OAES wheat variety. It is well adapted across Oklahoma, but its highest relative yields are observed routinely in the panhandle. The intent at this time is to have a release proposal for both candidates in place by summer 2018 if variety trial results continue to justify commercialization.

Next out of the pipeline, but likely one year away from a release recommendation, is OCW05S616T-2. It carries an outstanding disease resistance package with one possible exception being tan spot, and it is susceptible to Hessian fly. No other experimental line exceeds OCW05S616T-2 in average two-year yield rank since 2016. Without Hessian fly protection, it may not displace Gallagher, even with 18 percent or 10 bushels per acre (P<0.001) superiority in statewide average yield (Table 10) and equivalent test weight. OCW05S616T-2 will compete very well against any other susceptible variety, and at this time it appears to be next in line after Bentley as a broad-utility, high-quality HRW variety from this program. Additional yield comparisons of OCW05S616T-2 with Bentley are needed in 2018, because Bentley performed no better than Gallagher in 2017 due to severe leaf rust infections.

OK12206-127206-2 is currently OSU's best HRW beardless line at this stage of advancement, but showed weakness for the first time in 2017 for high variability in test weight (very poor

Table 10. Two-year yield comparison for OCW05S616T-2 versus Gallagher in replicated breeding trials across Oklahoma. Boldface indicates significantly higher (P<0.05) yield for the given pairwise comparison.

	Lahoma		*Okmulgee*		*Altus*	*Tipton*		*Goodwell*	
Variety	*2016*	*2017*	*2016*	*2017*	*2017*	2016	2017 (25% N)	2016 (irrig.)	2017
	----------	----------	----------	----------	bu/A	----------	----------	----------	----------
OCW05S616T-2	**89**	**70**	**88**	54	**52**	**37**	**32**	79	**64**
Gallagher	78	56	75	**61**	41	29	24	70	48
LSD (0.05)	9	10	13	6	6	6	6	12	10

to above average). The inconsistency did not appear to be related to threshability. Low and high test weight samples showed similar cleanliness. OK12206-127206-2 exhibits an exceptional range of disease resistance, in addition to Hessian fly resistance and very good end-use quality.

OK13P016 and OK14319 have outstanding dual-purpose capabilities with no shortcomings for end-use quality. They are both well adapted to the southern regions of Oklahoma. Under formal agreement, the Noble Foundation also is evaluating these candidates to determine if they might fit their commercial portfolio of grazing-first characteristics. OK13625 continues to show promise for grain production and baking quality under commercial organic conditions in Oklahoma. A request to release with the appropriate restriction on seed distribution is forthcoming in early 2018.

A group of five candidates carries the unique distinction of exhibiting varying degrees of protection against WSM. On a historical note, WIT probably erred in not releasing in 2011 the Endurance-like candidate variety OK05312 with unusually good resistance to multiple biotypes of curl mite. The rationale at that time centered on gene stewardship first and end-use quality second. In other words, widespread distribution of such a valuable genetic stock for curl mite resistance might shift virulence in the insect population unfavorably toward OK05312, thus compromising WIT's ultimate and long-term objective to combine or stack the insect resistance with confirmed gene sources of WSM resistance. Since that time, other breeding programs have attempted to widely circulate curl mite resistance as a short-term and sole blockade of WSM spread, albeit with questionable end-use quality.

OK12612 offers the greatest protection against WSM among the five candidates listed, but with inferior yield potential and limited resistance to diseases other than stripe rust. In contrast, OK14P212 and OK168512 have shown inconsistent resistance to WSM in artificially inoculated nurseries in Nebraska, but with superior yield potential and better disease resistance. OK168513, a sister line to OK168512, fits a handyman description because it offers the best combination of WSM resistance and yielding ability, without sacrificing protection against other common diseases and quality. OK11P139 has demonstrated moderately good WSM resistance in central Oklahoma, but its range of best adaptation is limited to the High Plains. All five candidates were resubmitted for WSM testing in Nebraska in fall 2017. The lowest level of disease resistance among all candidate varieties moving forward happens to be this group with WSM resistance. This trait is not necessarily antagonistic to selection for other disease resistance targets. Broader disease protection will be an area of focus once the OSU germplasm base with WSM resistance expands.

