Partners in Progress
WHEAT

Wheat Research at OSU 2019

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-1058

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Partnerships Enhance Wheat Research

Partners in Progress Oklahoma Agricultural Experiment Station has a long-standing partnership with the Oklahoma Wheat Commission (OWC) and the Oklahoma Wheat Research Foundation (OWRF) to develop wheat varieties that are specifically adapted to the climate, diseases and pests found in Oklahoma and the surrounding area.

The partnerships not only provide partial funding for our research programs; they also are sources of valuable feedback from producers to help keep our research programs focused and relevant.

These partnerships are truly one of the best examples of the Division of Agricultural Sciences and Natural Resources (DASNR) working in a cooperative relationship with commodity groups to achieve common goals.

The Partners in Progress Wheat Research Report is one of a series of annual reports from the Experiment Station highlighting research results and impacts of funded projects. This information is utilized throughout the year in educational 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 aims to meet the needs of Oklahoma wheat producers.

At the start of this report is a summary of accomplishments for fiscal year 2018-19 and follow up with detailed narratives that describe progress.

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.

As the Green Blade Riseth

As the green blade riseth from the buried grain, which then emerges, we must continue with tenacity and strength! The 2019 wheat harvest season was anything but effortless for Oklahoma wheat producers as they faced continued saturation of moisture within wheat fields across the state. It was concerning to see the potential for end-use qualities that millers and bakers seek lost to less-than-favorable conditions at harvest time with an abundance of rain.

While producers persevered in getting the crop out, researchers at OSU continued work in many areas with fitting results and evaluations that are allowing us to move forward in the world of wheat. Management studies and continued efforts for end-use quality strengths within the OSU variety development program tell the story of stronger, more durable varieties that certainly rose to the challenge.

In 2019, global production increases with unfavorable foreign trade negotiations impacted price by making the marketing of this crop more challenging for U.S. wheat producers. The end-use qualities from the Southern Plains, however, were much more favorable than expected and actually had higher quality rankings than much of the global wheat crop in other places. The wheat quality from Oklahoma in 2019 was much more favorable than what was harvested in the Australian and Argentine markets when dealing with kernel size, test weights, protein levels and falling numbers. With a more favorable trade outlook based on new negotiations between the U.S., China, Canada and Mexico, we are more hopeful things will look better as we move into the winter and spring months.

To carry on with the successes of more sound quality, given the adversity of environments that this crop faced from planting to harvest, the OSU small grains variety program moved full steam ahead. The program evaluated 505 Wheat Improvement Team experimental lines for seedling reaction to leaf rust, powdery mildew and tan spot, with 260 of these lines also being evaluated for adult plant resistance (APR) to leaf rust and 105 evaluated for APR to powdery mildew. In total, more than 43,000 single plant ratings were made, according to Dr. Bob Hunger, OSU Extension Wheat Pathologist. Also, the top six of seven varieties planted for acreage in Oklahoma were developed by the OSU Wheat Improvement Team (WIT), according to an Oklahoma Wheat Commission sponsored survey conducted by USDA-NASS in 2019.

This year, a long-awaited beardless cultivar OK Corral was released from OSU, replacing the performance of varieties like Deliver and Pete, representing a significant breakthrough with higher yielding ability, while also having better end-use quality and pest resistance for Hard Red Winter (HRW) wheat.

The data collected from OSU research plots made available in the variety performance tests yield summary helps ensure farmers and ranchers have an opportunity to observe the newest genetics in research demonstration plots throughout Oklahoma. The unique OSU small grains variety testing program is made possible with the teamwork of OSU Extension and farmer cooperators who allow trials on privately owned land.

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

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

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Partners in Progress WHEAT

Genetic Improvement and Variety Release of Hard Winter Wheat

Wheat Improvement Team (WIT)

2018-2019 progress made possible through OWRF/OWC support

- **Claimed the top six of seven varieties for planted acreage in Oklahoma, according to a survey sponsored by the Oklahoma Wheat Commission conducted by USDA-National Agricultural Statistics Service in 2019 (WIT).**
- **Released a long-awaited beardless cultivar, OK Corral, from the OSU pipeline to fill the productivity gap left by older OSU releases Deliver and Pete (WIT).**
- **Placed 12 candidates under preliminary or extended seed increase by Oklahoma Foundation Seed Stocks, six of which await a final decision by WIT to prepare release documentation. One candidate (OK168512) was confirmed to have strong resistance to wheat streak mosaic with top-tier yielding ability in the Oklahoma panhandle, whereas one candidate (OK16D101089) features a novel BYD resistance gene complex never before deployed in Oklahoma. One candidate (OK14124-2) provides a legitimate option for late-planted acres in Oklahoma with accelerated maturity, while OK12912C-138407-2 provides a legitimate option to Doublestop CL+ in central Oklahoma. OCW04S717T-6W, a hard white candidate, features blanket protection to eight diseases common in central Oklahoma and to another devastating disease that hopefully never appears in Oklahoma called wheat blast (WIT).**

OK168512	Overley+/Fuller//2*CSU exptl.
OK16D101089	OK12621/Bentley
OK14124-2	NI04430/OK05303//Fuller
OK12912C-138407-2	N91D2308-13/OK03926C//OK03928C
OCW04S717T-6W	CIMMYT seln/KS exptl.//KS91W047

- **Evaluated 1,781 wheat breeder lines (including 805 WIT lines) in the field for reaction to the wheat soil-borne mosaic/wheat spindle streak mosaic complex. The latest WIT release, OK Corral, features a high level of resistance (Hunger).**
- **Evaluated 505 WIT experimental lines in the greenhouse for seedling reaction to leaf rust, powdery mildew and tan spot, with 260 of these lines also being evaluated for adult plant resistance (APR) to leaf rust and 105 also evaluated for APR to powdery mildew. In total, more than 43,000 single-plant ratings were made (Hunger).**
- **Identified 16 WIT experimental lines (plus Doublestop CL+) as resistant to wheat streak mosaic by tests conducted in Nebraska (Hunger).**
- **Transformed isolates of *Pyrenophora tritici-repentis* (causal fungus of tan spot of wheat) to track and compare infection in tan spot susceptible and resistant wheat cultivars (Hunger).**
- **Expanded the OSU wheat germplasm base by continuing to import and hybridize with experimental lines from Hungary, Romania and Turkey (Hunger, Carver).**
- **Produced agronomically desirable experimental lines with moderate to high tolerance to bird cherry-oat feeding during seedling growth. End-use quality has not yet been fully characterized (Giles, Zarrabi, Carver).**

- Discovered a new greenbug resistance gene designated *Gb8* in the reselection line PI 595379-1. This gene confers resistance to economically important biotypes B, C, E, H, I and FL and can be directly used to enhance greenbug resistance in breeding populations (Xu).
- Developed PCR-based, high-throughput KASP markers for greenbug resistance gene *Gb5*, paving the way for its use in breeding populations (Xu).
- Identified a new powdery mildew resistance gene designated *Pm65* in the high-yielding Chinese cultivar Xinmai208. *Pm65* confers near-immunity to most U.S. powdery mildew isolates (Xu).
- Identified a novel leaf rust resistance gene designated *Lr622111* in Iranian landrace PI 622111. *Lr622111* confers resistance to multiple leaf rust races in the Great Plains (Xu).
- Developed a suite of four high-throughput KASP assays targeting unique sequences in the Duster allele for *QYld.osu-1BS*. With the purported yield benefit of *QYld.osu-1BS* and no known detriment to end-use quality, these assays provide a platform to introgress a highly valuable piece of Duster's genome into contemporary cultivars (Yan).
- Performed transgenic experiments to validate candidate gene *TaRG4* for *TaHf-A1*, and developed a KASP marker assay to facility selection of this unique and powerful Hessian fly resistance gene originally found in Duster (Yan).
- Evaluated 24 fungicide x fungicide rate combinations for control of wheat foliar diseases in field trials (Hunger).
- Provided in-season electronic wheat disease updates to wheat growers, consultants, Extension educators and researchers via an electronic format (Hunger).
- Confirmed absence of Karnal bunt in Oklahoma wheat grain samples to allow Oklahoma wheat to move without restriction into the export market (Hunger).

WIT is now 21 years in operation and 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 cultivars and dissemination of the knowledge that best captures their genetic potential.

WIT's latest commercial product, OK Corral, will fill a widening gap in wheat genetics intended for graze-out and wheat-for-hay acres. The challenge was not in producing a forage-type cultivar suited for those uses, but instead to produce a complete cultivar with the requisite forage capacity and grain-producing capacity *with* quality. OK Corral fits that bill by having these noted features: rapid stand establishment, good vegetative and reproductive recovery from grazing, high yield potential from central Oklahoma to the panhandle and exceptionally high gluten strength at an average wheat protein.

WIT scientists who received funding from the OWRF in 2018-2019 and reported their findings are **Bob Hunger**, wheat pathology research and development of disease-resistant germplasm; **Xiangyang Xu**, pest resistance discovery and introgression; **Kris Giles and Ali Zarrabi**, bird cherry-oat aphid, or BCOA, resistance discovery; **Charles Chen** and **Liuling Yan**, gene discovery and genomic technology; **Brian Arnall and Gopal Kakani**, nitrogen-use efficiency; and **Brett Carver**, wheat breeding and cultivar development.

WIT was delighted to welcome two new members in 2019: **Misha Manuchehri**, weed management and wheat herbicide tolerance; and **Amanda de Oliveira Silva**, wheat information exchange and physiology (with emphasis on maximizing protein yield).

Recurring research projects in wheat response to diseases and insects, development of improved molecular tools to optimize breeding efficiencies, better understanding of nitrogen responsiveness and cultivar development are common themes of WIT's output. These must continue to sustain or build upon the advances made thus far. However, each year, WIT breaks new ground on several research fronts and uses this report to highlight exciting new discoveries that lay the foundation for future success.

Just a few of the advances reported here are:

- confirmation of useful levels of wheat streak mosaic resistance in high yielding and functionally appealing genetic backgrounds,
- identification of BCOA tolerance at a yield level suitable for commercialization,
- emergence of new greenbug, leaf rust and powdery mildew resistance genes with their ancillary markers, and
- discovery and cloning of the gene responsible for Duster's Hessian fly resistance.

Locally adapted germplasm with wheat streak mosaic or barley yellow dwarf resistance has finally reached the level of commercial readiness. All that lies ahead is to identify the best choices for deployment in Oklahoma. These decisions are on the release docket for early 2020, including a realistic hard red winter alternative to spring wheat in late-planting situations and a new Clearfield® wheat.

WIT also has expanded its reach to more effectively serve wheat producers in far western Oklahoma, now in its eighth year of executing a smaller but highly targeted cultivar development program at Goodwell as a part of the larger conventional breeding program. A typical breeding cycle, without doubled haploids, requires about nine to 12 years, so this part of the WIT pipeline will soon be accessible to seed producers in the High Plains.

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.

Wheat Pathology Research and Development of Disease-Resistant Germplasm

Bob Hunger

Entomology and Plant Pathology

Evaluating wheat lines for multiple disease reactions is critical to developing improved wheat cultivars. More than 100 diseases of wheat are caused by a variety of organisms including fungi, bacteria, viruses and nematodes. The key diseases addressed by WIT include the wheat soil-borne mosaic/wheat spindle streak mosaic (WSBM/WSSM) complex, leaf rust, stripe rust, powdery mildew; leaf spotting diseases such as tan spot, Septoria tritici blotch and spot blotch; mite-transmitted virus diseases such as wheat streak mosaic (WSM); and aphid-transmitted virus diseases such as barley yellow dwarf (BYD). Not all of these diseases can be evaluated every year in Oklahoma due to lack of disease pressure in the field or ineffective methods to provide consistent and reliable results. Hence, WIT has focused its efforts on a combination of field and greenhouse tests to characterize breeding lines for reaction to the WSBM / WSSM complex, leaf rust, powdery mildew, tan spot and the aphid / BYD complex, while relying on external evaluations for information related to diseases such as stripe rust and WSM.

Building a disease package for Oklahoma wheat cultivars

Table 1 summarizes the number of lines evaluated for reaction to eight diseases during the last 10 years. Table 2 provides a historical perspective of disease screening that occurred from 1983 through 2019. As indicated in these tables, evaluation of breeder lines for disease resistance involves both field and greenhouse testing. Field testing under naturally high disease pressure is ideal, but greenhouse testing allows for testing large numbers of lines in a shorter time period with minimal bias of

Table 1. Number of WIT experimental lines tested for disease reaction in the last 10 years. Data do not include ratings collected in breeding or Extension trials.

		Disease[a]						
Year	*Testing location*	*WSBM/WSSM*	*LR*	*YR*	*PM*	*TS*	*STB*	*BYD*
2010	Field	1,500						
	Greenhouse		400		400	400	400	
2011	Field	1,400						
	Greenhouse		324		67	262	262	
2012	Field	1,030			65			573
	Greenhouse		427		618	170	105	
2013	Field	2,410			197	95		150
	Greenhouse		347		150	277	277	
2014	Field	1,700				21		705
	Greenhouse		466		141	411		
2015	Field	1,500					75	160
	Greenhouse		385		115	385		
2016	Field	1,421		385			145	145
	Greenhouse		385			385		
2017	Field	1,523						
	Greenhouse		331		331	331		
2018	Field	1,800						
	Greenhouse		465		465	465		
2019	Field	2,136						
	Greenhouse		805		505	505		
Total	Field & greenhouse evaluations	16,420	4,335	385	3,054	3,707	1,264	1,733

[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.

Table 2. Summary of WIT experimental lines evaluated for reaction to specific diseases from 1983 through 2019. Data do not include ratings collected in breeding or extension trials.

Disease	*Year evaluations started*	*Evaluation location*[a]	*Number of lines evaluated*
WSBM/WSSM[b]	1983	GH	500
		Field	38,014
Leaf rust	1983	GH - seedling	22,496
	2017	GH – adult plant	3470
	1983	Field	5,230
Powdery mildew	2000	GH	3,615
	2011	Field	1,630
Tan spot	2003	GH	3,756
	2014	Field	45
Septoria tritici blotch	2004	GH	1,200
	2014	Field	215
Barley yellow dwarf	2011	Field	505
Spot blotch/common root rot	2014	GH	25
Total	1983-2018	GH	31,257
		Field	43,886
	1983-2018	GH + field	75,143

[a] GH=greenhouse

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

competing diseases. Greenhouse testing also provides results if the disease is lacking in the field. Often, greenhouse testing identifies susceptible lines to remove from the pipeline, with lines identified as resistant subsequently tested in the field for confirmation. Hence, greenhouse testing typically is conducted on many or all of the breeder nurseries (23 were tested in 2019 for a total of 805 lines), whereas evaluation in field nurseries is directed more at the diseases occurring at a high severity in a given year.

In 2019, funding provided by the Oklahoma Wheat Research Foundation (OWRF) directly supported seedling and adult plant evaluations in the greenhouse for leaf rust (505 lines; 10,780 single-plant ratings), powdery mildew (505 lines; 11,858 single-plant ratings) and tan spot (505 lines; 21,168 single-plant ratings) for a combined total of 43,806 plant ratings made in the greenhouse. These ratings were combined with field ratings from Oklahoma and other states to facilitate line advancement toward cultivar development.

A field nursery dedicated to BYD and powdery mildew

This nursery is located in Stillwater. The cultivar Pete, which is susceptible to both powdery mildew and BYD, was planted in strips between breeder lines to facilitate incidence and severity of both diseases. The nursery was planted in mid to late September 2018 to enhance the opportunity of infestation with aphids carrying the BYD virus. To enhance incidence and severity of powdery mildew, the nursery was fertilized with 100% of the amount of nitrogen recommended from a soil test, as well as 50% of that amount again applied in late winter. This was done because high nitrogen favors powdery mildew.

In 2019, powdery mildew and aphids/BYD were lacking around Stillwater and the state. Hence, no powdery mildew or BYD field ratings were possible; however, greenhouse testing for reaction to powdery mildew provided information on both the reaction of seedlings as well as adult plants for many of the OSU breeder lines under observation (see next section on powdery mildew). Moving forward, BYD field ratings are anticipated, given the history of BYD incidence in the Stillwater area. These field ratings will be needed to validate genotypic predictions of novel sources of BYD resistance emerging from the variety development pipeline (see **Carver** report).

Post-vernalization greenhouse tests for adult plant reactions to leaf rust and powdery mildew

The combination of seedling ratings with adult plant resistance (APR) ratings in the greenhouse provides a comprehensive and important selection tool for leaf rust and powdery mildew resistance. Table 3 shows the results of this paired testing of seedlings and adult plants, in combination with leaf rust ratings of selected cultivars in the Oklahoma Wheat Variety Comparison charts (Extension fact sheet PSS-2142). Note how the combination of seedling and APR tests in the greenhouse indicates APR for a variety such as Deliver, which is then confirmed by the field rating from the OSU variety comparison chart. The consistency of greenhouse and field leaf rust ratings indicates that selection of lines for advancement based on greenhouse testing can be reliable.

In 2018-19, this same effort for leaf rust was extended to powdery mildew and appears to have been successful, as indicated in Table 4. Note the agreement of seedling ratings with adult plant ratings. Monitoring will continue as WIT fully assesses the reliability of this new greenhouse test relative to field reactions.

Table 3. Leaf rust ratings of selected cultivars based on reactions of seedlings and adult plants in the greenhouse, and ratings as presented in the Oklahoma Wheat Variety Comparison chart in 2019.

Entry	*Seedling rating[a] (greenhouse)*	*Adult plant rating[a] (greenhouse)*	*Adult plant field rating[b]*
Deliver (APR control)	S	MR	R
TAM 110 (S control)	S	S	S
Chisolm	S	S	S
Duster	MR	R	R
Gallagher	MR	R	R
Smith's Gold	S	MS	MR
Bentley	S	I	MS
Lonerider	S	MR	I
Joe	MR	R	R

[a] S = susceptible; MS = moderately susceptible; I = intermediate; MR = moderately resistant; R = resistant.

[b] Adult plant ratings as presented in the Variety Comparison Chart from Oklahoma (PSS-2142).

Table 4. Selected comparisons of seedling (greenhouse) versus adult plant ratings (greenhouse) for reaction to wheat powdery mildew. Note the high level of agreement between ratings for seedlings versus ratings for adult plants.

Entry	*Seedling rating*[a]	*Adult plant rating*[a] *(post-vernalization)*
Bentley	MR	S
OK09915C-1 (Doublestop CL+)	R	R
OK12912C-138407-2	R	R
OK149132C	MR	MR
OK128084C	R	MR
OK09922C-1-14RHf-3C19	R	R
OK149072C-17HR-1	I	MS
OK149072C-17HR-2	MS	I
OK15932C-17HR-1	R	R
OK15927C-17HR-1	R	MR
OK15919C-17HR-2	R	R
OK15919C-17HR-4	R	R
OK15928C-17HR-2	R	MR
OK15928C-17HR-3	R	I
OK15924C-17HR-2	R	R
OK15924C-17HR-3	R	R
OK15922C-17HR-2	R	R
OK15909C-17HR-4	R	R
OK15909C-17HR-5	R	MR
OK16903C-17HR-1	R	MR
OK16906C-17HR-2	R	MR
OK16907C-17HR-3	I	I
OK16908WC-17HR-1	R	R
OK188402C	R	R
OK188403C	R	MR
OK188405C	S	I
OK188407C	R	MR
OK188410C	R	R
OK188413C	R	R
OK188417C	MS	S
OK188420C	R	R
OK188421C	MS	S
OK188422C	I	MS
OK188423C	---	R
OK188425C	R	R

[a] S = susceptible; MS = moderately susceptible; I = intermediate; MR = moderately resistant; R = resistant; Seg = segregating for reaction.