Two new Clearfield Plus candidates under continued Foundation Seed increase are OK12912C-138407-2 and OK128084C. Another round of breeder trials, variety trials in Oklahoma and Kansas, and BASF qualification trials in 2017 did not reveal a clear winner between these two candidates or against Doublestop CL+. Thus a release recommendation will be delayed another year.

After two or more years of replicated yield and quality trials, two HW candidates were identified in 2017 worthy of preliminary increase by OFSS. OK11709W-139122-1 carries the greatest distinction of consistently very high pre-harvest sprout tolerance. That feature alone would be insufficient to justify a Foundation Seed launch; but, with its very broad disease package and yield potential equal to but not necessarily superior to current HRW varieties (Table 11), WIT has designated this candidate as the most qualified follow-up to Stardust. In the only year, 2017, for which direct comparisons were made, OK11709W-139122-1 significantly exceeded Stardust in statewide grain yield by four bushels per acre or 10 percent (P<0.05). Equivalent in yield but less consistent across years in pre-harvest sprouting tolerance was OCW04S717T-6W. This candidate also possesses a broad disease package but may be best positioned for southwestern Oklahoma. It is not well adapted to the panhandle region due to susceptibility to late winter freeze events.

All of the previously mentioned candidates are summarized in Tables 12 and 13. With a grain of irony, the most noteworthy statement about candidate varieties may concern an experimental line that is not even listed as a candidate. Named OK12621-138232-2, it was the highest yielding entry statewide in the OET3 nursery in 2017. It features unprecedented barley yellow dwarf protection from two resistance genes, and it excels in yielding ability from one Oklahoma border to the other. A Duster descendent, it would likely attract significant acreage in Oklahoma due to its tenacity throughout the season and exceptional grazeability. However, unless WIT can identify a selection from this line with better end-use quality than the line itself, OK12621-138232-2 may be relegated to breeding stock only.

Table 11. Two-year yield comparison for OK11709W-139122-1 versus Gallagher in replicated grain-only breeding trials across Oklahoma and in south central Kansas. Boldface indicates significantly higher (*P*<0.05) yield for the given pairwise comparison.

	Lahoma		*Okmulgee*		*Goodwell*		*Altus*	*S. Haven*
Variety	*2016*	*2017*	*2016*	*2017*	*2016 (irrig.)*	*2017*	*2016*	*2017*
	------------------------------------bu/A							--------------------------------------
OK11709W-139122-1	84	61	68	49	71	52	**43**	66
Gallagher	87	60	77	**55**	75	44	34	68
LSD (0.05)	6	8	11	5	8	11	7	6

Table 12. OSU candidate varieties placed under seed increase in fall 2017 with Oklahoma Foundation Seed Stocks. Number of years of Foundation Seed production indicated as of summer 2018. Grey, HRW elite; orange, WSM-resistant candidates; dark orange, Clearfield Plus candidates; no highlight, HW elite with pre-harvest sprout tolerance.

Candidate[a]	*Pedigree*	*OFSS*	*Feature traits*
OK12716	OK Rising/OK98G508W-2-49	1	HW/HRW versions; highest 6-yr yield rank and HF-R
OK13209	OK Bullet/TX00D1390//Shocker	2	Best combination of rust resistance, test weight, protein
OK12DP22004-016	Everest/OK08328//OK09634	2	Very short and early; yields best in NC OK; **Gold*n*Grain**
OK13621	Billings/TX00D1390	2	Best stripe rust resistance; dough strength; **Gold*n*Grain**
OK12206-127206-2	Y98-912/OK00611W//OK03716W	2	Beardless with disease and HF resistance; high quality
OCW05S616T-2	Babax+Lr42/Fannin//KS00F5-11-2	1	Best disease package; highest 2-yr yield rank
OK13P016	Billings/Duster	1	Targeted southern OK, dual-purpose, HF-R, high quality
OK14319	NE01533/OK02125//Duster	2	Targeted NE OK; high grazeability with quality
OK13625	Billings/Fannin sib	3	High N-use efficiency – organic production; **Gold*n*Grain**
OK14P212	OK01307/Duster//OK06822W	1	WSM tolerant; standability+test weight+disease resistance
OK168512	Overley+/Fuller//2*CSU exptl.	1	Moderate WSM resistance; better yielding ability of 2 sibs
OK168513	Overley+/Fuller//2*CSU exptl.	1	Highly WSM-resistant; moderate yield potential
OK12612	N02Y5078/OK05741W	1	Highly WSM-resistant; low yielding ability east of panhandle
OK11P139	TX94V6920/TAM 303//OK Bullet	1	Moderate WSM resistance; panhandle-adapted beardless
OK12912C-138407-2	N91D2308-13/OK03926C//OK03928C	2	Doublestop upgrade for straw strength
OK128084C	N91D2308-13/OK04902C//OK05907C	2	Higher yielding and better HF resistance vs. OK12912C
OK11709W-139122-1	OK02523W/OK00608W//OK00611W	1	High pre-harvest sprout tolerance; broad disease resistance
OCW04S717T-6W	CIMMYT seln/KS exptl.//KS91W047	1	Similar to OK11709W-139122-1 but beardless; **Gold*n*Grain**

a Not listed here are five candidates the featuring soft red winter class adapted to eastern Oklahoma, Arkansas, Missouri and areas further north (OCW03S580S-8WF); Gallagher re-selections with uniform stripe rust resistance (OK15807, OK15811), plus one with slightly later maturity (OK15818); and one beardless HRW candidate best fit for the panhandle with unconfirmed WSM resistance (OK11P228).

Table 13. Trait ratings (1-to-5 scale) for OSU candidate varieties placed under seed increase in fall 2017 with Oklahoma Foundation Seed Stocks. Grey, HRW elite; orange, WSM-resistant candidates; dark orange, Clearfield Plus candidates; no highlight, HW elite with pre-harvest sprout tolerance.

	Trait category[a]										
Candidate	DP	HF	YR	LR	TS	PM	V	AST	SS	BQ	Weaknesses
OK12716	2	1	2	4	5	3	1	2	2	3	Prostrate growth
OK13209	2	1	1	1	4	4	1	1	1	1	April freeze
OK12DP22004-016	4	2	3	3	4	2	1	1	1	1	Grazing recovery
OK13621	1	5	1	4	3	2	1	3	2	1	April freeze
OK12206-127206-2	1	1	1	2	3	2	1	2	1	1	Test wt., sprouting
OCW05S616T-2	2	4	2	1	4	1	1	1	2	1	Moderately tall
OK13P016	1	1	1	2	3	4	1	1	2	1	
OK14319	1	1	1	1	1	2	1	1	1	2	April freeze
OK13625	4	5	2	1	2	2	1	1	3	1	Winter injury
OK14P212	1	1	2	1	5	--	1	3	1	1	
OK168512	--	2	2	3	2	--	1	3	1	2	
OK168513	--	2	2	1	2	--	1	3	3	2	
OK12612	2	5	3	5	5	--	1	3	2	3	Yield potential
OK11P139	2	5	2	4	3	1	1	2	2	3	Limited target area
OK12912C-138407-2	1	3	1	1	3	2	1	1	1	1	Tall
OK128084C	3	2	1	2	3	--	1	1	1	2	April freeze
OK11709W-139122-1	1	5	2	1	2	2	1	3	1	2	Tall
OCW04S717T-6W	1	5	1	1	1	1	1	4	2	1	April freeze

a Trait categories 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, WSBM/WSSM 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.

Wheat Variety Trials

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The 2017 Oklahoma wheat production is estimated to be approximately 98.6 million bushels, which is about 28 percent less than 2016 production (Table 14) and 0.2 percent less than 2015 production. The lower total grain production compared to 2016 is the result of fewer wheat acres planted in the state this year. The 4.5 million planted acres were down 10 percent compared to the previous year, and with low wheat prices during the season, harvested acres were down as well. The number of harvested acres is estimated at 2.9 million, which is 17 percent less than in 2016 (Table 14). Despite the lower harvested acres, the statewide average yield is projected at 34 bushels per acre. This is five bushels per acre (13 percent) less than the record-tying 2016 state average but five bushels per acre (17 percent) greater than the previous 10-year average.

Table 14. Oklahoma wheat production for 2016 and 2017 as estimated by OK NASS, June 2017.