Leaf spotting diseases and WSM

Repeated attempts to establish a field nursery to evaluate reactions to the leaf spotting diseases tan spot and Septoria tritici blotch have not been successful. However, testing of seedlings in the greenhouse for reaction to tan spot has been reliable and consistent. Hence, future efforts are planned to expand tan spot testing to include adult plant tests, as has been done successfully for leaf rust and powdery mildew. An experimental Septoria greenhouse assay in the seedling stage also will be pursued.

Wheat streak mosaic testing is conducted in western Nebraska in cooperation with Dr. Gary Hein, University of Nebraska-Lincoln. Hein established a field trial similar to WIT's test for reaction to the WSBM/WSSM complex. In his test, wheat is planted in the summer and grows much as volunteer wheat would in a typical field after a hailstorm. Wheat to be tested is then planted in the fall into this volunteer wheat, which by then is heavily infested with the wheat curl mite and the *Wheat streak mosaic virus*. (Figure 1). When symptoms occur in the spring, visual ratings are taken on a scale of 0 to 3 (0 = resistant/no symptoms and 3 = susceptible/severe symptoms) and a Soil Plant Analysis Development (SPAD) meter is used to take readings that indicate the amount of leaf greenness. With SPAD values, the higher the value, the greener the leaf. Since WSM causes severe yellowing and tissue death, SPAD readings from susceptible plants will be lower because leaves are less green. Twenty OSU wheat lines (19 experimental lines and Doublestop CL+) were tested in 2018-19. Sixteen of those lines and Doublestop CL+ were identified as being as or more resistant than the resistant check cultivar Mace (Table 5). This testing has allowed WIT to rapidly move toward release of a WSM-resistant cultivar adapted to Oklahoma. The most likely candidate for release consideration is OK168512 (see **Carver's** report).

Investigations into the wheat tan spot pathosystem

Tan spot, caused by the fungus *Pyrenophora tritici-repentis* (PTR), primarily affects wheat plants by the production of toxins named *ToxA*, *ToxB* and *ToxC*. *ToxA* induces necrosis or tissue death, whereas *ToxB* and *ToxC* induce chlorosis or tissue yellowing (Figure 2). Research during 2018-19 revealed that PTR race 1, which produces *ToxA*, is the most common race in Oklahoma and that 95% of Oklahoma PTR isolates carry the gene to produce *ToxA*. No isolates were identified to carry the gene to produce *ToxB* and the tools to diagnose for *ToxC* have not been sufficiently developed to investigate this toxin.

Since PTR *ToxA* is a major pathogenicity factor, isolates containing and lacking the *ToxA* gene were selected and transformed to express green fluorescence in order to compare the infection and colonization process on susceptible versus resistant wheat differentials. Two isolates containing the *ToxA* gene and two isolates lacking the *ToxA* gene were transformed using *Agrobacterium*-mediated transformation. Using these transformed isolates, the

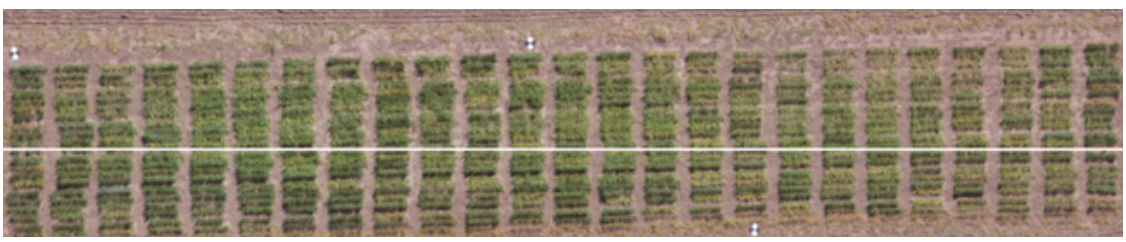

Figure 1. Aerial view of the wheat streak mosaic screening nursery in Nebraska. Note the dying wheat around the edge of the trial that was planted and grew through the summer to serve as the green bridge for the wheat curl mite and *Wheat streak mosaic virus*.

Table 5. Reaction of selected WIT experimental lines to wheat streak mosaic as tested in Nebraska by University of Nebraska-Lincoln (UNL) scientist Gary Hein. Values for Mace and Tomahawk are the mean of eight replicates; all other values are the mean of two replicates.

Entry (reaction by UNL)	*SPAD[a] reading (leaf greenness)*	*Visual rating (0-3)[b]*
Mace (R)[b]	44.9	0.5
Tomahawk (S)	39.5	1.9
Doublestop CL+ (MR)	41.9	1.0
Doublestop CL+ reselection (MR)	44.2	1.0
OK168512 (MR)	45.1	1.0
OK168517 (MR)	42.7	1.0
OK16107125 (R)	44.1	0.5
OK16107055 (R)	43.8	0.0
OK12222 (R)	42.6	0.5
OK16107028 (S)	41.6	3.0
OK16107109 (S)	40.6	2.0
OK16107112 (S)	40.6	2.5

[a] SPAD reading indicates leaf greenness and overall canopy hygiene. Higher values indicate better hygiene. Symptoms of WSM cause yellowing and necrosis (tissue death), so lower SPAD values indicate more pronounced WSM symptoms.

[b] Higher visual ratings indicate increasing susceptibility to WSM.

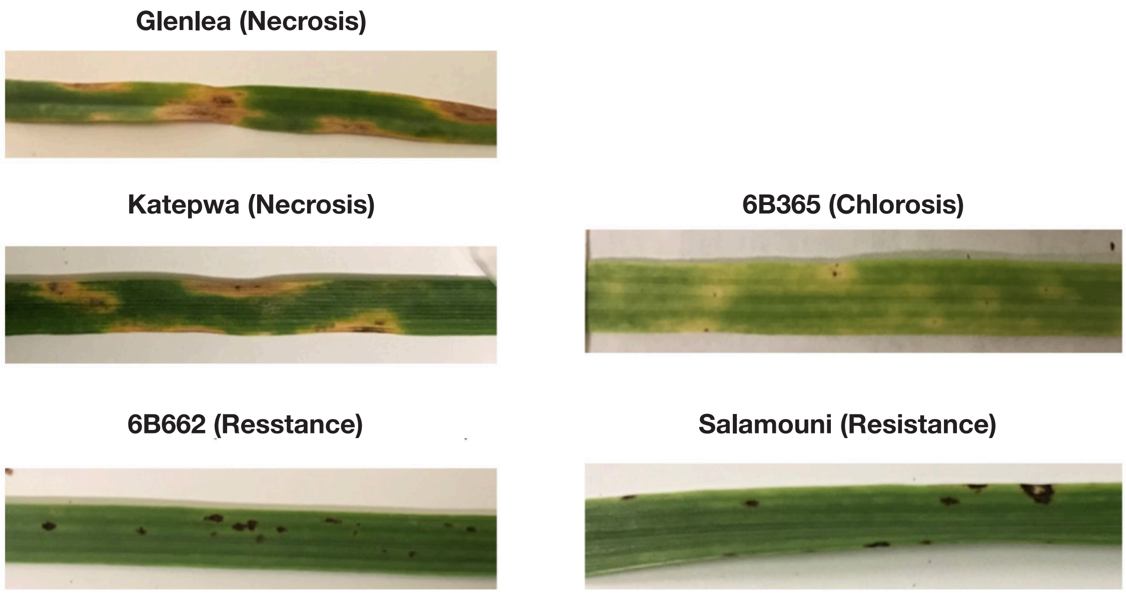

Figure 2. Symptoms caused on wheat leaves by toxins produced by *Pyrenophora tritici-repentis* (causal fungus of tan spot of wheat). Necrosis (tissue death) produced on Glenlea and Katepwa is induced by *Tox A*; chlorosis (yellowing) produced on 6B365 is induced by *Tox B* and *ToxC*. Salamouni and 6B662 are wheat varieties resistant to all toxins, hence, also resistant to tan spot.

infection process was compared on a tan spot susceptible variety (Glenlea; Figure 3) and a tan spot resistant variety (Salamouni; Figure 4). Symptoms were scored at three, five and seven days post inoculation (DPI) and fungal infection was observed directly using epifluorescence microscopy. On the susceptible cultivar Glenlea, necrosis was first observed at three DPI and continued to expand on the leaf tissue through the epidermal and mesophyll cells (Figure 3). On the resistant cultivar Salamouni, the fungus penetrated the leaf tissue as indicated by the green fluorescence, but at five DPI, the plant started to produce a hypersensitive response (cell death) that prevented the fungus from spreading to other parts of the plant (Figure 4). These results are preliminary and will continue to be pursued to define the mechanism(s) of resistance to tan spot.

Novel wheat germplasm imported from European countries

Novel wheat germplasm was exchanged once again in 2019 with the national wheat breeding programs in Hungary, Romania and Turkey. This

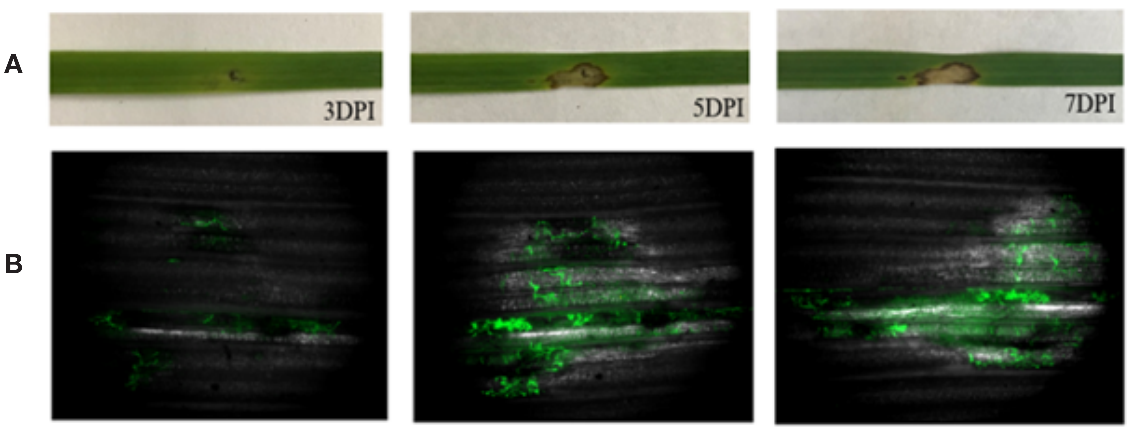

Figure 3. (A) Symptoms on the tan spot susceptible wheat variety Glenlea three, five and seven days post inoculation (DPI). Note large area of necrosis around the point of infection. (B) Infection by *Pyrenophora tritici-repentis* (PTR) on Glenlea expressing green fluorescent protein at three, five and seven DPI.

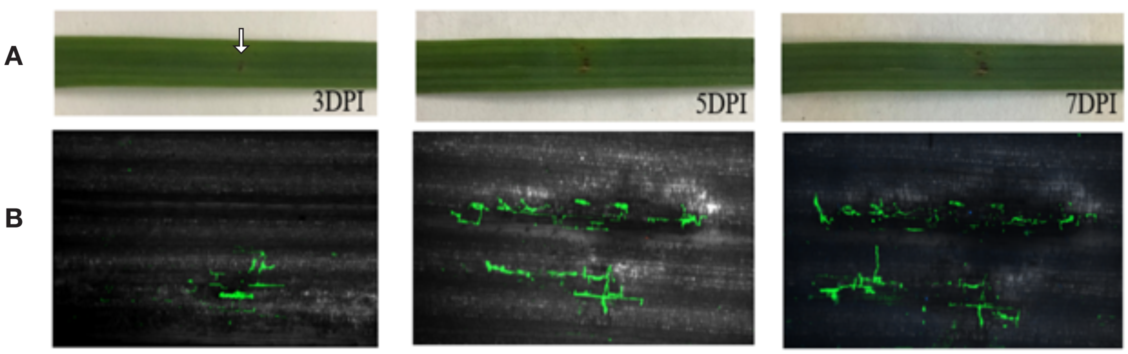

Figure 4. (A) Symptoms on the tan spot resistant wheat variety Salamouni three, five and seven days post inoculation (DPI). Note small point of dark infection indicated by arrow. (B) Infection by *Pyrenophora tritici-repentis* (PTR) on Salamouni expressing green fluorescent protein at three, five and seven DPI.

germplasm was used to hybridize with lines adapted to Oklahoma for the purpose of introgressing novel and useful traits into the OSU wheat gene pool. Expanding the OSU wheat gene pool in this manner is a constant goal.

Related activities not directly funded by OWRF

The 2019 Oklahoma wheat crop was tested (20 samples from 10 counties) for the presence of Karnal bunt. Results from this testing 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. The area used to evaluate foliar fungicides in 2019 was flooded twice—in late May and early June—and that flooding combined with strong winds resulted in extensive lodging before plants matured. Because of that lodging and driftwood deposited in the trial, the trial was abandoned and not harvested. Electronic updates on the status of wheat diseases were provided to wheat producers, Extension educators and personnel in the wheat industry.

Pest Resistance Discovery and Introgression

Xiangyang Xu
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Wheat, peanut and other field crops research unit

This part of the WIT report is dedicated to using multiple tools from several disciplines, including wheat pathology and entomology, molecular genetics and wheat pre-breeding to diversify and fortify the germplasm base on which WIT's development pipeline depends. Gene introgression is a highly worthy, but time-consuming process that often involves multiple steps to reach a commercial product. A research project may be mentioned here but go unmentioned in a subsequent *Partners in Progress* report, as gene introgression plays out over several breeding cycles. Every attempt will be made to connect work reported here to past *Partners in Progress* reports.

Genetics behind greenbug resistance

Greenbug is a worldwide insect pest that poses a serious threat to wheat production, and resistance sources are needed for wheat improvement. Thanks to the support of OWRF, a greenbug-resistant line PI 595379-1 was identified and reported in *Partners in Progress, 2018*. As a follow-up in 2019, WIT tested the response of PI 595379-1 to a set of economically important greenbug biotypes and found that PI 595379-1 confers a wide spectrum of resistance to greenbug biotypes B, C, E, H, I and FL (Table 6). Genetic analysis was conducted for the response to greenbug biotype E, a biotype common to Oklahoma, in an $F_{2:3}$ population derived from the cross PI 595379-1 x PI 243735. A single gene, herein designated *Gb8*, conferred resistance to biotype E. Linkage analysis placed *Gb8* in a 2.7-Mb interval in the terminal bin of chromosome 7DL (7DL3-082-1.0), spanning 595.6 to 598.3 Mb in the Chinese Spring reference sequence (IWGSC RefSeq v1.0) (Figure 5). *Gb8* co-segregated with a newly developed SSR marker *Xstars508*, positioned at 596.4 Mb in the reference sequence. Allelism

Table 6. Responses of PI 595379-1, Largo (*Gb3*), CI 17959 (*Gb4*), W7984 (*Gb8*) and Custer to greenbug biotypes B, C, E, F, H, I and FL.

Biotype	*PI 595379-1*	*Largo*	*CI 17959*	*W7984*	*Custer*
B	R[a]	S	S	S	S
C	R	R	R	S	S
E	R	R	R	R	S
F	S	S	S	S	S
H	R	R	S	S	S
I	R	R	R	R	S
FL	R	S	S	S	S

[a] R = resistant; S = susceptible.

tests showed that *Gb8* was different from three permanently named genes on the same chromosome arm and the estimated genetic distance between *Gb8* and *Gb3* was 15.35 ± 1.35 cM.

PI 595379-1 is a reselection of PI 595379 (KS95WGRC33) that is phenotypically similar to wheat cultivar TAM 107. Except for greenbug resistance, no obvious difference was observed in other traits between PI 595379 and PI 595379-1. Therefore, *Gb8* can be directly used in wheat improvement programs using linked molecular markers as tags to the resistance allele, such as *Xstars505*, *Xstars506*, *Xstars508* and *Xstars511*. WIT initiated a project aimed at transferring *Gb8* into WIT breeding lines OK16D101089, OK16107131 and OK16107155, which carry Hessian fly resistance from Duster and BYD resistance gene *Bdv2/3*. PI 595379 also carries genes conferring resistance to leaf rust (*Lr41*), Septoria tritici blotch, glume blotch, Stagonospora nodorum blotch, tan spot and wheat curl mite, so it is expected that PI 595379-1 also carries these genes. Successful characterization of these genes in PI 595379-1 will make it feasible to simultaneously transfer multiple biotic stress resistance genes from this source to elite Oklahoma-adapted cultivars.

Another greenbug resistance gene, *Gb5*, was originally identified in older accessions CI 17883, CI 17884 (TA 3516) and CI 17885 (pedigree: CI 15092/T. speltoides// Fletcher/3/ 5*Centurk), and it confers resistance to greenbug biotypes C, E, I, K, TX5 and TX7. *Gb5* was located to an alien chromosomal segment transferred from *Triticum speltoides* chromosome 7S to wheat chromosome 7A. This chromosome translocation consists of the complete long arm of *speltoides* chromosome 7S, most of the short arm of 7S and the terminal region of the short arm of wheat chromosome 7A. Lukaszewski et al. (2000) transferred the alien chromosome segment to spring wheat cultivar Pavon F76 and used recombination induced by the *ph1b* mutation to reduce the length of the alien chromosomal segment, leading to the development of the breeding line PI 603919 (UCRBW98-2) containing a shorter interstitial translocation carrying *Gb5*.