	2016	*2017*
Harvested acres	3.5 million	2.9 million
Yield (bu/A)	39	34
Total bushels	136.5 million	98.6 million

The 2016-2017 wheat growing season can be characterized overall by periods of rainfall and near optimal growing conditions at critical times. The growing season got an early start with rainfall in late August, prompting producers interested in targeting fall forage to begin planting. Planting continued to move rapidly during early September, and most of the wheat at this time was sown into adequate soil moisture and emerged rapidly. Wheat intended for grain-only was sown during the average timeframe of early- to mid-October. A majority of the wheat sown at this time also had adequate soil moisture for good establishment, but most of the northwest and panhandle regions of the state were not as fortunate. Dry soil conditions in those regions resulted in suboptimal stands or no germination at all. After mid-October, little precipitation fell throughout the state for the remainder of the fall, and temperatures were above normal. Crop conditions during the early part of the growing season were rated mostly good, but with the lack of rainfall during the latter part of fall, crop conditions began deteriorating by the end of November. Fortunately, most of the wheat that was sown into adequate soil moisture was able to establish adequate above- and below-ground growth before going into winter dormancy.

Warmer-than-normal temperatures continued throughout much of the winter. January and February are normally very dry months for the southern Great Plains. Fortunately, much of the state received 2 to 4 inches of precipitation during mid-January. While some of the precipitation came in the form of ice in the Woodward area, it did not do much damage to the crop. It also provided the soil moisture needed for some wheat to germinate in the northwest and panhandle regions that had been sown in dry conditions.

With the above-average temperatures during the winter, plants broke winter dormancy early, and spring green-up advanced quickly. The first hollow stem growth stage was reached for many varieties before the end of February, almost two weeks ahead of normal. Another round of widespread showers fell across much of the Wheat Belt on Feb. 20, excluding the panhandle and northeastern parts of the state. For some areas, this provided a boost to help plants recover from grazing injury. Other areas, especially south central Oklahoma, did not receive as much of this needed rainfall, and as a result, some grazed wheat pastures did not recover as well. Considering the warm temperatures during spring green-up, the prevailing thought was that much of the wheat would be mature and harvested by mid-May. However, temperatures returned to normal and slightly below normal during mid- to late-March. Many areas received another round of rainfall at the end of March, providing adequate soil moisture as the wheat crop transitioned into reproductive growth. Cool temperatures and adequate soil moisture persisted throughout heading and grain fill, favoring kernel filling. One abnormal weather event that occurred this year was a foot of snow that accumulated in the panhandle on the last weekend in April. This did result in lodged plants and lower test weight values, but the overall effect on yield was not as detrimental as expected at the time.

Most wheat was mature in southwestern Oklahoma by the middle of May and by the end of May in the central part of the state. Producers, for the most part, were not delayed by rainfall events, and with the dry weather during June, much of the wheat was harvested timely and quickly. Overall, harvest was almost complete in the state by late June.

Yields throughout Oklahoma were variable depending on location but were above average overall. Part of this variability was due to overgrazing and/or rainfall variability. Rainfall mostly occurred about every three to four weeks throughout the beginning of 2017. Field averages of 30 to 40 bushels per acre were the norm across much of the state, but higher averages, even into the 60 to 70 bushels per acre range, were not uncommon in some areas. Test weights throughout harvest remained at or above 60 pounds per acre for early-harvested fields and did not drop much below the upper 50s towards the end of harvest.

Different insect pressures were a concern at times during the growing season, but few were widespread, overlapping or season long. Some of the wheat planted in late August into early September was hit hard by fall armyworms, and some fields had to be replanted. Dead tillers on varieties susceptible to Hessian fly showed up on early planted wheat in areas of southwest Oklahoma during mid-fall, but only a couple reports of Hessian fly were documented during the spring. The dry weather in northwest Oklahoma through the winter provided ideal conditions for winter grain mite and brown wheat mite to thrive on wheat plants coming out of winter dormancy. Aphids were not really on the radar of most producers until mid-March, but this turned out to be not as big of a problem as had been observed in previous years. Despite the low aphid numbers, it was not hard to find BYD as flag leaves and heads started to emerge. While there was quite a bit of purpling and yellowing associated with BYD, there was not as much stunting as sometimes observed with early-season transmission of the virus. Wheat Streak Mosaic, or WSM, transmitted by the wheat curl mite, was a significant issue for producers around the state, but the majority of the affected areas seemed to be concentrated in southwestern and northwestern Oklahoma, as well as the panhandle region. Yield reductions were very apparent in fields infected with WSM.