To determine the location of *Gb5*, Pavon F76, PI 603919 and TA3516 were genotyped using a set of SSR markers newly developed by WIT. PI 603919 is a near-isogenic line of Pavon F76, and TA3516 carried the original translocation segment. The

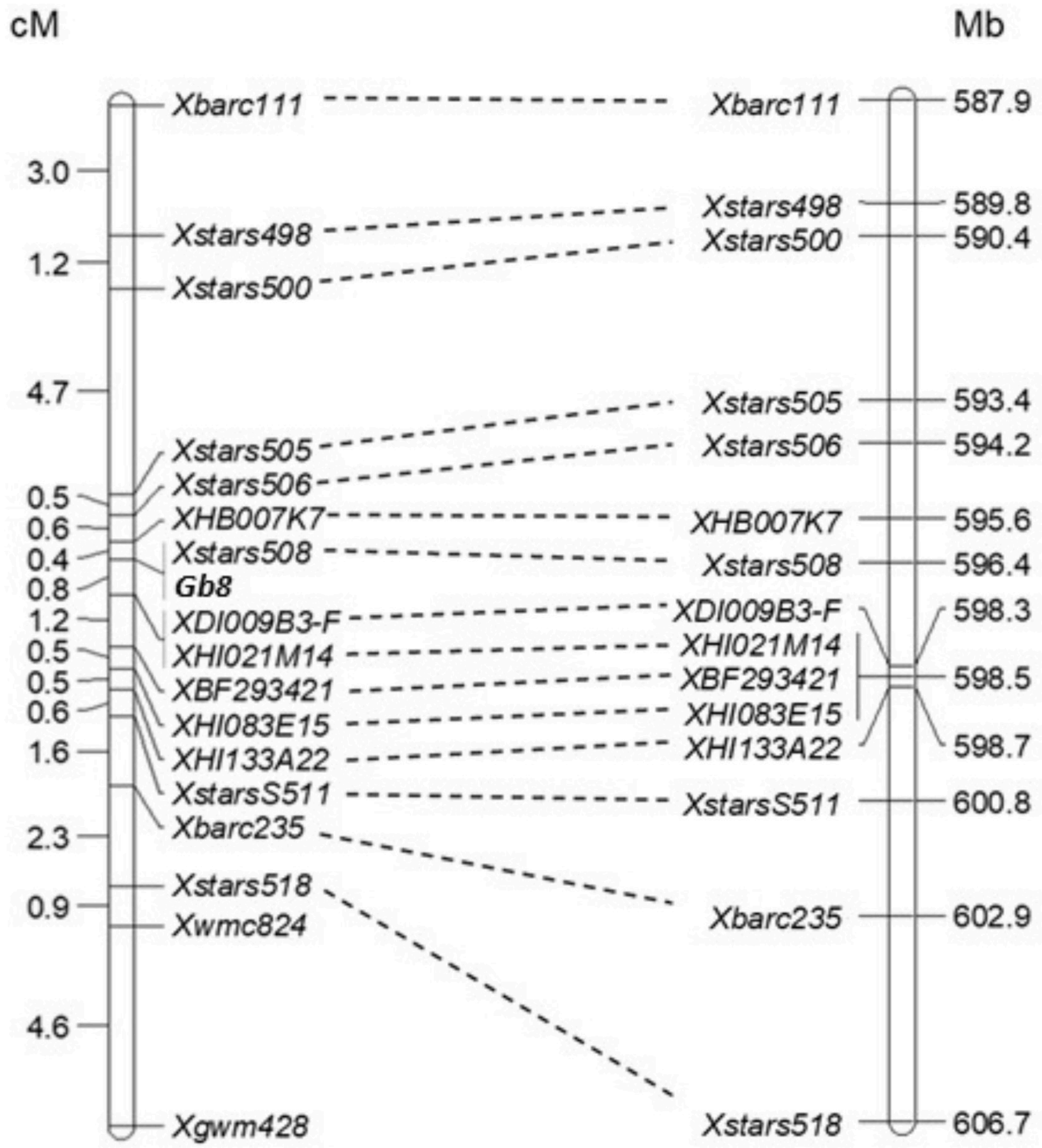

Figure 5. Linkage (left) and physical (right) map of *Gb8*. Marker names are shown at the right of the linkage map and the left of the physical map. Genetic distances in cM are given on the left of the linkage map and the physical positions of some markers on the Chinese Spring reference assembly (IWGSC RefSeq v1.0) are provided to the right of the physical map.

genotyping results indicated that the *T. speltoides* chromosome segment in PI 603919 is approximately 73 Mb, spanning from 655 to 728 Mb in the Chinese Spring reference sequence. As reported in *Partners in Progress, 2018*, WIT genotyped a recombinant inbred ine (RIL) population derived from the cross TA3516 × Bainong418 and identified a large set of single-nucleotide polymorphism (SNP) markers between bread wheat chromosome 7AL and *T. speltoides* chromosome 7SL. Given that the *T. speltoides* chromosome segment in PI 603919 carries *Gb5*, four genotyping by sequencing (GBS) markers in the target region were selected and successfully converted to PCR-based, high-throughput Kompetitive Allele Specific PCR (KASP) markers. These markers were tested in the RIL population, and the genotyping results indicated they can be used to tag *Gb5*, paving the way to use *Gb5* in breeding programs (Figure 6).

New resistance genes for powdery mildew and leaf rust

In addition to the phenotyping work discussed in **Hunger's** report, a high breeding priority is to identify novel powdery mildew resistance genes that can be readily used either alone or complexed with known resistance genes. An F_2 population and 227 $F_{2:3}$ families derived from the cross Xinmai 208 × Stardust were generated to map a powdery mildew resistance gene in Xinmai 208, a high-yielding Chinese wheat cultivar. Genetic analysis indicated that Xinmai 208 carried a

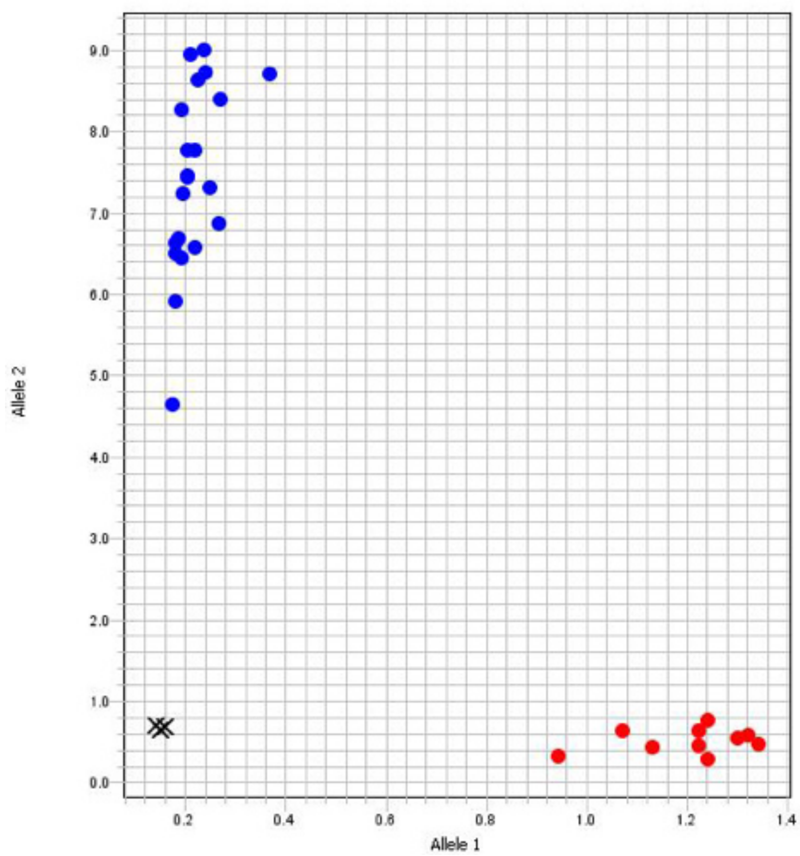

Figure 6. Segregation of the resistant (blue) and susceptible alleles at the KASP marker S7A-664269174 locus in a RIL population. Black symbols represent controls.

single dominant powdery mildew resistance gene, designated herein *Pm65*. Linkage analysis delimited *Pm65* to a 0.5 cM interval covering 531.8 Kb (763,289,667–763,821,463 bp) on chromosome 2AL in the Chinese Spring reference sequence (Figure 7). An allelism test indicated that *Pm65* is a new gene about 10.3 cM distal to the *Pm4* locus. *Pm65* was 0.3 cM proximal to *Xstars355* and 0.2 cM distal to *Xstars356*. It conferred near immunity to 19 of 20 *Bgt* isolates collected from different wheat-growing regions of the U.S. (Table 7). Coming from a high-yield potential cultivar, *Pm65* can be directly used to enhance powdery mildew resistance in wheat. The newly developed SSR markers *Xstars355* and *Xstars356* have the potential to tag *Pm65* for line selection, which will prove useful as 108 $F_{3:5}$ experimental lines featuring *Pm65* introgressed into a Stardust background and were planted in fall 2019 at Stillwater.

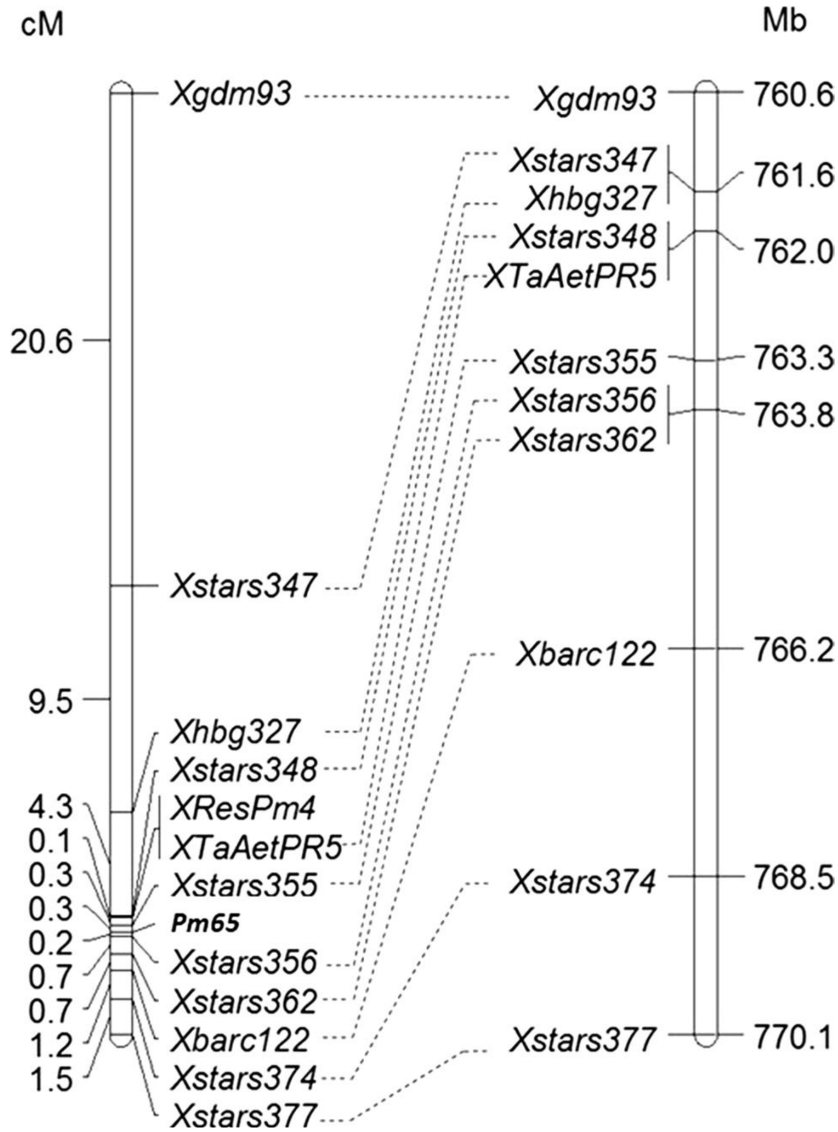

Figure 7. Genetic (left) and physical (right) map of chromosome 2AL containing *Pm65*. Marker names are shown at the right of the linkage map, and genetic distances in cM on the left. The physical positions of molecular markers are given at the far right of the physical map.

As with powdery mildew resistance genes, most leaf rust resistance genes have lost effectiveness in the Great Plains of the U.S. because of the abundant variation in *Puccinia triticina* Eriks. (*Pt*) populations. Identification of novel leaf rust resistance genes is imperative for sustainable wheat production. To characterize the leaf rust resistance gene in Iranian landrace PI 622111, an F_2 population and 175 $F_{2:3}$ lines derived from PI 622111 × Yuyuan 3 were evaluated for seedling responses to *Pt* race *Pt52-2* (MMPSD). The χ^2 tests indicated a single gene segregated in the F_2 and F_3 populations ($\chi^2_{3:1} = 1.15$, $df = 1$, $p = 0.28$; $\chi^2_{1:2:1} = 2.39$, $df = 2$, $p = 0.30$). Based on $F_{2:3}$ phenotypic data, 12 F_2 plants showing homozygous resistance and 12 F_2 plants exhibiting homozygous susceptibility were sequenced to develop GBS markers, leading to the identification of locus *S5B_9219863*, positioned at 9,219,863 bp on the short arm of chromosome 5B in the Chinese Spring reference sequence. All resistant or susceptible plants carried the nucleotide 'A' or 'G,' respectively, representing different alleles at the *S5B_9219863* locus.

Thus, the leaf rust resistance gene in PI 622111 is close to *S5B_9219863*.

Table 7. Responses of the powdery mildew-susceptible check cultivar Jagalene and wheat cultivars carrying *Pm65*, *Pm4a* and *Pm4b* to *Bgt* isolates collected from different wheat growing regions of the USA.

Bgt isolate	*State*	*Region*	*Jagalene*	*CI 14123 Pm4a*	*Ronos Pm4b*	*Xinmai 208 Pm65*
GAP-A-2-3	Georgia	Southeast	S[a]	S	R	R
GAP-B-2-2	Georgia	Southeast	S	S	R	R
MSG-A-3-1	Mississippi	Southeast	S	R	R	R
MSG-C-3-4	Mississippi	Southeast	S	S	I	R
NCC-B-1-3	North Carolina	Mid-Atlantic	S	S	R	R
NCF-D-1-1	North Carolina	Mid-Atlantic	S	R	I	R
MIR(14)-D-3-3	Michigan	Great Lakes	S	R	R	R
MIR(14)-E-1-3	Michigan	Great Lakes	S	R	R	R
NYA-E-3-3	New York	Great Lakes	S	S	R	R
NYB-E-1-2	New York	Great Lakes	S	S	R	S
PAF(14)-D-1-2	Pennsylvania	Great Lakes	S	S	R	R
PAF-E-2-2	Pennsylvania	Great Lakes	S	R	R	R
MTG1-1a	Montana	Northwest	S	R	R	R
MTG1-3a	Montana	Northwest	S	S	R	R
NEI 1-3	Nebraska	Great Plains	S	R	R	R
NEI 3-1	Nebraska	Great Plains	S	R	R	R
NEI 5-5	Nebraska	Great Plains	S	S	R	R
OKH-A-2-3	Oklahoma	Great Plains	S	R	R	R
OKS-A-2-2	Oklahoma	Great Plains	S	S	R	R
OKS-B-2-2	Oklahoma	Great Plains	S	R	R	R

[a] R = resistant, S = susceptible and I = intermediate responses.

A total of 1,445 SSR loci was identified in the terminal region (0-13.5 Mb) of chromosome 5BS, and 48 of them were chosen to develop SSR markers. Linkage analysis delimited the leaf rust resistance gene in PI 622111, designated *Lr622111*, to an interval of 1.1 Mb flanked by *Xstars669* (6.5 Mb) and *Xstars678* (7.6 Mb) (Figure 8). *Lr622111* was 0.5 cM proximal to *Xstars669* and 6.1 cM distal to *Xstars678*. *Lr622111* is a new gene differing from *Lr52*, a leaf rust resistance gene located also on 5BS, in response to *Pt* races. *Lr622111* will be used to enhance leaf rust resistance in WIT germplasm.

BCOA Resistance

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Ali Zarrabi
Entomology and Plant Pathology

During the last five years, segregating breeding populations were enriched for resistance to bird-cherry oat aphid, or BCOA, feeding, followed by the development of experimental lines with seedling tolerance to high infestations. For the 2018-2019 funding cycle, three research activities were emphasized: 1) field-collected BCOA were introduced

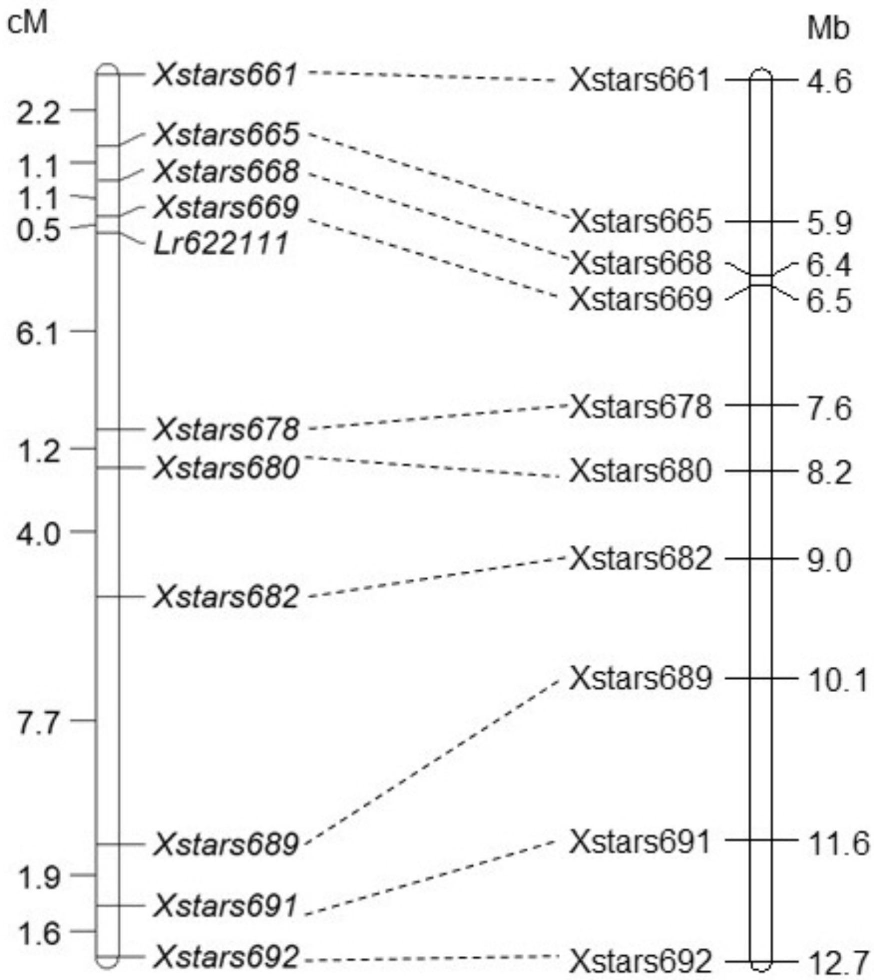

Figure 8. Linkage (left) and physical (right) maps for *Lr622111*. Marker loci names are shown at the right of the linkage map, and genetic distances are shown in cM on the left. The physical positions of molecular markers are given at the far right of the physical map.

into laboratory colonies to maintain wild-type virulence; 2) a laboratory phenotyping assay was once again validated by confirming susceptibility of previously screened entries tested in the 2019 OET2 and OET3 nurseries; and most importantly, 3) tolerance to BCOA feeding was validated among experimental lines developed within this project and simultaneous to field testing in breeding trials across Oklahoma. Twenty-two of those entries were classified as moderately tolerant to highly tolerant (Table 8). Five entries are undergoing further field testing in small plots (infested vs. non-infested) to demonstrate the yield benefits of seedling tolerance.

Entries with BCOA tolerance that have desirable agronomic and quality traits are being used in designed crossing schemes to incorporate BYD and other disease-resistant traits into the same cultivar, a feat yet to be accomplished in any wheat breeding program. Going forward, emphasis will be placed on improvement of the screening procedure by incorporating quantitative seedling measurements into the resistance score. This should allow for more rapid and reliable phenotyping. Now only one to two years away, WIT lines with validated BCOA tolerance that perform consistently well in statewide yield and quality trials during the 2019-20 crop year have a high probability of direct commercialization.

Table 8. Tolerance scores for advanced WIT experimental lines selected from 2018-19 breeding trials with confirmed tolerance to BCOA infestations.

Experimental line	*Score (1-5)*	*Classification*
OK19105021	2.3	highly tolerant
OK19105023	2.5	highly tolerant
OK19105100	2.5	highly tolerant
OK19105010	2.6	tolerant
OK1980035	2.6	tolerant
OK19105055	2.6	tolerant
OK19105120	2.7	tolerant
OK19105115	3.0	tolerant
OK19105122	3.0	tolerant
OK19105126	3.0	tolerant
OK19105004	3.1	tolerant
OK19105110	3.1	moderately tolerant
OK19105001	3.2	moderately tolerant
OK19105134	3.3	moderately tolerant
OK19105139	3.3	moderately tolerant
OK19105038	3.4	moderately tolerant
OK19105059	3.5	moderately tolerant
OK19105050	3.6	moderately tolerant
OK19105060	3.6	moderately tolerant
OK1980063	3.6	moderately tolerant
OK19105111	3.6	moderately tolerant
OK19105130	3.6	moderately tolerant
OK16D101089 (check)	3.5	moderately tolerant

Gene Discovery, Transformation and Genomic Applications

Liuling Yan
Plant and Soil Sciences

Functional validation of the candidate gene for TaHf-A1 for Hessian fly resistance in Duster

Hessian fly (HF) is one of the most destructive pests of U.S. wheat, and the Great Plains (GP) biotype is the most prevalent in the southern Great Plains. In previous work of this laboratory, WIT reported that only three candidate genes remained to be identified in the targeted 169 Kb region of *TaHf-A1*, the locus discovered by this group as the genetic key to unlocking HF resistance in Duster. The *TaHf-A1* locus on the short arm of chromosome 1A contains a unique gene that confers stable resistance against biotype GP.