The warm temperatures and available moisture during the fall prompted the development of some foliar diseases, primarily leaf rust. Leaf rust spores were able to survive the winter due to mild conditions, but the disease was slowed by hot temperatures and lack of available moisture during spring green-up. However, when temperatures returned to normal during mid- to late-March, the abundant inoculum present allowed leaf rust to become one of the top diseases for producers across most of the state. The presence of leaf rust during 2017 was abnormal compared to previous years as it developed sooner and persisted through grain fill while also reaching a wider geographic area. In addition to leaf rust, stripe rust was present, but at low to moderate levels in isolated areas and not as widespread throughout the state as it was in 2015 and 2016. Because of the impact that both rusts have had over the past couple years, producers were more open to apply a foliar fungicide to susceptible varieties, with many fields throughout the state receiving at least one fungicide application. Variety trial results from Apache, Chickasha and Lahoma indicated again this year that producers were well justified in spraying many of these acres. This year, grain yield of the variety Bentley, for example, resulted in a 27 bushels per acre increase at Lahoma when treated once with a foliar fungicide at flag leaf emergence. The results at Lahoma also showed the power of genetic resistance to disease in varieties such as Doublestop CL+ in which the fungicide treated plots only resulted in a 1 bushel per acre increase in yield over the nontreated plots.

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 a fungicide, 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 cone-seeded, 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 30 feet at harvest. Wheel tracks were included in the plot area for yield calculation, for a total plot width of 60 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-till 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 Hege 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 was generally below 12 percent, and maximum and minimum grain moisture for all plots at a location typically ranged no more than 2 percent. Keyes plots were not harvested due to severe hail damage in late June, and the Lamont plots were not harvested due to severe Italian ryegrass pressure. The Hooker plots were harvested, but data are not reported as the trial coefficient of variation exceeded 25.

Additional information on the Web

A copy of this publication as well as additional information on varieties and wheat management can be found at:

Website: www.wheat.okstate.edu
Blog: www.osuwheat.com
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Wheat protein data are available in Extension Current Report CR-2135 Protein Content of Winter Wheat Varieties in Oklahoma, 2016-2017.

2016-2017 Oklahoma Wheat Variety Performance Tests Summary.

Source	Variety	Afton	Altus	Alva	Apache	Apache Fungicide	Balko	Buffalo	Cherokee	Chickasha	Chickasha IWM	Goodwell Irrigated
		-----	-----	-----	-----	-----	grain yield (bu/A)	-----	-----	-----	-----	-----
AGSECO	AG Icon	-	31	-	-	-	-	-	-	30	41	43
AGSECO	AG Robust	-	27	-	-	-	-	-	-	26	36	41
PlainsGold	Avery	-	-	50	-	-	37	84	60	-	-	41
OGI	Bentley	32	25	56	60	72	29	75	75	18	47	52
OGI	Billings	32	28	-	-	-	-	-	-	25	44	55
Syngenta	Bob Dole	-	38	-	-	-	-	-	-	37	49	45
PlainsGold	Brawl CL +	-	-	61	-	-	31	76	72	-	-	45
PlainsGold	Byrd	-	-	51	-	-	35	74	67	-	-	47
OGI	Doublestop CL +	29	32	64	58	61	33	84	75	33	48	46
OGI	Duster	33	34	52	57	61	32	75	59	37	56	52
OSU	Endurance	32	24	58	60	64	31	67	66	29	41	42
OGI	Gallagher	32	32	57	72	76	26	66	71	28	48	45
AGSECO	Hot Rod	-	29	-	-	-	-	-	-	45	54	50
OGI	Iba	33	32	62	70	68	35	82	77	30	53	50
KWA	Joe	26	39	68	-	-	49	89	89	34	50	55
PlainsGold	Langin	-	-	55	-	-	35	-	73	-	-	42
KWA	Larry	24	20	60	-	-	30	75	72	16	42	49
LCS	LCS Chrome	20	26	66	68	72	33	76	77	29	39	42
LCS	LCS Mint	28	22	64	51	68	36	71	62	14	32	43
LCS	LCS Pistol	30	27	55	59	64	42	75	64	27	48	48
LCS	LCS Wizard	-	26	-	-	-	-	-	-	30	47	48
OGI	Lonerider	35	-	54	-	-	32	-	-	-	-	54
Dyna-Gro	Long Branch	-	32	-	-	-	-	-	-	24	45	48
OGI	NF 101	-	23	-	-	-	-	-	-	36	52	46
OGI	Ruby Lee	41	27	59	67	73	23	74	74	33	49	44
OGI	Smith's Gold	-	34	55	66	66	30	-	66	34	54	46
OGI	Spirit Rider	-	-	-	-	-	20	-	71	-	-	39
OGI	Stardust	-	31	-	-	-	-	-	-	18	39	43
Syngenta	SY Achieve CL2	-	34	-	-	-	-	-	-	27	53	45
Syngenta	SY Benefit	44	24	-	-	-	-	-	-	22	50	43
Syngenta	SY Drifter	-	30	-	-	-	-	-	-	32	41	51
Syngenta	SY Flint	35	26	-	51	59	-	-	-	21	46	49
Syngenta	SY Grit	-	25	-	-	-	-	-	-	20	48	42
Syngenta	SY Llano	30	30	-	45	60	-	-	-	27	43	-
Syngenta	SY Monument	33	-	64	-	-	36	73	78	-	-	40
Syngenta	SY Razor	-	29	-	60	56	-	-	-	33	42	-
Syngenta	SY Rugged	-	27	-	-	-	-	-	-	27	42	55
LCS	T158	-	31	-	-	-	-	-	-	26	56	57
Watley Seed	TAM 112	-	-	50	-	-	27	72	60	-	-	38
AGSECO	TAM 114	-	33	-	-	-	-	-	-	39	61	43
Watley Seed	TAM 204	30	-	45	64	71	31	-	66	14	42	57
KWA	Tatanka	30	30	55	-	-	49	-	73	25	49	52
WestBred	WB4269	-	39	-	-	-	-	-	-	38	57	53
WestBred	WB4303	-	28	-	-	-	-	-	-	29	51	46
WestBred	WB4458	31	28	-	70	76	-	-	-	20	45	58
WestBred	WB4515	-	30	-	-	-	-	-	-	33	58	42
WestBred	WB4721	-	36	-	-	-	-	-	-	29	52	49
WestBred	WB-Cedar	36	31	50	-	-	24	-	64	40	58	46
WestBred	WB-Grainfield	31	-	66	68	85	37	81	84	30	61	49
WestBred	Winterhawk	-	34	55	76	83	36	76	83	30	58	54
KWA	Zenda	-	32	-	-	-	-	-	-	36	46	58
OSU Experimentals												
	OK11755W-9W	-	28	-	-	-	-	-	-	-	-	51
	OK11D25005	-	-	-	-	-	-	-	78	-	-	-
	OK12206-2	37	-	61	-	-	-	-	64	-	-	56
	OK12621	46	-	-	-	-	-	-	-	-	-	-
	OK12716R/W	29	28	62	62	63	29	-	84	27	54	46
	OK12912C-2	-	32	65	60	60	-	-	-	-	-	-
	OK12D22002-077	24	24	55	53	61	28	-	-	19	43	46
	OK12D22004-016	38	-	-	-	-	-	-	-	-	-	61
	OK13209	31	30	63	66	63	-	-	-	34	48	-
	OK13621	-	33	-	-	-	-	-	-	29	54	52
	OK14319	28	-	-	-	-	-	-	74	-	-	-
	Mean	**32**	**30**	**58**	**62**	**67**	**33**	**76**	**72**	**29**	**48**	**48**
	LSD (0.05)	**6**	**6**	**5**	**11**	**12**	**6**	**12**	**7**	**7**	**7**	**8**

Notes: Shaded values are not statistically different from the highest value within a column.