In 2019, *TaHf-A1* was cloned in this laboratory, marking the first wheat gene to be cloned for insect resistance. More than 35 genes for Hessian fly resistance have been reported in wheat, but none of them has been cloned. No gene has been cloned for any resistance against other insects, including greenbug, Russian wheat aphid and wheat curl mite.

Transgenic experiments were performed in 2019 to validate candidate gene *TaRG4* for *TaHf-A1*. Over-expression of *TaRG4* in susceptible cultivar Jagger was sufficient to provide resistance to biotype GP in two individual transgenic T_0 plants. Furthermore, the *TaRG4* protein provided a positive bait to identify effectors or avirulent proteins from HF biotype GP. Experiments on T_1 populations derived from self-pollinated T_0 plants are currently in progress to further validate the function of *TaHf-A1* at a level that qualifies for publication.

Long before the *TaHf-A1* sequence is published in 2020, molecular markers will have been developed to accelerate deployment of this gene in the WIT and other wheat breeding programs. A preliminary but diagnostic polymerase chain reaction, or PCR, marker was developed and tested among five Oklahoma elite cultivars. Both Gallagher and Iba have Duster in their pedigree, but they differ in that Gallagher inherited the resistance allele from Duster, while Iba did not (Figure 9A). The Duster resistance allele was not effectively selected (by the breeder) during line development. The PCR products were digested with restriction enzyme *Cla*I to show polymorphic band patterns for the resistance allele and the susceptibility allele.

To more effectively and efficiently select the Duster resistance allele in current and future breeding materials, a Kompetitive Allele Specific PCR (KASP) marker for the Duster resistance allele is preferred (Figure 9B). The FAM™ axis shows the Duster allele in blue and the HEX™ axis shows the Billings allele in green, whereas the non-template control is indicated in black. FAM and HEX are trademarked names of dyes used in the assay and more broadly in DNA sequencing. This KASP assay can be used to accurately distinguish between the Duster resistance allele and the susceptible allele in Billings and many other cultivars to serve as a high-throughput screening platform. This will be critical in further proliferation of the Duster HF resistance trait throughout the WIT development pipeline. While 13 of 31 experimental lines in the most advanced breeding nursery (OET3) in

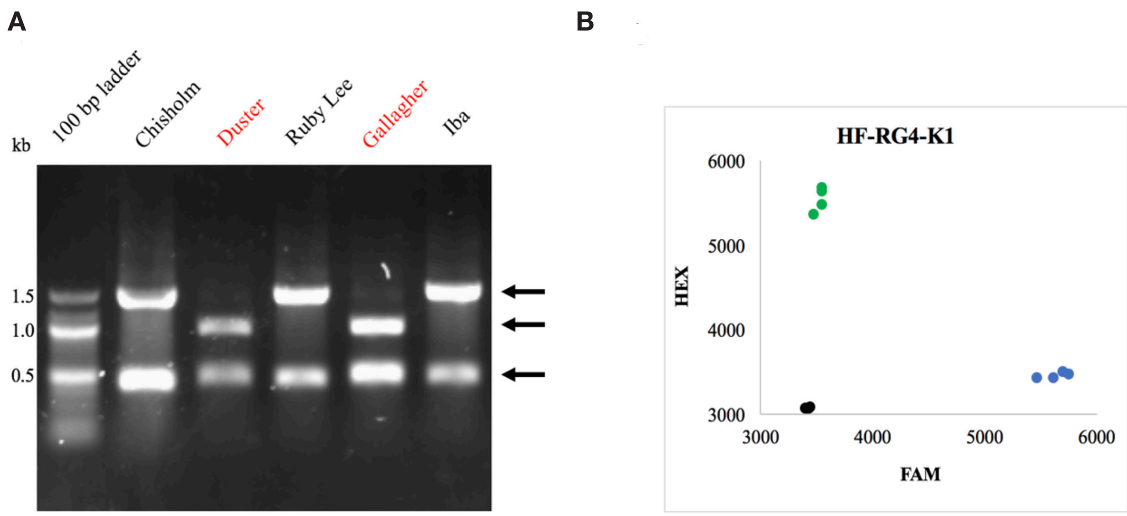

Figure 9. Molecular markers for *TaHf-A1* in wheat. (A) A PCR marker based on the restriction enzyme digestion and (B) a more convenient KASP marker.

2019-20 are positive carriers of Duster-derived HF resistance, this frequency could be and should be much higher if marker-based selection was initiated earlier in the line development process. Otherwise, hundreds of experimental lines are chosen to enter the line-testing phase sight unseen for HF resistance. This luck-of-the-draw strategy will soon change due to more sophisticated selection strategies outlined here and in Xu's report.

Development and deployment of KASP markers for *QYld.osu-1BS*

Another favorable gene discovered in Duster is *QYld.osu-1B*, which actually is a very large quantitative trait locus (QTL) on the short arm of chromosome 1B, that was found to increase grain yield 20% to 25% compared with the same genetic locus in Billings, another OSU cultivar with high yield potential conferred by other yield genes. Previously, this laboratory located *QYld.osu-1B* to an approximate 25 Mb region on chromosome 1BS (short arm) in Duster.

In 2019, the targeted region was "narrowed" to an approximate 18 Mb span, by testing progeny plants of recombinants screened from 6,406 gametes. However, the abnormally low recombination rate in the *QYld.osu-1B* region has inhibited cloning of the gene responsible for *QYld-.osu-1B* using a conventional positional cloning approach. Positional cloning of the gene in a genomic region with low recombination rate is a difficult task, even though a draft of genomic sequences in wheat is available. Before the gene is cloned, unique sequences identified in the *QYld.osu-1BS* region can be used as molecular markers for accelerating deployment of the gene for *QYld.osu-1BS* in WIT breeding populations. Amazingly, none of about 200 hard winter wheat lines from Southern Plains breeding programs carried the same allele at *QYld.osu-1B* from Duster.

This laboratory has identified four KASP markers corresponding to unique sequences in *QYld.osu-1B* from Duster that can be used with greater impact

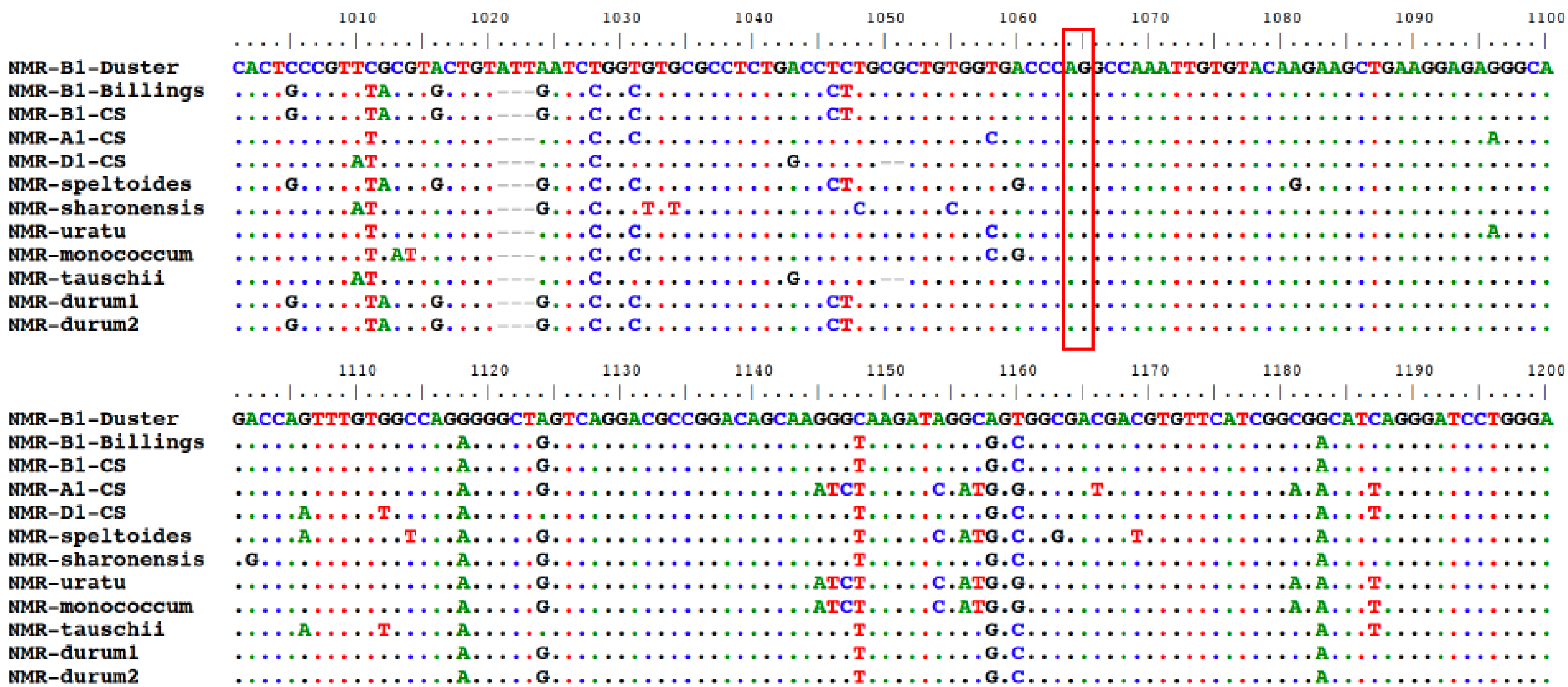

Figure 10. Sequence alignment of *NMR-B1* genes from Duster, Billings, Chinese Spring and several related wild species. Unique sequences were found throughout 2,150 bp of the complete *NMR-B1* gene, including conserved exon regions in Duster. Partial sequences, including exon 2 of the *NMR-B1* genes, are aligned to indicate differences between Duster and other sources available in the IWGSC database. The AG splicing site at the 3´ end of intron 1 of the *NMR-B1* genes is indicated with a red rectangle. Top and bottom alignments were split arbitrarily at 1100 bp to allow full view of the excerpted 200 bp sequence.

and utility in conventional selection. One example of a unique sequence identified in the *QYld.osu-1B* region is *NMR*, short for nitrogen metabolic regulator (*TraesCS1B02G037100*). In the *NMR-B1* gene sequence, Duster was unique compared with orthologous and homoeologous genes in diploid, tetraploid and hexaploid wheat, whereas Billings was 100% identical to Chinese Spring (Figure 10).

The corresponding four high-throughput KASP assays targeting unique sequences in Duster are displayed in Figure 11. KASP-12 was designed for the SNP at 1,253,260 bp, KASP-17 was designed for the SNP at 10,104,175 bp, KASP-8 was designed for the SNP at 18,386,168 bp and KASP-10 was designed for the SNP at 24,163,331 bp. Execution of all four assays ensures the whole genomic region of the Duster allele may be tracked in breeding populations derived from Duster or its progeny known to carry *QYld.osu-1BS*. With the purported yield benefit of *QYld.osu-1BS* and no known detriment to end-use quality, these assays provide a platform to introgress a highly valuable piece of Duster's genome into contemporary cultivars.

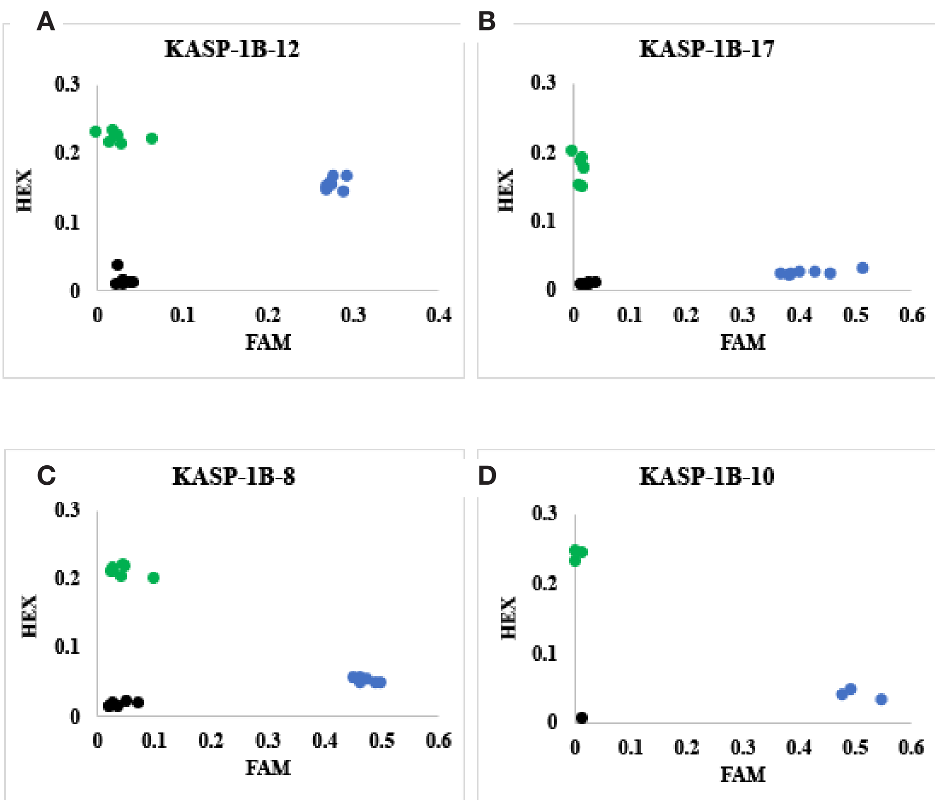

Figure 11. Unique to the Duster allele of *QYld.osu-1BS* are four KASP markers developed for SNPs. (A) KASP-12 at 1,253,260 bp; (B) KASP-17 at 10,104,175 bp; (C) KASP-12 at 18,386,168 bp; (D) KASP-10 at 24,163,331 bp. The Duster allele is indicated in blue on the KASP-FAM™ axis, whereas the Billings allele is indicated in green on the KASP-HEX™ axis. The non-template control is indicated with black dots.

Genetic Variation on a Genomewide Scale

Charles Chen

Biochemistry and Molecular Biology

Oklahoma is located in a climatically marginal region between the more humid eastern and semi-arid western climates, where drought stress historically led to the emigration of over 59,000 residents at a cost exceeding $1 billion in federal assistance in the 1930s. In 2012, Oklahoma alone lost more than $2 billion in drought-related agricultural damage. As the frequency of extreme climate disasters continues to rise, WIT aims at unraveling both the genetic and regulatory elements responsible for the drought-mediated physiological response and thereby ensuring improved resilience of Oklahoma's winter wheat crop.

Drought-induced structural changes in the Duster genome

Duster seeds were sown for a greenhouse drought experiment, using 100 plants in 30 pots, equally watered on a regular schedule apart from the treatment period. Water stress was imposed at the boot stage, where water was withheld for six days (drought treatment, DT), while control pots continued with regularly scheduled watering (control, well-watered treatment, WW). The drought treatment showed a gravimetric loss of approximately 10% and mean relative water content decrease of 15.2% (Figures 12A and 12B). The mean differences between WW and DT plants for rates of photosynthesis and transpiration were indicative of increased levels of activity in WW as demonstrated by positive values, whereas a negative value of instantaneous water use efficiency (IWUE) suggested drought stress (Table 9). Rates of photosynthesis and transpiration reflected 70% and 37 % of untreated (well-watered) plant potential, respectively, which led to an increase of IWUE by 52% in response to drought.

To investigate DNA structural changes in the Duster genome in response to the drought treatment, WIT and colleagues in the OSU biochemistry and molecular biology department developed a protocol to extract nuclei and to cleave the genome regions protected by the condensation of DNA due to applied drought stress. This new technique allows WIT to uncover the drought-induced, differential accessibility of the wheat genome that is directly associated with regulation of gene expression.

As shown in Figure 13A, about 1.5% of the Duster wheat genome was found differentially accessible, represented by 203.22 Mb (1.4%) in WW and 157.17 Mb (1.1%) in DT. With only 10.35 Mb of accessible regions shared between treatments (Figure 13A), highly differential DNA structural changes occurred as a result of environmental stress.

Table 9. Mean differences in photosynthesis, or Pn, transpiration, or Tr and instantaneous water use efficiency, or IWUE, between the well watered, WW, treatment and drought treatment, DT.

Measurement	*Mean*	*s.d.*
$Pn_{(WW-DT)}$	2.15	0.51
$Tr_{(WW-DT)}$	2.66	0.88
$IWUE_{(WW-DT)}$	-1.57	1.13

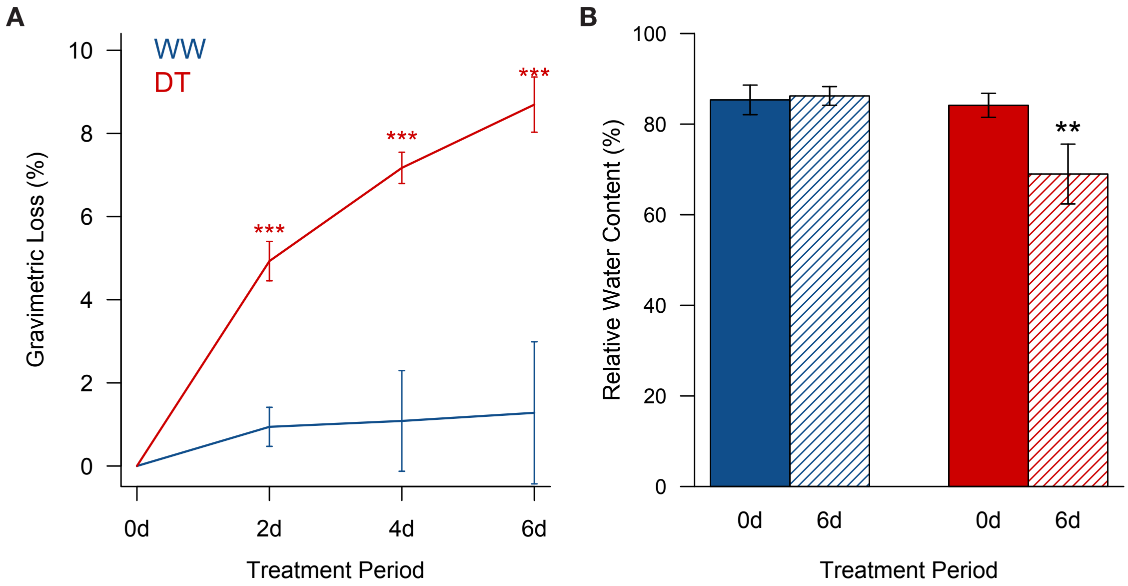

Figure 12. Assessment of the physiological response of Duster to drought. Pot water status was assessed by gravimetric loss (Figure 12A). The mean loss of droughted pots (red) was significantly greater (*P* < 0.001) than that of well-watered pots (blue), which maintained relatively stable pot weights throughout he treatment period. Relative water content, or RWC, was used as a measurement of plant water status (Figure 12B). No difference in mean RWC was detected in well-watered plants (blue) before (0 days) and after (six days) the drought treatment. Mean RWC of droughted plants (red) showed a significant difference (*P*< 0.01) after the treatment period (six days).

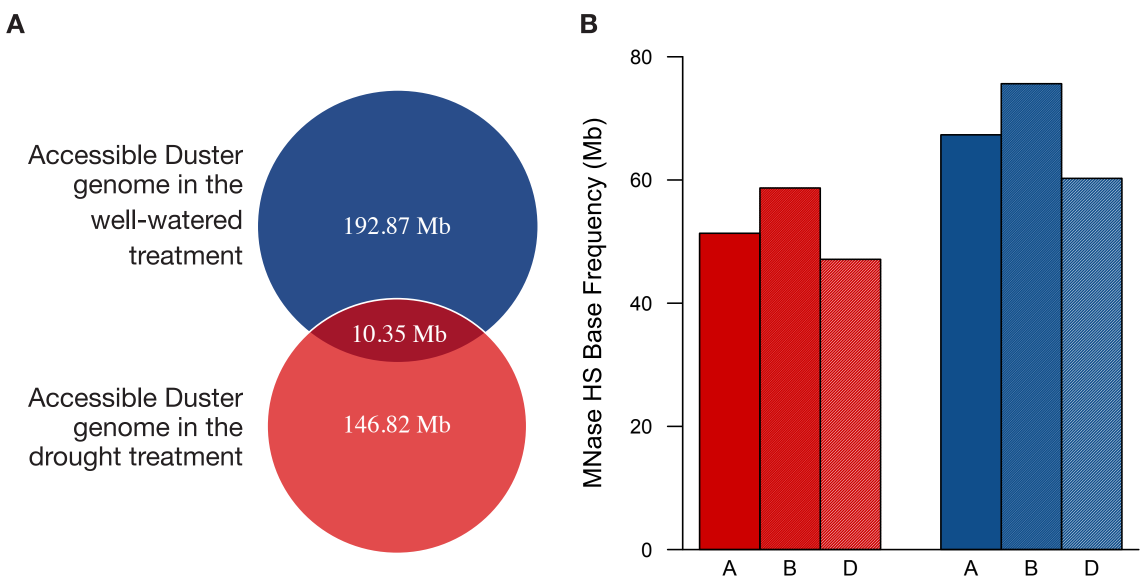

Figure 13. Comparative profiles of genomewide accessibility of the Duster genome. (A) Total proportion of the accessible regions of the genome (FDR<0.01) in WW (blue) and DT (red) and the intersection between the two conditions. (B) Distribution of the accessible genome regions across A, B and D genomes in WW (blue) and DT (red).

Representation across sub-genomes were proportional to their size, with the B and D genomes having the highest and lowest frequencies of accessible regions, respectively (Figure 13B). In WW, accessible regions where higher transcriptional activities can be expected were mostly found in the telomeres, corresponding with increased gene density (Figure 14). Most obvious in the D genome, DT consistently exhibited lower accessibility, indicative of a reduced level of transcriptional activity in the D genome, except for a 500 kb region in the telomere region. Though inaccessibility of the Duster genome in response to drought stress was evident genomewide, a number of drought-induced, accessible genome regions were identified on chromosomes 1B, 4A, 6A and 6B, and in the centromere region of chromosomes 5A and 5B (Figure 14).

Compared with the control treatment, accessibility of the drought-treated Duster genome was reduced significantly in the gene body, or genic regions, comprised of the transcriptional regions of the genome (introns and exons), as well as in the regulatory regions comprised of promoter regions and transcription start and termination sites. All of this suggest a role for DNA structural changes in regulation of transcriptional activity, which is the first main stage of gene expression (Figure 15). Functional interpretation using GO (gene ontology) term enrichment analysis revealed that the differential accessibility of Duster genome under drought stress was significantly associated with thylakoid structures (GO: 0009579, $P = 3.47E-24$) and photosynthesis (GO:0015979, P value = 2.62E-21) (Table 10).

The enrichment results offer insights on Duster's yielding capacity under water stress, suggesting that regions of the genome remained accessible for transcriptional activities related to chloroplast development and carbon sequestration for carbohydrate synthesis, while repressing other transcriptional activities by genome-wide chromatin condensation.

Nitrogen-use Efficiency at the Genetic Level

Brian Arnall
Plant and Soil Sciences

The wheat variety trials allow WIT a good opportunity to see how multiple genetics from all breeding programs react across a wide range of environments. Using the report submitted by Dr. Silva (see page 57), varieties can be easily differentiated in terms of protein production. With more than 50 cultivars tested in 2018-19,

Table 10. Functional enrichment of the accessible genome under drought conditions, based upon the top 10 overrepresented gene ontology categories.

Gene ontology category	*Adjusted p-value*
Thylakoid	3.47E-24
Thylakoid part	3.47E-24
Photosynthetic membrane	5.16E-22
Photosynthesis	2.62E-21
Photosystem	5.15E-21
Macromolecular complex	8.97E-17
Protein complex	4.58E-14
Photosystem II	1.41E-13
Photosystem II reaction center	2.11E-13
NADH dehydrogenase activity	2.61E-12

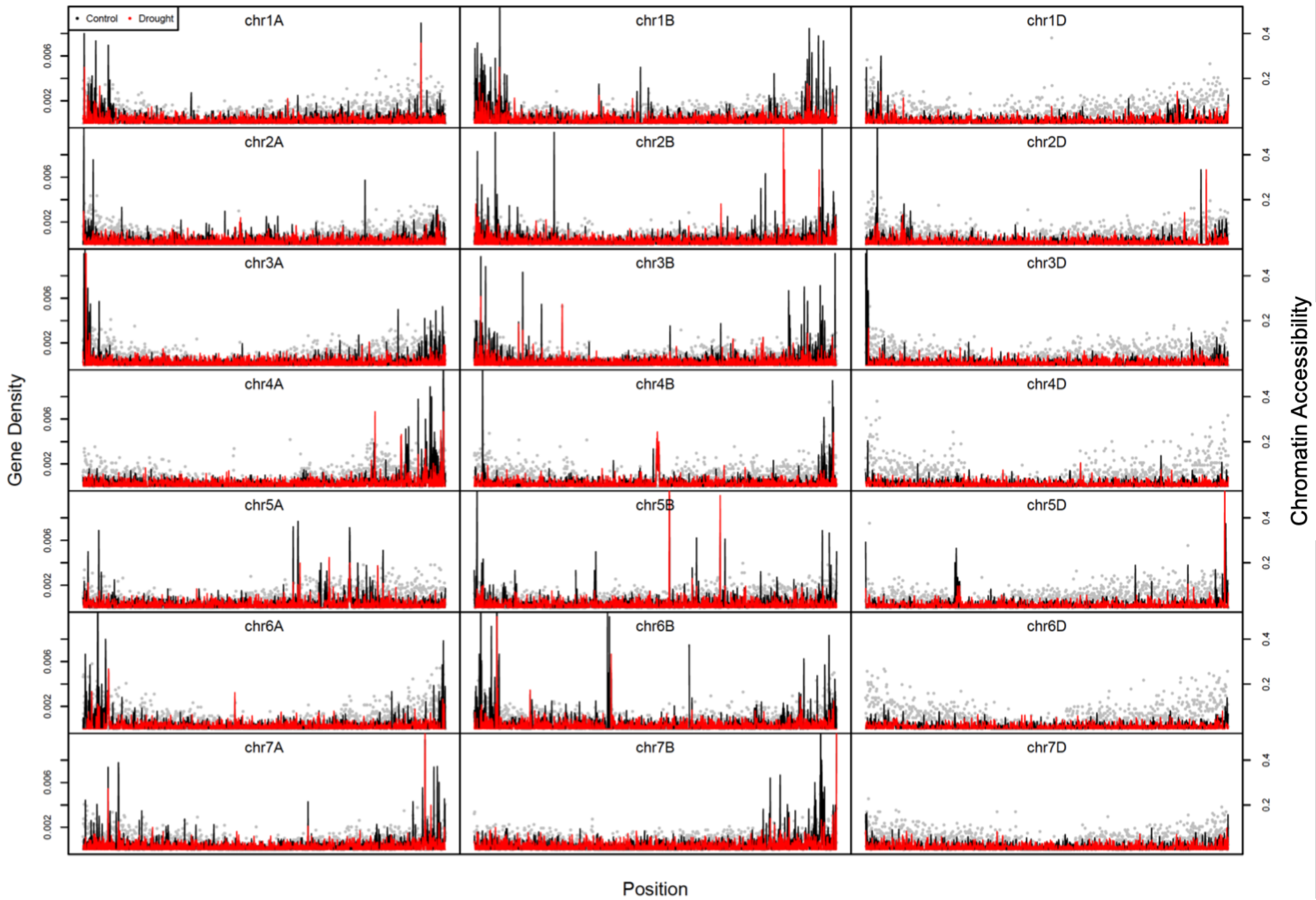

Figure 14. Global genomeview of changes in accessibility of Duster's genome by chromosome (chr) in WW (black peaks) and DT (red peaks).

Figure 15. Differential accessibility of the Duster genome in WW (black line) and DT (red line) in genic regions. Under drought, a significant reduction in genome accessibility of the Duster genome was observed in the gene body, as well as in promoter regions and transcription start and termination sites.

two showed consistency in producing relatively high protein values. Green Hammer and Doublestop Cl+ ranked as the best or not different from the best in 60% of the locations tested. Green Hammer was evaluated at 15 locations, whereas Doublestop was evaluated in 21 locations. The next most consistent variety was LCS Chrome, which produced relatively high protein values in 24% of the 21 locations tested. These results discriminate only on the basis of protein quantity, not protein quality. Doublestop Cl+, Green Hammer and LCS Chrome differ markedly in protein quality, expressed as dough strength or mixing tolerance from high to lower ranking, respectively.

The previous work of evaluating only a few candidate cultivars across a range of nitrogen rates was discontinued in 2019. The nitrogen use efficiency work at Tipton, however, was expanded. Instead of testing all intermediate and advanced experimental lines under nitrogen stress and just a few advanced lines under optimum nitrogen, all advanced lines were tested with three rates of nitrogen (extreme stress or 25% optimum, moderate stress at 50% optimum and optimum nitrogen). All lines were still tested at 25% optimum nitrogen.

A strong and positive yield correlation was observed with the addition of nitrogen, averaging 37 (25%), 41 (50%) and 47 (optimum) bushels per acre for the indicated nitrogen treatments for one set of advanced lines and checks. A second set of advanced lines and checks averaged 32 bushels per acre (25%), 36 bushels per acre (50%) and 41 bushels per acre (optimum). Lines that rank in the top-yielding group in the optimum nitrogen treatment, yet retain 70% or more of their potential yield at the 25% nitrogen level, are prioritized for advancement in the breeding program and plausibly represent germplasm with improved nitrogen uptake or utilization capacity, strictly on a yield-performance basis.

Due to the surprising results seen from the delayed nitrogen study that was first reported at the Oklahoma Wheat Growers Association wheat review in August 2018, the study was repeated for a third year at two locations, the Lake Carl Blackwell (LCB) research station near Perry and the Ballagh research farm near Newkirk. Due to excessive rainfall at planting, trials were established later than normal. A cool winter and spring delayed stem elongation compared with the first two cropping seasons. Nitrogen applications were initiated before symptom differences could be visually distinguished between the nitrogen-rich strip (pre-plant) and the rest of the field. Similar to the two previous years of this study, the timing of nitrogen application influenced wheat yield and protein. At LCB, the yield increased with a delay of nitrogen application until early March, with yields decreasing below the pre-plant nitrogen treatment when nitrogen was applied in mid-April. At the Ballagh farm, there was no yield benefit from delaying nitrogen after pre-plant, but there was a steady increase in wheat protein with delayed nitrogen application; again at this location yield decreased when nitrogen application was delayed past mid-April. At both of these locations, crop development in mid-April was past Feekes 7 growth stage.

After three cropping seasons with extremely different weather patterns, this work showed that the pre-plant nitrogen application never produced higher yield than in-season nitrogen applied prior to mid-April or before Feekes 7. In most cases, nitrogen applied in-season produced yields and protein values greater than those of the pre-plant nitrogen treatment. The message from this project is multi-fold:

1) A pre-plant nitrogen application may be cheaper and easier, but it often falls short of in-season applications for yield and protein.
2) There is no reason to rush applying top-dress nitrogen. The application window is much wider than ever expected, and the better the yield and quality will likely be when application is at peak demand.
3) Make the application of nitrogen when conditions are most conducive to getting the nitrogen into the soil profile to limit losses.

This report was shared on the OSUNPK.com Blog site at https://osunpk.com/2019/08/14/how-long-can-wheat-wait-for-nitrogen-one-more-year-of-data/

The future of this project entails a deep dive into how cultivars respond to nitrogen stress. At two locations, five cultivars have been sown with and without nitrogen. These cultivars represent lines that have been identified as high and low NUE cultivars. At critical points during the growing season, tissue samples will be collected to determine nutrient concentrations in different portions of the plant and to better understand how improved NUE is being achieved.

Wheat Breeding and Variety Development

Brett Carver
Plant and Soil Sciences

What is fast becoming the recurring theme year after year, the 2018-19 crop season had little to do with previous seasons. Even more striking, the environmental conditions of 2019 were a polar opposite to those of 2018. Dramatic shifts in growing conditions from one year to the next enable a wheat breeder to paint with a very broad stroke, that is, expose their breeding material to a wide range of selection pressures that can lead to cultivars with broader adaptation. However, this constant helter-skelter shift in selection pressures wreak havoc on interpretation of yield and quality results in any given year. This is the key rationale in advising producers to make variety choice decisions not on the convenience of single-year results so readily available in the form of this year, but instead on the reliability of trial results from the past three years. It is not known what nature will throw at the wheat crop from one year to the next, but we do know next year will likely not resemble the one just past.

To illustrate the polarity in conditions between 2018 and 2019, Table 11 summarizes the disease pressures most likely to occur in Oklahoma and impact selection decisions in the OSU wheat breeding program. Certainly, there are other diseases to consider, such as Fusarium head blight (head scab) or stem rust, but their frequency is too low to rely on field selection in Oklahoma for resistance. Compare that lineup with the most influential diseases experienced in 2019 (Table 12). This combination of leaf rust, Septoria tritici blotch and bacterial leaf streak was historic. Never before in this century has such a unique amalgamation of selection pressures wielded its influence on OSU breeding populations. Natural resistance to all three diseases, as expressed in the experimental line OCW04S717T-6W, was infrequent because breeding lines and the populations that produced those lines had not been adequately exposed beforehand. In the preceding crop year (2018), the primary influences were season-long drought stress and multiple April freeze events with little, if any, influence by diseases. That is polarity by nature.

That discussion will resurface later, but for now, consider the following imperative to any plant breeder, and especially to a wheat breeder in Oklahoma. Self-monitoring of long-term genetic gains in one's own program enables a more complete understanding of past progress which, in turn, enables timely adjustments to be made to ensure or improve future progress. Genetic progress can be monitored in various ways, but one method that is convenient for reporting hinges on the inclusion of a consistent check cultivar in the most advanced testing nursery in the program. The use of a constant check enables removal of some of the environmental noise from year to year. That check is the 1983 OSU HRW release, Chisholm, and the nursery is the Oklahoma Elite Trial 3 (OET3).

The OET3, one of three advanced line nurseries, is conducted in full public view by WIT member Amanda de Oliveira Silva, currently at Kingfisher, Oklahoma and adjacent to the OCES wheat variety trial (WVT). Within the breeding program, the OET3 appears statewide each year in the form of seven to 10 replicated sites per year composed

Table 11. Fungal, viral and bacterial diseases most likely encountered in Oklahoma and targeted by WIT, given the opportunity.

Fungal	*Viral*	*Bacterial*
Leaf rust	Barley yellow dwarf	Bacterial leaf streak
Stripe rust	Wheat soil-borne mosic	
Powdery mildew	Wheat spindle streak mosaic	
Septoria tritici blotch	Wheat streak mosaic	
Tan spot	Triticum mosaic	
Spot blotch		
Stagonospora glume blotch		
Dryland root rot		

Table 12. Diseases encountered with sufficient regularity during the 2018-19 crop season in Oklahoma to significantly influence line-advancement decisions.

Fungal	*Viral*	*Bacterial*
Leaf rust		Bacterial leaf streak
Septoria tritici blotch		

of 25 to 30 advanced (elite) experimental lines, five to eight contemporary cultivars and the long-term check Chisholm. No fungicide treatment is applied in these trials, with the exception of the Okmulgee site. A plot of the mean of all experimental lines across sites for a given year, adjusted as a percentage of the Chisholm mean, provides a running assessment of genetic progress through time (Figure 16), starting with 1998 OET3 and ending with 2019 OET3.

The use of a long-term check like Chisholm assumes the genetic composition of this variety does not change through time; thus, its response (e.g., for yield) is strictly a response to changing environmental conditions. Another critical assumption, and one that does not always hold, is Chisholm's response to changing environmental conditions is no different from the environmental response of the experimental lines to which it is compared.

In Figure 16, genetic gains have been positive as expected (and highly erratic), but one trend is perplexing if not disturbing. The rate of genetic gain, relative to Chisholm, from 1998 to 2016 was 1.4% per year, but tacking on the last three years has dropped the overall gain by one-half to 0.7%. Since 2017,

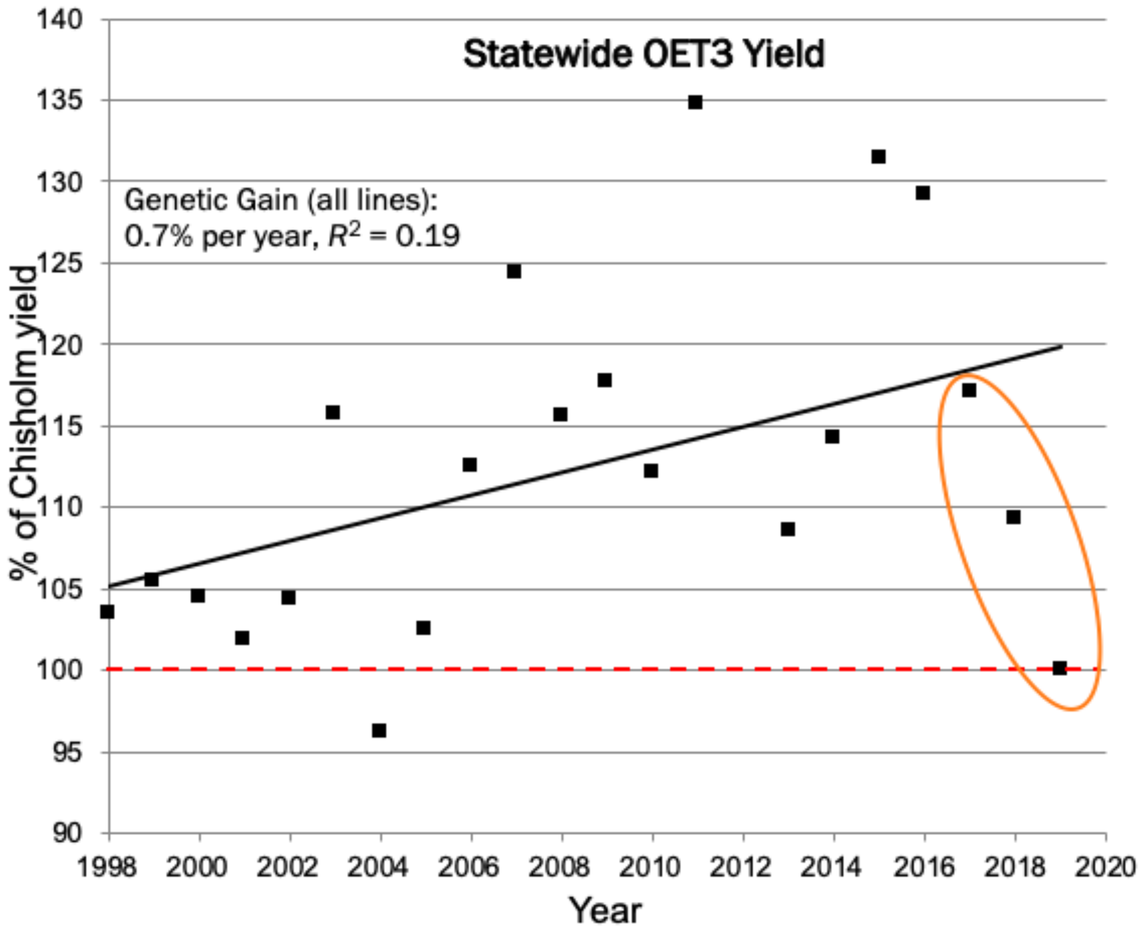

Figure 16. Genetic gain for grain yield in the OSU wheat improvement program, expressed as the statewide mean of all experimental lines in the Stage 3 Oklahoma Elite Trial (OET3) as a percentage of the mean for Chisholm, the long-term check entry used in the OET3 since the 1980s. Genetic gain is plotted beginning in the year WIT was formed in 1998.

advanced lines in this trial obviously have not performed as well relative to the long-term check as those lines tested in 2016 and before. A doomsday interpretation of Figure 16 is that genetic progress for yield only is headed in the wrong direction, considering the past three years.