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

Source	Variety	*Homestead*	*Kildare*	*Kingfisher*	*Lahoma*	*Lahoma Fungicide*	*Marshall Dual-Purpose*	*Marshall Grain-Only*	*Thomas*	*Union City*	*Walters*
		grain yield (bu/A)									
AGSECO	AG Icon	-	-	-	65	67	-	-	-	-	-
AGSECO	AG Robust	-	-	-	65	75	-	-	-	-	-
PlainsGold	Avery	-	-	-	37	67	-	-	-	-	-
OGI	Bentley	52	57	20	53	79	20	26	58	42	19
OGI	Billings	43	34	18	54	66	20	20	66	26	-
Syngenta	Bob Dole	-	-	-	70	75	-	-	-	-	-
PlainsGold	Brawl CL +	-	-	-	66	83	-	-	-	-	-
PlainsGold	Byrd	-	-	-	48	80	-	-	-	-	-
OGI	Doublestop CL +	53	56	23	62	63	-	32	58	40	20
OGI	Duster	51	46	26	50	64	24	38	63	34	19
OSU	Endurance	44	45	19	48	63	24	33	56	31	15
OGI	Gallagher	51	45	24	67	76	22	30	71	36	17
AGSECO	Hot Rod	-	-	-	83	92	-	-	-	-	-
OGI	Iba	52	55	21	56	71	-	40	65	32	19
KWA	Joe	53	57	-	72	77	36	44	68	-	-
PlainsGold	Langin	-	-	-	60	84	-	-	-	-	-
KWA	Larry	45	51	17	43	77	-	16	50	-	-
LCS	LCS Chrome	55	52	32	58	66	16	34	61	40	21
LCS	LCS Mint	51	40	-	40	58	14	17	54	34	12
LCS	LCS Pistol	50	46	-	49	72	11	20	56	36	20
LCS	LCS Wizard	-	-	-	51	69	-	-	-	-	-
OGI	Lonerider	53	-	-	-	-	-	-	74	-	-
Dyna-Gro	Long Branch	-	-	-	45	67	-	-	-	-	-
OGI	NF 101	-	-	-	62	75	-	-	-	-	-
OGI	Ruby Lee	56	49	19	64	77	20	29	53	26	19
OGI	Smith's Gold	47	44	25	64	78	28	28	64	47	17
OGI	Spirit Rider	-	50	-	-	-	-	-	-	-	-
OGI	Stardust	42	-	-	45	62	14	21	-	-	-
Syngenta	SY Achieve CL2	-	-	-	65	82	-	-	-	-	-
Syngenta	SY Benefit	-	-	-	51	74	-	-	-	-	-
Syngenta	SY Drifter	-	-	-	60	70	-	-	-	-	-
Syngenta	SY Flint	43	54	22	56	70	19	27	52	42	17
Syngenta	SY Grit	-	-	-	54	80	-	-	-	-	-
Syngenta	SY Llano	36	35	18	58	71	14	-	52	33	15
Syngenta	SY Monument	55	48	23	72	84	29	40	65	-	-
Syngenta	SY Razor	-	-	-	-	-	-	-	-	44	12
Syngenta	SY Rugged	-	-	-	62	74	-	-	-	-	-
LCS	T158	-	-	-	55	83	-	-	-	-	-
Watley Seed	TAM 112	-	-	-	36	67	-	-	-	-	-
AGSECO	TAM 114	-	-	-	69	89	-	-	-	-	-
Watley Seed	TAM 204	47	46	25	49	77	16	14	53	43	16
KWA	Tatanka	53	51	-	53	77	14	22	57	-	-
WestBred	WB4269	-	-	-	78	88	-	-	-	-	-
WestBred	WB4303	-	-	-	69	80	-	-	-	-	-
WestBred	WB4458	49	47	16	59	75	21	27	54	35	12
WestBred	WB4515	-	-	-	67	88	-	-	-	-	-
WestBred	WB4721	-	-	-	64	82	-	-	-	-	-
WestBred	WB-Cedar	42	37	23	62	72	34	31	63	38	-
WestBred	WB-Grainfield	56	62	26	64	88	17	31	60	32	15
WestBred	Winterhawk	-	-	-	64	82	-	-	-	-	19
KWA	Zenda	-	-	-	67	82	-	-	-	-	-
OSU Experimentals											
	OK11755W-9W	-	-	-	52	78	-	-	-	-	-
	OK11D25005	-	-	-	-	-	-	29	-	22	21
	OK12206-2	-	-	-	61	78	17	28	-	-	-
	OK12621	-	-	-	-	-	21	35	-	-	-
	OK12716R/W	48	56	27	61	77	21	27	59	49	22
	OK12912C-2	44	-	21	70	67	-	-	-	-	-
	OK12D22002-077	39	44	18	48	62	-	-	-	-	-
	OK12D22004-016	-	-	-	69	84	-	-	-	-	-
	OK13209	43	-	17	77	77	-	-	-	-	-
	OK13621	-	-	-	68	78	-	-	-	-	-
	OK14319	-	-	-	-	-	28	40	-	43	-
	Mean	**48**	**48**	**22**	**59**	**75**	**21**	**29**	**60**	**37**	**17**
	LSD (0.05)	**8**	**7**	**5**	**8**	**8**	**6**	**8**	**7**	**7**	**2**

Notes: Shaded values are not statistically different from the highest value within a column.

Notes

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