One obvious common factor to the depressed gains in 2017 and 2019 was leaf rust, which was extremely heavy in both years, though other less common diseases factored into 2019 yields. Yields of experimental lines susceptible to leaf rust, Septoria tritici blotch and bacterial leaf streak fared very poorly relative to the susceptible check, Chisholm, even though Chisholm is considered susceptible to leaf rust.

In 2018, the causal factor behind the relative yield decline was likely multiple spring freeze events in April. The April 2018 freeze events are not as concerning as leaf rust to future genetic gains, given this was a temporary combination of weaker freeze tolerance of the germplasm tested in 2018 and unusual freeze pressure.

Experimental lines reacted to the conditions in 2017, 2018 and 2019 no differently from or less favorably than Chisholm did, as if they were not genetically equipped to handle the conditions. The converse argument could be made in 2015 (Figure 16), when stripe rust attacked Chisholm like never before, whereas most elite lines in the OET3 handled the stripe rust epidemic quite well because they were prepared for it (i.e., they were selected for it) following the epidemics of 2010 and 2012.

Thus, the recent downturn in genetic gains since 2017 is considered only temporary, albeit significant. The advanced materials cycling through the WIT pipeline during this three-year period did not have the advantage of adequate exposure to leaf rust during years leading up to OET3 testing —from 2010 through 2016. WIT has somewhat righted that ship already, but this correction will take more time. In the meantime, recent cultivar releases have emphasized stronger levels of adult plant resistance to leaf rust, including all-season resistance, when the opportunity presented itself. Recent releases such as Green Hammer and Skydance, and pending releases such as OK16D101089, OK12912C-138407-2 and OK14124-2, represent steps in that direction. Instituting a reliable adult plant assay for leaf rust resistance in greenhouse conditions since 2017 also will reverse the downward trend in Figure 1 (see **Hunger's** report).

Finally, this downward trend, was programmatically self-inflicted. If the breeder's objective is always to select lines exceeding a certain threshold for grain yield and nothing below it, then this phenomenon of depressed genetic gains have a much lower likelihood. However, this is not how the world of wheat breeding turns. The remainder of this report should make clear one emerging practice of WIT that does not necessarily lend itself to incremental gains in the OET3 mean for yield. This practice entails putting the right genetics in the right spot, if only for a limited area, to fill certain gaps of opportunity. Examples may include i) a cultivar with exceptional disease resistance and yielding ability in a certain restricted geographic area, but lacks broad adaptation to inflate the yield mean on a statewide basis, or ii) a cultivar that will yield (and bake) exceptionally well under certain management conditions (e.g., late planted conditions), but lacks adaptation in the conventional management system. These are only two examples, but there are more.

Filling the opportunity gaps

Other than Spirit Rider (for optimally managed conditions) and Skydance (for organic production), the last seven cultivars released since 2017 were targeted for vast wheat acreages in certain regions of the Southern Plains. For example, Lonerider was intended for production in the High Plains of Texas, Oklahoma, Colorado and Kansas, while Showdown has adaptation to an equally expansive region in the central corridor of the Southern Plains. These general utility cultivars could address some specific needs. For example, the high-end dough strength of Baker's Ann could be used to condition otherwise poor-performing flours in customized flour blends, but all seven cultivars are known to advance fitness of the crop on a broader ecological scale. Nonetheless, the release of a home run hitter may forsake critical needs on smaller acreages with enhanced economic value.

Beardless wheat. OK Corral (OK12206-127206-2), released by OAES in September 2019, represents a significant breakthrough in yield ability, end-use quality and pest resistance for HRW wheat adapted to the Southern Plains. It just happens to have one distinguishing characteristic: its spikes lack awns. OK Corral has the pedigree Y98-912/OK00611W//OK03716W.

Extracting information from the pending application for plant variety protection, Y98-912 was an advanced experimental line developed by the former WestBred soft wheat breeding program (located in Indiana) and was tested in the 2003 USDA-ARS Uniform Eastern Soft Red Winter Wheat Nursery. Y98-912 was eventually released as a soft red winter wheat cultivar named W2-912. OK00611W was an advanced experimental hard white line produced by WIT in the early 2000s that traced to a sister headrow selection of OK Bullet. Thus, the pedigree of OK00611W is Jagger/KS96WGRC39. OK03716W was an advanced hard white experimental line developed by OAES with the pedigree, N44/OK94P455. N44 was developed at the Institute of Plant Breeding in Odessa, Ukraine and was introduced in a germplasm exchange with USDA-ARS in the fall 1994. OK94P455 was developed as an experimental line in the former Pioneer hard winter wheat breeding program and was derived from Pioneer and Kansas State University experimental lines according to the expanded pedigree, W0405D/KS831957//W3416/KS831957.

Altogether, no released wheat cultivar from OSU resembles this pedigree, a distinction that may impact future discovery and characterization of important pest resistance genes in OK Corral. The first gene discovery project, taken up already in Dr. Yan's laboratory, will be focused on its potentially novel Hessian fly resistance, which resembles Duster in phenotype, but confirmed to carry a different resistance gene than Duster.

In lieu of a spot in the 2019 OSU WVTs, OK Corral was extensively tested in the 2019 OET2 breeding nursery (elite lines) statewide. OK Corral averaged 7 bushels per acre superior to Bentley and Gallagher, where its best relative yield performance occurred in central, southwest and the panhandle of Oklahoma (Table 13). OK Corral has a history of wide variability in test

Table 13. Grain yield (bu/A) in the 2019 Oklahoma Elite Trial (OET2) containing 38 experimentals and two check cultivars.

Name	*State*	*Goodwell dryland*	*Tipton optimal N*	*Tipton Interm. N*	*Tipton 25% N*	*Okarche dual-purpose*	*Lahoma*	*Chickasha*	*Okmulgee*
OK Corral	57[a]	82	46	41	37	68	45	71	69
Bentley	50	72	32	30	33	57	46	63	67
Gallagher	50	77	41	36	33	43	44	48	80
Mean (40 entries)	51	75	41	36	32	55	39	57	70
LSD (0.05)	4	12	5	6	7	7	7	5	9

[a] Entries with shaded values are not statistically different from the highest yielding entry (among 40 entries) within a column.

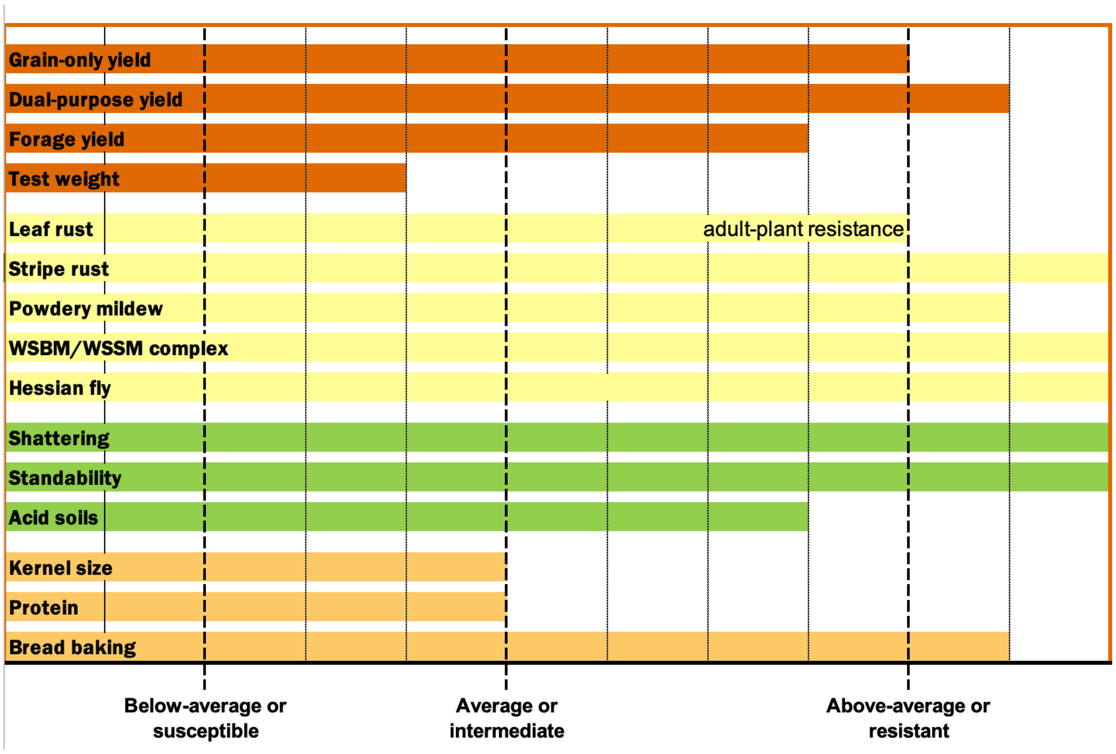

Figure 17. Trait comparison chart for OK Corral at time of release (September 2019).

weight from unacceptable to above average, and this was the only holdup in recommending release in 2018. What OK Corral lacks in test weight (about 1.9 pounds per bushel less than Gallagher), it makes up for in stripe rust resistance, grazing tolerance and Hessian fly resistance (Figure 17).

WIT continues to evaluate a second beardless HRW candidate, OK11208 (Deliver/Santa Fe) with potentially higher-yielding ability and acceptable test weight and end-use quality. Because it segregated for various plant types when originally formed as an $F_{4:6}$ line in 2011, it was subsequently partitioned into three near-isolines, or closely related sibs which differ in one or a few genes, varying in maturity date by about nine days (Figure 18). Interestingly, in 2019, delayed maturity within this line was associated with a 17% decrease in statewide grain yield (a decrease of 17 bushels per acre in Okmulgee alone), but more importantly, a 3-pound loss in test weight (Table 14). WIT's objective for the next beardless candidate cultivar is to exceed the test weight of OK Corral, so on that basis alone, the earlier maturing isoline will be favored for final evaluation in 2020. This line will be named for future reference OK11208E-24C19 as it is tested in the 2020 OET3, and the best nine component selections will be subjected to breeder-seed increase and purification at Stillwater prior to transfer to OFSS in fall 2020.

Arrival of WSM resistance

Presence of WSM resistance throughout the WIT pipeline is at an all-time high. While other sources of resistance are now widely available, some with unknown origin like the resistance in Doublestop CL Plus, two specific gene sources are commonly used. *Wsm1* was originally deployed in the USDA-ARS (Lincoln, NE) cultivar Mace following introgression from intermediate wheatgrass, a species of

Figure 18. OK11208 near-isolines (left to right: late, medium and early maturity) as they appeared in Stillwater on May 24, 2019.

Table 14. Correlated effect of maturity on grain yield and test weight of OK11208 near-isolines differing only for maturity gene(s).

	Heading date statewide		*Grain yield*		*Test weight statewide*
		Statewide	*Okarche DP*[1]	*Okmulgee*	
	day of year	-------------------	bu/A	----------------	lb/bu
Gallagher	124	52	43	80	56.7
OK11208-Early	121	54	57	84	56.3
OK11208-Medium	127	48	59	67	54.1
OK11208-Late	130	45	56	67	53.4
OK Corral	125	60	68	69	54.9
Trial mean	123	53	55	70	56.1
LSD (0.05)	--	4	7	9	1.8

[1] Dual-purpose management system.

Thinopyum. *Wsm2* was first reported in the Colorado State University experimental line CO960293-2, then first deployed commercially in hard winter wheat cultivars Snowmass and RonL, but its origin remains unknown. Both sources confer virus resistance by temperature-dependent impairment of virus movement in the plant. In the simplest description, WSM resistance is expressed at 18 C (64 F) but not at 24 C (75 F). The WIT has introgressed *Wsm1* and *Wsm2* singly and together into Oklahoma-adapted germplasm, though *Wsm1* is favored for its dual resistance to WSM and to Triticum mosaic. *Wsm2* only confers resistance to WSM. The flip side is germplasm introgressed with *Wsm1* shows greater linkage drag, a term commonly used among breeders to indicate the corresponding reduction in yield or quality in a cultivar due to inadvertent introduction of deleterious genes along with the target gene (such as *Wsm1*) during introgression. Germplasm created at Kansas State University featured a shorter chromosome segment carrying *Wsm1* from *Thinopyrum* and putatively less linkage drag. This germplasm eventually led to the development of adapted, but unimproved, populations at CSU, which were distributed to HRW wheat breeders in the Great Plains. Dozens of WIT experimental lines were produced by WIT from those unimproved CSU populations, leading to the elite experimental line and candidate cultivar OK168512 and several sister lines originally reported in *Wheat Partners in Progress 2018*.

The pedigree of OK168512 can be stated as Overley (+*Wsm1*)/Fuller // CO050270/3/CO050337-8. Overley (+*Wsm1*) possessed the reduced translocation segment with *Wsm1* from *Thinopyrum*. This parent was produced at KSU and crossed with the HRW cultivar Fuller. The subsequent hybrid was crossed at CSU with CO050270, a CSU experimental line also used to produce the HRW cultivar Langin. Finally, that resulting hybrid was crossed at CSU with CO050337-8, another CSU experimental line and sib-related to the HRW cultivar Denali. The nonselected and F2 seed population from that hybrid was provided to interested wheat breeders. OK168512 was created in 2016 by WIT as a fixed line and tested in replicated breeder nurseries from 2016 to 2019, earning a spot in the 2019 WVT in the Oklahoma panhandle region where it placed in the top-yielding group among all cultivars (Table 15) and features similar or better characteristics expected of a cultivar lacking WSM resistance (Figure 19).

Arrival of BYD resistance

Among the last five HRW cultivars released (Showdown, Green Hammer, Baker's Ann, Skydance and OK Corral), all have the common characteristic of lacking a desirable level of BYD tolerance. The primary reason for this weakness is genetics. None of the five cultivars claim Duster as a parent, or

Table 15. Grain yield and test weight reported in the 2019 OSU wheat variety trials, averaged across four sites in the Oklahoma panhandle.

Entry	*Grain yield*[a] *(bu/A)*	*Test weight*[a] *(lb/bu)*
OK168512	**81**	**59.1**
Joe	85	58.7
Langin	84	57.1
WB-Grainfield	83	57.9
Showdown	82	56.7
Lonerider	82	58.1
Bentley	81	56.8
Iba	80	58.9
SY Monument	78	56.9
TAM 204	76	53.4
WB4303	76	53.3
TAM 112	75	58.4
TAM 114	74	59.0
Gallagher	74	56.6
Mean (30 varieties)	77	57.1
LSD (0.05)	5	0.8

[a] Test sites included Balko, Goodwell (irrigated), Hooker and Keyes. Entries with shaded values are not statistically different from the highest-value entry (among 30 varieties) within a column.

The complete report can be found at http://wheat.okstate.edu/variety-testing/summary-of-all-regions/2018-19-panhandle-region-summary-yield-results

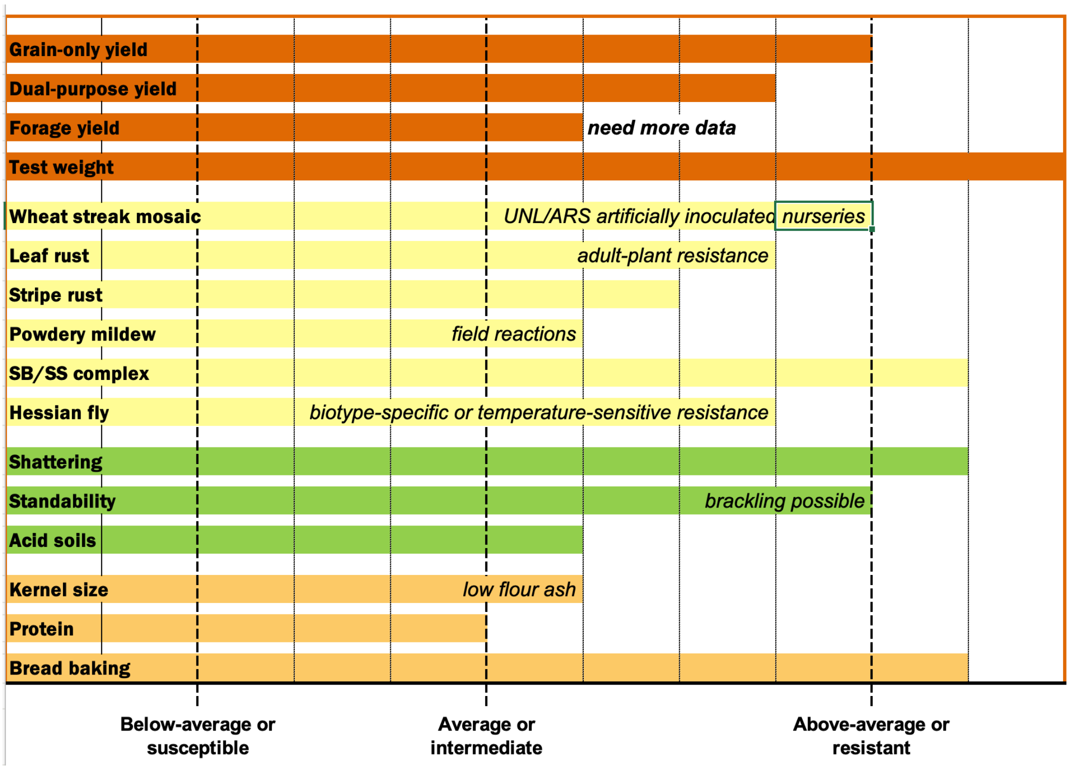

Figure 19. Trait comparison chart for OK168512 as of September 2019.

even as a grandparent, and Duster is WIT's most common source of BYD tolerance. Duster derivatives with better BYD protection than most would be Gallagher, Iba and Smith's Gold (but not Lonerider). However, even the level of resistance present in those cultivars is not perfect or complete.

A more complete BYD protection package must come with the addition of a unique gene source, that when stacked with the *Bdv1*-conferred resistance from Duster, produces an incrementally higher level of resistance. The second gene for BYD resistance targeted by WIT for almost 10 years is called *Bdv2/3*, transferred from soft red winter wheat germplasm developed by Purdue University. WIT has informally called this two-gene stack BYD2G, now present in the candidate cultivar OK16D101089.

In the 2019 WVTs, OK16D101089 placed in the top statistical yield group in seven of the 10 tested replicated trials (Table 16), an unusually high frequency for any cultivar. One of its two parents, Bentley, placed in one of those yield groups. This striking level of yield superiority did not have the benefit of BYD pressure to force potentially greater differentiation between OK16D101089 and other cultivars lacking BYD resistance.

OK16D101089 was featured in the 2019 Wheat Quality Council growout at Lahoma (Figure 20), where it exhibited exceptional canopy hygiene in the presence of Septoria tritici blotch, leaf rust and other diseases. Results from the WQC evaluation program will arrive in February 2020 and will provide a driving force behind any release recommendation. Based on regional testing by USDA-ARS in the 2019 Southern Regional Performance Nursery (SRPN), OK16D101089 appears most competitive in the central corridor

Table 16. Yield differences between OK16D101089 or Bentley versus the mean of the trial in 10 environments of the 2019 OSU wheat variety trials at which OK16D101089 was tested. Those differences given in boldface represent sites where OK16D101089 or Bentley performed in the top statistical yield group for a given environment.

	Kildare	*Kingfisher*	*Lahoma*	*Lahoma (fung.)*	*Thomas*	*Union City*	*Walters*	*Altus*	*Chickasha*	*Chickasha (fung.)*
	----------	----------	----------	----------	----------	*bu/ac*	----------	----------	----------	----------
OK16D101089	**+6**	-2	**+19**	**+11**	**+15**	**+19**	-4	+8	**+16**	**+6**
Bentley	**+5**	+4	-1	+4	0	0	-1	-7	+2	-2
Trial mean	66	67	37	61	48	43	21	56	55	73

of the Southern Plains, but poorly adapted to the High Plains (Figure 21). As a footnote, OK16D101089 was not the highest yielding candidate tested in the 2019 OSU WVTs. That status belonged to OK16729W, which edged out all other cultivars when analyzed across the four regional trials (wheat.okstate.edu/variety-testing/summary-of-all-regions/2018-19-regional-trial-location-summary-yield-results).

The best of the rest

Three advanced lines round out a release docket designed to fill significant opportunity gaps for 2020. Taking a diametric approach from the **Graze*n*Grain**® breeding system, WIT found OK14124-2 well fit for late-planted conditions (December) with minimal yield drag caused by planting-delayed maturity. To the contrary, its extreme earliness makes OK14124-2 well fit to delayed planting. Other OAES 2019 releases to fit this adaptation window were Green Hammer and Baker's Ann, but in non-replicated strip plots, their December-planted yields were about 10% lower than the yield of OK14124-2, and their harvest-maturity dates were one to four days later.

A new 2-gene Clearfield line will be proposed for OAES release before June 2020, pending BASF pre-approval. OK12912C-138407-2 is similar to Doublestop CL+ in pedigree, plant stature, test weight and protein content; but exhibits slightly earlier maturity, more aggressive canopy closure in the early fall and slightly higher yielding ability in central Oklahoma where weed pressure is potentially greatest.

If not for its Hessian fly susceptibility and average acid soil tolerance, the one candidate that shines the brightest has a white brancoat and lacks awns. White or red, beardless or bearded, OCW04S717T-6W may be the best overall candidate to explore a release option in 2020, as it topped the OET3 trial statewide in 2019 and consistently performed well in replicated yield trials and industry evaluations for the past five years. The question, or

Figure 20. Wheat Quality Council growout of OK16D101089 and sister line OK16D101073 at Lahoma, in the presence of leaf rust, Septoria leaf blotch and bacterial leaf streak. Photo taken May 6, 2019.

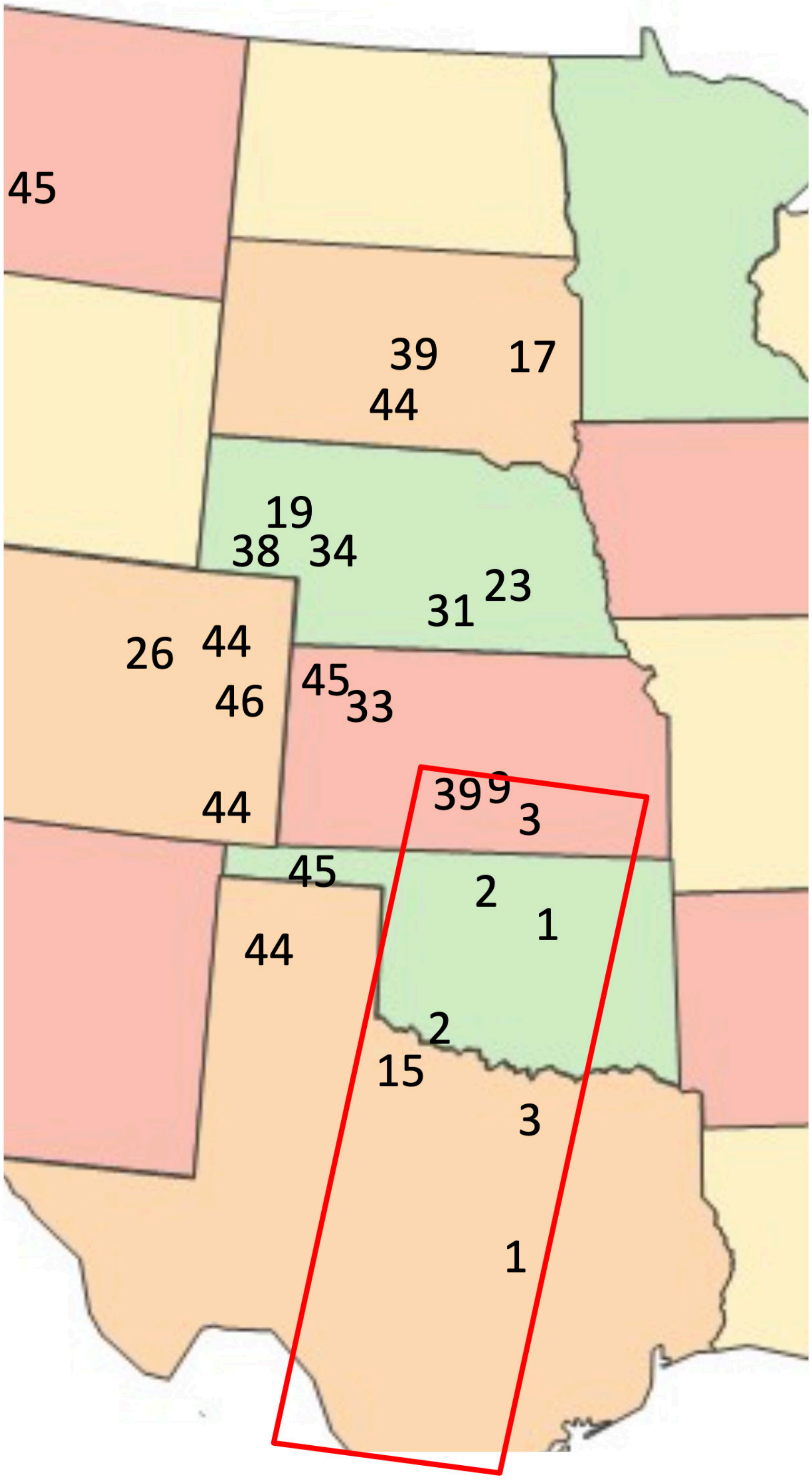

Figure 21. Yield rank value, from 1 (highest yield) to 49 (lowest yield), for OK16D101089 in the 2019 Southern Regional Performance Nursery (SRPN) conducted by USDA-ARS across the entire HRW region of the Great Plains at 26 sites. This nursery contained 49 entries, six of those developed by OSU. The red box indicates the region of best adaptation for OK16D101089 based on higher yield ranks in the 2019 SRPN.

conundrum, becomes how best to launch a variety that end users would stand to benefit immensely but could disrupt their same supply chain if not maintained, at least in part, in an identity preserved production system. Mainly intended for grain production, threshability could be problematic with beardless wheat, but this likely is not the case with OCW04S717T-6W. Indirect evidence, in the form of test weight patterns, provides WIT the best clue for threshability, and thus far, test weight of OCW04S717T-6W has been acceptable to above average.

The USDA-ARS Hard Winter Wheat Quality Laboratory in Manhattan, Kansas provided critical industry relevant data on functionality for all candidate cultivars reported thus far, including the 2019 release OK Corral (Table 17). Their analysis usually is conducted in the spring of each year; thus, the data reported in Table 17 represents the 2018 crop. Consideration of milling and baking quality is not an afterthought to WIT, nor is it an exercise in just squeaking by. A cultivar without class-appropriate quality may fly under the radar of a commodity based marketing system, but through time, this aircraft becomes an albatross to the greater market class. None of the candidates, including OK Corral, fall short of industry standards, and even some such as OK14124-2, OK12912C-138407-2 and OCW04S717T-6W have the functionality and physical characteristics to well exceed industry standards and earn OSU's **Gold*n*Grain**® tag.

Candidate cultivar lineup, 2019-2020

Following the 2019 harvest, and after thorough consideration of all advanced lines under breeder seed increase in 2018-2019, WIT submitted breeder seed of four new HRW and HW candidates for grow-out and on-farm evaluation by Oklahoma Foundation Seed Stocks, or OFSS, in 2019-2020. Another 10 candidates previously under Foundation Seed increase in 2018-2019 were carried over to 2019-2020. Eleven of these candidates are characterized fully in Tables 18 and 19. The first five candidates highlighted in orange were discussed in this report and they await foundation seed production and release approval (if requested). Those in the unshaded area remain under WIT's watch for further yield and quality testing, and for specific performance traits of interest to WIT, while foundation seed production ramps up.

This summary looks unlike the one presented in the 2018 *Partners in Progress* report. Several candidates favored in 2018 were since terminated due to poor protection against leaf rust in 2019 (OK14P212, OK168513, OK149132C and OK14736W) or lacking the desired level of industry assessed, functional quality (OK1059018 reseln, OK16D101073).

Table 17. Wheat and flour characteristics of releases targeted in 2019 and for 2020. Each sample was formed as a grain composite from breeding nurseries across Oklahoma in 2018. Exceptional values noted by bold; undesirable values noted by red. Data provided by Richard Chen, Hard Winter Wheat Quality Laboratory, USDA-ARS, Manhattan, Kansas.

Entry	*Test wt.* lb/bu	*Kernel wt.* mg	*Kernel diam.* mm	*Wheat protein* %	*Flour ash* %	*Loaf vol.* cc	*Crumb score* 0-6	*Farinograph absorp.* %	*Farinograph peak time* min	*Farinograph stability* min	*Alveograph W* (10E-4J)	*Polyphenol oxidase activity*
OK Corral	56.9	29.5	2.52	12.8	0.48	935	4.0	54.7	11.5	16.3	206	**0.197**
OK168512	**62.1**	29.3	2.54	12.8	**0.38**	885	4.0	54.6	17.8	**28.9**	225	0.638
OK16D101089	61.6	29.1	**2.64**	13.4	**0.38**	990	4.0	57.1	9.0	15.2	242	0.561
OK14124-2	**62.6**	**38.0**	**2.89**	**15.2**	0.42	**1075**	3.5	59.2	15.2	**26.4**	**344**	**0.160**
OK12912C-138407-2	60.4	32.3	**2.68**	**14.2**	0.41	980	**4.5**	**60.4**	9.5	15.4	**315**	0.468
OCW04S717T-6W	58.7	30.3	**2.63**	**14.1**	0.51	**1060**	4.0	58.5	12.5	18.6	**324**	0.569
Doublestop CL+	61.6	**33.4**	**2.76**	**14.4**	0.44	1005	3.5	58.8	11.8	**28.3**	**315**	0.567

Table 18. OSU candidate cultivars placed under seed increase in fall 2019 with Oklahoma Foundation Seed Stocks. Number of years of Foundation Seed production projected as of summer 2020. First flush of candidates indicated by orange highlight; second flush, no highlight.

Candidate[a]	*Pedigree*	*OFSS*	*Feature traits*
OK168512	Overley+/Fuller//2*CSU exptl.	3	Good WSM resistance; best yield/test weight/quality package with WSM-R
OK16D101089	OK12621/Bentley	2	Significant breakthrough in BYD protection; unexplainable leaf rust resistance
OK14124-2	NI04430/OK05303//Fuller	2	High protein/functionality/test weight. suited for late planting, early harvest
OK12912C-138407-2	N91D2308-13/OK03926C//OK03928C	4	Doublestop upgrade for straw strength, forage production, maturity
OCW04S717T-6W	CIMMYT seln/KS exptl.//KS91W047	3	Exceptional quality HW beardless; top-tier yield and disease protection
OCW03S580S-8WF	G991502/BULK SELN 00F5-11-2	2	Exceptional SRW with HRW-like functionality adapted statewide
OK12716W	Showdown (full sib)	2	Same as Showdown (HRW)
OK16729W	LA98149BUB-3-4-B/Billings//OK07231	1	Highest-yield entry statewide - 2019 WVTs; quality may prevent release
OK15MASBx7 ARS 8-1	Gallagher*3/Snowmass	1	Gallagher twin with added glutenin for HRS-like dough strength
OK16D101157	OK09520/Cedar	1	Short high-yield ceiling for northeastern Oklahoma, with straw strength
OK13P016	Billings/Duster	2	Southern Oklahoma, grazing-tolerant; Hessian fly resistant; tortilla quality

[a]Not listed is a Gallagher reselection (reseln) with uniform stripe rust resistance and slightly later maturity (OK15818).

Table 19. Trait ratings (1 to 5 scale) for OSU candidate cultivars placed under seed increase in fall 2019 with Oklahoma Foundation Seed Stocks. First flush of candidates indicated by orange highlight; second flush, no highlight.

	Trait category[a]											
Candidate	*DP*	*HF*	*YR*	*LR*	*TS*	*PM*	*V*	*AST*	*SS*	*BQ*	*TW*	*Weaknesses*
OK168512	2	2	2	3	2	2	1	3	1	1	1	Kernel size
OK16D101089	2	5	2	1	4	1	1	1	1	2	2	Fine canopy texture
OK14124-2	5	5	2	1	2	4	1	1	1	1	1	Inopportune plant date
OK12912C-138407-2	1	3	1	1	3	1	1	1	1	1	1	Tall
OCW04S717T-6W	1	5	1	1	1	1	1	3	1	1	3	April freeze
OCW03S580S-8WF	3	3	2	1	2	1	1	1	1	2	4	Minor shattering
OK12716W	2	1	2	4	5	4	1	2	2	3	4	Prostrate growth
OK16729W	1	5	1	1	3	4	1	3	2	3	1	Mixing tolerance
OK15MASBx7 ARS 8-1	2	1	1	2	5	3	1	3	2	1	3	Nitrogen use efficiency
OK16D101157	3	1	3	3	4	4	1	3	1	2	1	Fungicide advisable
OK13P016	1	1	1	2	3	4	1	1	3	1	2	Powdery mildew

[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; AS = acid-soil tolerance; SS = straw strength; BQ = baking quality; TW = test weight. Values ≤2 are considered very desirable; those ≥4 are undesirable. No value (--) indicates inconsistent or insufficient data for postulation.

Improving Oklahoma Wheat Yield and Quality through Weed Management

Misha Manuchehri and Gary Strickland
Weed Science

Partners in Progress WHEAT

Weed Management Strategies for Control of Herbicide Resistant Italian Ryegrass

Most Italian ryegrass populations in Oklahoma are resistant to ALS herbicides such as Finesse® Cereal & Fallow and PowerFlex® HL. Recently, ACCase (Axial® XL) resistant Italian ryegrass populations also have been identified in Oklahoma with the first resistant biotypes being confirmed in Caddo and Grady counties. Due to Axial® XL resistance, there are little to no postemergence herbicide options; however, there are several products (Axiom® DF, Anthem® Flex and Zidua®) that can be applied at the delayed preemergence timing, shortly after wheat emerges. When applied at the proper rate and incorporated by rainfall, these products have the potential to control ryegrass 90% to 97% throughout the winter wheat season (Figure 22).

Use of the Clearfield® and CoAXium® Systems to Manage Feral Rye and Rescuegrass

Studies using both Clearfield® and CoAXium® herbicide tolerant technologies have been conducted during the last three growing seasons and will continue to be evaluated. Rescuegrass control was the highest following postemergence fall or fall + spring applications of Beyond® + NIS or MSO (data not shown). Exceptional control was achieved following quizalofop-P-ethyl (Aggressor® - CoAXium® System herbicide), regardless of application timing or surfactant used (Figure 23). Feral rye control with Aggressor® was at least 99% in 2018-19 for fall and early spring applications regardless of rye density, herbicide rate or surfactant (Figure 24). However, late spring Aggressor® applications significantly reduced wheat yield due to crop injury (data not shown) and poorly controlled feral rye (Figure 24). Studies currently are being carried out to further investigate the potential challenge with late spring applications.

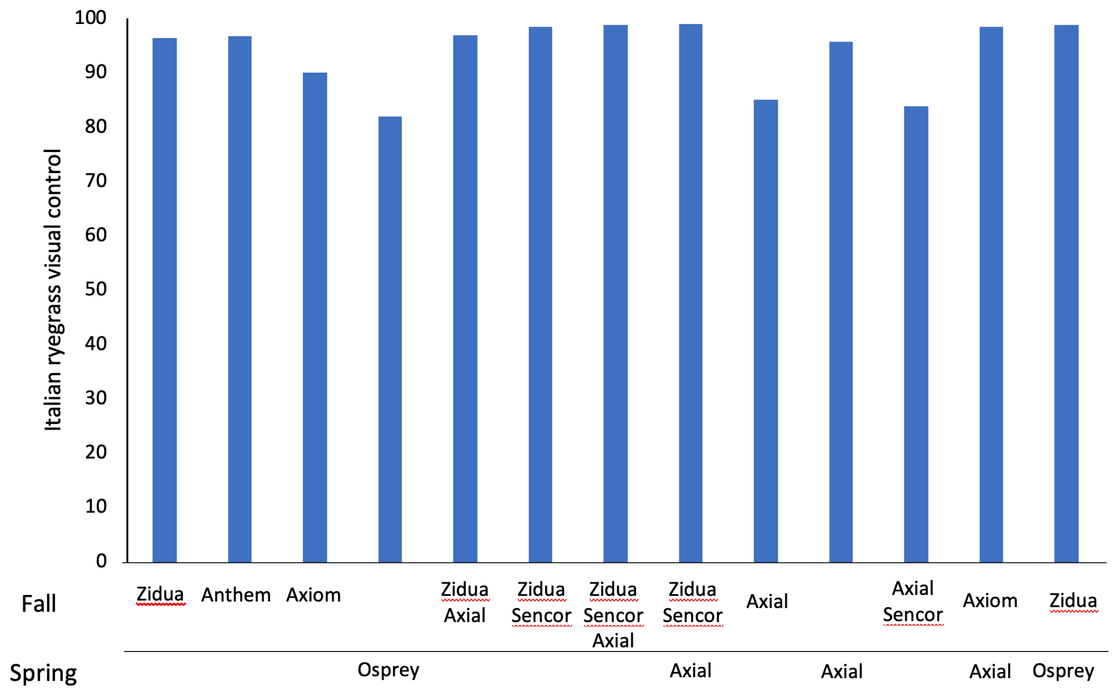

Figure 22. End-of-season Italian ryegrass control at Perkins during the 2018-19 winter wheat growing season.

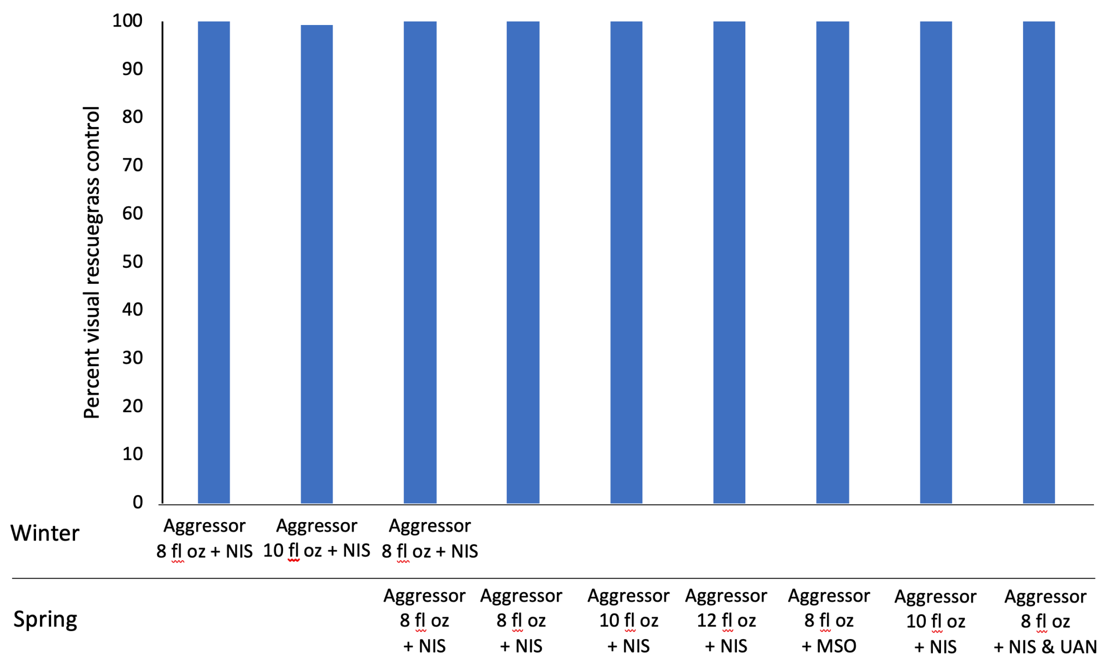

Figure 23. End-of-season rescuegrass control in Tipton during the 2018-19 winter wheat growing season.

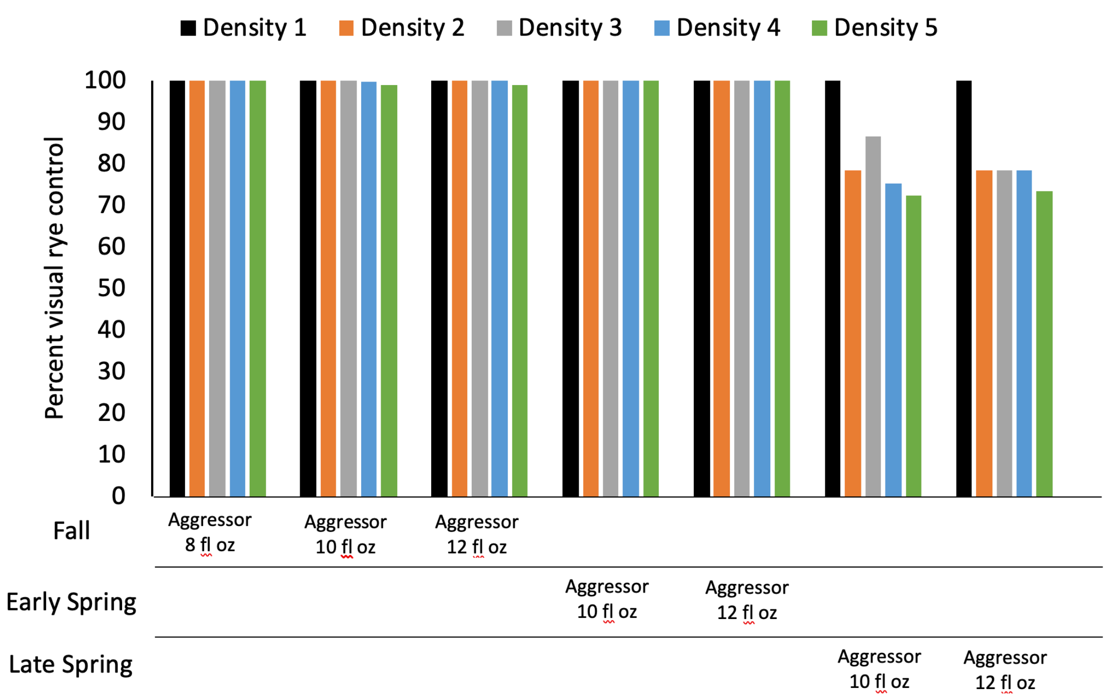

Figure 24. Feral rye control in Perkins during the 2018-19 winter wheat growing season. Density 1 represents a low rye population and Density 5 represents a high rye infestation.

Herbicide Resistance Screening

To date, the OSU Weed Science Herbicide Resistance Screening Program has screened close to 2,000 suspected herbicide-resistant weed biotypes. From these screenings, three new cases have been documented and posted to weedscience.org, the website for the International Survey of Herbicide Resistant Weeds. Cases include glyphosate resistant Palmer amaranth, mesosulfuron and chlorsulfuron (Finesse® Cereal & Fallow) resistant horseweed/marestail, and recently pinoxaden (Axial® XL) resistant Italian ryegrass. All of these weeds are competitive in winter wheat cropping systems and Palmer amaranth and horseweed also compete with summer crops that are the foundation of many of our wheat rotations.

Partners in Progress WHEAT

Wheat Variety Trials

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Plant and Soil Sciences

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According to the August 2019 USDA crop report, Oklahoma wheat production was estimated to be approximately 110 million bushels, which is about 57% greater than 2018 production (Table 20) and 12% greater than 2017 production. The increase in total grain production is the result of 250,000 more harvested acres than in 2018 and much greater yield per acre. The 4.3 million acres planted in the 2019 crop year was a 2% decrease compared to the previous year, and was 16% lower than the previous 10-year average. The number of harvested acres was estimated at 2.75 million, which is 10% greater than in 2018 (Table 20). The statewide average yield was projected at 40 bushels per acre, which would be a new record. This is 12 bushels per acre (43%) greater than the 2018 state average and 11.5 bushels per acre (40%) greater than the previous 10-year average.

Table 20. Oklahoma wheat production for 2018 and 2019 as estimated by USDA NASS, August 2019.

	2018	*2019*
Harvested acres	2.5 million	2.75 million
Yield (bu/ac)	28	40
Total bushels	70 million	110 million

The 2018-2019 wheat growing season was challenging from establishment through grain fill, but the end result was a harvest that exceeded expectations for most producers. Dual-purpose wheat producers in most areas of the state benefitted from a full profile of moisture in early September and favorable conditions for wheat growth. Wheat forage production was well above average, with some varieties producing more than 2 tons of forage per acre by mid-December (see CR-2141, "Fall forage production and first hollow stem date for small grain varieties during the 2018-2019 crop year" for more information).

The same rains that fueled fall forage growth kept many grain-only producers from planting in a timely fashion. Sowing wheat in late October through the end of November was the norm, and many wheat fields entered the winter months still trying to emerge or with only one or two leaves. Cool conditions further delayed development and occurrence of first hollow stem was approximately one week later than the long-term average. Fortunately, moderate temperatures and ample moisture allowed a late-emerging and under-developed wheat crop to add tillers and develop a plant canopy.

Conditions for wheat development and grain fill remained mostly favorable until excessive rainfall events in May had many producers again questioning whether or not a wheat crop would be harvested in 2019. The October 1, 2018 to July 22, 2019 time frame was the fourth wettest on record for Oklahoma, and May stood out as an extreme month in an already wet production year. The Oklahoma Mesonet station at Lahoma recorded 12.7 inches of rainfall in May 2019, which is approximately 8 inches more than normal. The Kingfisher station reported 15.9 inches of May rainfall, which is more than 10 inches above normal. Several fields were complete losses due to flooding, and several additional fields were severely lodged from waterlogged soil conditions. There was concern that waterlogged soil conditions would adversely affect seed development and seed fill, resulting in poor yields or low test weights.

These wet and cool conditions also paved the way for severe disease incidence and severity in the 2019 Oklahoma wheat crop, especially in north-central Oklahoma. Few diseases were observed during the fall of 2018, with leaf rust at a low incidence being the primary disease reported. Lack of disease in the fall was probably the result of a significantly later planting date across much of the state. Foliar disease was slow to start in the spring, but with the cool and moist weather extending into the late spring, both rusts (leaf and stripe) and the leaf spot diseases (Septoria, Stagonospora and tan spot) were much more widespread and severe across Oklahoma in 2019. Often, Septoria and Stagonospora were found on the upper wheat leaves and flag leaf, which is atypical in Oklahoma. At many locations, foliar diseases were not observed until well into May, and a few locations (e.g. northwestern Oklahoma and the Panhandle) had lighter foliar disease pressure than the rest of Oklahoma. Most locations in north-central and central Oklahoma had at least one foliar disease of moderate to high severity with a few locations having a high severity of several diseases. Septoria and leaf rust remained the most prominent diseases across the state. Physiological leaf spot was detectable on some cultivars when symptoms of Septoria or leaf rust were delayed or suppressed by a fungicide treatment.

Root rots (primarily dryland root rot caused by the fungus Fusarium) and black chaff (caused by the bacterium Xanthomonas) were more prevalent than typical for Oklahoma. Fusarium head blight (scab) also occurred primarily in northeastern Oklahoma, but fortunately did not occur at a high incidence over the main wheat area of Oklahoma. Barley yellow dwarf was sporadic and was observed at only a few locations. The wheat curl mite-transmitted virus diseases (wheat streak mosaic, Triticum mosaic and High Plains Disease) were found, but at a much lower level as found in the past couple of years. Delayed planting is a recommended management strategy for these insect-vectored diseases, and the delayed planting associated with the wet fall probably helped reduce the incidence of barley yellow dwarf and the mite-transmitted virus diseases. Powdery mildew was observed at a lower incidence and severity than in most years. In summary, it was a very active year for diseases in Oklahoma with the mild and wet weather facilitating many diseases. The mild and wet weather also improved yield prospects by the time producers were making decisions regarding application of foliar fungicides, and many producers chose to protect yield potential with foliar fungicides. Data from fungicide treated and nontreated variety trial comparisons at Lahoma, Apache and Chickasha provide indication of the impact of foliar disease on grain yield and suggest that applying a foliar fungicide was a profitable decision for many Oklahoma wheat farmers in 2019.

Harvest started approximately one week later than normal with no reports of wheat harvested prior to Memorial Day in 2019. Rainfall resulted in a very slow and intermittent start to harvest, and waterlogged soil conditions presented challenges. Weather and soil conditions improved by mid-June, and harvest continued at a steady pace until conclusion in the latter half of July in the Oklahoma Panhandle. Grain yields exceeded expectations with some of the best yields coming from Harper County west through the Panhandle. The delayed harvest and waterlogged soil conditions did result in some low test weights, but the extent of the damage varied by geography and variety.

Testing 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 with the plot combine to 19 feet at harvest. Panhandle dryland locations were 35 feet long at planting and trimmed to 29 feet at harvest. Wheel tracks were included in the plot area for yield calculation for a total plot width of 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-plot arrangement of a randomized complete block with four replications where whole plots were fungicide treated or non-treated, and sub-plots 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 (DP) trial, Union City, Walters and forage trials, were sown at 120 pounds per acre. The Panhandle irrigated and dryland locations were sown at 90 and 45 pounds per acre, respectively. All other locations were sown at 60 pounds per acre. Grazing intensity, 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. Grain weight, test weight and moisture content were collected from each plot, and grain yields were corrected to 12% moisture content. Grain moisture at all sites was generally below

12%, and maximum and minimum grain moisture for all plots at a location typically ranged no more than 2%. The Afton plots were harvested, but data not reported, as the trial coefficient of variation (c.v.) exceeded 25. The Marshall plots were not harvested due to severe weed pressure.

Data Interpretation

Yield and test weight data for each location and regional summary were analyzed using the appropriate statistical methods. At the bottom of Table 21, the mean and least significant difference (LSD) values are reported. The LSD is a test statistic that aids in determining whether there is a true difference in yield or test weight. In this report, one can be 95% confident the difference between two varieties is real if the difference is equal to or greater than the LSD value. Data that is not significant is indicated by NS. For example, if the LSD value is 4 bushels per acre in a trial which Variety A yielded 30 bushels per acre and Variety B yielded 26, then Variety A would be considered to have a statistically greater yield. However, if Variety C yielded 27 bushels per acre, then Variety A and Variety C would be considered to have a similar yield. In that same example trial, there is a 5% chance that the 4-bushels-per-acre difference between Variety A and Variety B does not truly exist, but random chance caused the 5-bushel difference. These chance factors may include differences in fertility, moisture availability and diseases, for example. To aid in determining the varieties with the highest yields and test weights, values highlighted in gray do not differ statistically from the highest value within a column. The performance of a variety may vary from year to year, even at the same location. Tests over two or more years and at multiple locations more accurately predict the variety performance.

Additional Information on the Web

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

Website: www.wheat.okstate.edu
Blog: www.osuwheat.com

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Cade Miller
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Dean Fuxa, Marshall
Greg Leonard, Afton

Table 21. 2018-2019 Oklahoma wheat variety performance test yield summary.

						Apache					Chickasha	Goodwell
		Altus	Alva	Apache	Fungicide	Balko	Buffalo	Cherokee	Chickasha	IWM	Irrigated	Homestead
Licensee	Variety	----------------				---grain yield (bu/ac)---						----------------
AGSECO	AG Gallant	59	68	-	-	81	72	53	29	66	74	-
AGSECO	AG Icon	67	75	-	-	88	66	59	47	68	90	64
AgriMAXX	AM Eastwood	49	59	40	65	81	-	39	27	62	93	48
OGI	Baker's Ann	58	-	-	-	85	-	60	39	69	100	-
OGI	Bentley	57	73	55	84	86	84	47	41	65	85	63
AgriPro	Bob Dole	49	90	-	-	-	86	68	54	78	83	77
PlainsGold	Canvas	71	-	-	-	-	-	-	32	60	98	-
CROPLAN	CP7826	57	70	61	74	83	-	47	41	64	67	50
CROPLAN	CP7869	67	-	-	-	-	-	-	30	56	91	-
CROPLAN	CP7909	57	-	-	-	-	-	-	49	79	90	-
PlainsGold	Crescent AX	44	-	-	-	-	-	-	38	71	96	-
OGI	Doublestop CL Plus	51	82	65	68	87	72	63	58	68	79	69
OGI	Duster	66	63	55	76	91	-	36	34	70	88	52
OGI	Gallagher	56	73	59	83	94	78	57	30	77	86	65
OGI	Green Hammer	70	-	64	73	-	-	60	44	72	-	68
OGI	Iba	62	67	48	80	92	74	53	30	72	93	59
KWA	Joe	64	78	-	-	97	-	50	42	65	97	68
KWA	KS Venada	40	-	-	-	-	-	-	39	68	80	-
KWA	KS080093K-18	53	-	-	-	-	-	-	32	58	91	-
PlainsGold	Langin	52	69	-	-	86	80	52	32	71	89	-
KWA	Larry	57	66	-	-	93	75	46	52	62	85	47
LCS	LCH15ACC7-7	61	-	-	-	-	-	-	35	71	88	-
LCS	LCS Chrome	52	80	70	68	86	74	55	41	57	94	66
LCS	LCS Pistol	62	-	-	-	-	-	-	34	67	86	-
OGI	Lonerider	58	60	-	-	93	75	47	28	70	94	-
Dyna-Gro	Long Branch	59	57	-	-	91	75	32	21	50	77	41
OGI	NF 101	46	-	47	65	-	-	-	29	61	72	-
OGI	Ruby Lee	50	64	76	82	81	-	53	49	76	87	66
OGI	Showdown	74	72	57	76	94	83	56	42	63	90	60
OGI	Skydance	50	70	72	79	-	-	-	54	72	83	-
OGI	Smith's Gold	61	66	64	77	90	80	51	46	65	79	64
OGI	Spirit Rider	50	-	-	-	-	-	-	41	78	92	62
OGI	Stardust	60	-	-	-	-	-	-	27	59	74	48
AgriPro	SY Achieve CL2	44	-	-	-	-	-	-	45	75	78	56
AgriPro	SY Benefit	33	-	54	75	-	-	-	33	65	71	45
AgriPro	SY Flint	51	-	54	78	-	-	-	40	67	87	47
AgriPro	SY Grit	38	63	50	77	93	71	47	31	60	91	47
AgriPro	SY Monument	-	74	-	-	91	-	57	-	-	98	66
AgriPro	SY Razor	33	-	63	67	-	-	-	43	59	-	-
AgriPro	SY Rugged	56	73	58	68	91	82	54	44	64	90	60
Watley	TAM 112	49	48	-	-	84	73	34	26	63	76	-
AGSECO	TAM 114	66	73	-	-	97	81	50	29	67	82	-
Watley	TAM 204	48	54	-	-	88	67	39	20	63	84	42
WestBred	WB4269	65	72	77	80	87	79	51	50	75	91	70
WestBred	WB4303	43	67	59	71	91	88	67	37	73	96	70
WestBred	WB4418	58	-	-	-	-	-	-	35	66	93	-
WestBred	WB4515	50	-	-	-	-	-	-	33	60	82	59
WestBred	WB4595	60	-	-	-	-	-	-	42	74	90	-
WestBred	WB4699	58	-	-	-	-	-	-	38	73	98	-
WestBred	WB4792	67	-	-	-	-	-	-	43	75	95	-
WestBred	WB-Grainfield	56	59	-	-	94	84	42	33	63	94	55
KWA	Zenda	57	-	-	-	-	-	-	44	69	79	-
OSU Experimentals												
	OCW04S717T-6W	-	-	-	-	-	-	-	60	70	-	66
	OK149132C	68	68	-	-	-	-	-	43	77	88	-
	OK14P212	77	57	36	73	89	88	44	-	-	98	59
	OK14P736W	60	55	41	71	77	69	43	-	-	92	-
	OK15MASBx7 8-1	-	-	-	-	-	-	-	-	-	-	-
	OK16729W	72	-	-	-	-	-	-	44	73	97	-
	OK168512	-	65	-	-	88	68	48	-	-	79	-
	OK16D101089	64	-	-	-	-	-	-	55	73	-	-
	Mean	**56**	**68**	**58**	**74**	**89**	**77**	**50**	**39**	**67**	**87**	**59**
	LSD (0.05)	**10**	**5**	**8**	**8**	**4**	**8**	**7**	**6**	**7**	**9**	**7**

Note: shaded values are not statistically different from the greatest value within a column (i.e., location).

Table 21. 2018-2019 Oklahoma wheat variety performance test yield summary. (cont'd)

Licensee	*Variety*	*Hooker*	*Keyes*	*Kildare*	*Kingfisher*	*Lahoma*	*Lahoma Fungicide*	*Lamont*	*Thomas*	*Union City*	*Walters*
		grain yield (bu/ac)									
AGSECO	AG Gallant	39	70	-	-	34	59	-	-	-	-
AGSECO	AG Icon	43	88	62	66	44	62	35	59	55	-
AgriMAXX	AM Eastwood	54	82	73	72	12	43	18	38	22	9
OGI	Baker's Ann	55	-	65	-	50	71	38	-	-	-
OGI	Bentley	59	91	77	71	36	65	38	48	43	20
AgriPro	Bob Dole	-	-	76	69	59	73	55	-	-	-
PlainsGold	Canvas	-	-	-	-	20	49	-	-	-	-
CROPLAN	CP7826	39	76	66	60	30	61	30	42	47	20
CROPLAN	CP7869	-	-	-	-	33	60	-	-	-	-
CROPLAN	CP7909	-	-	-	-	38	66	-	-	-	-
PlainsGold	Crescent AX	-	-	-	-	37	63	-	-	-	-
OGI	Doublestop CL Plus	49	76	68	60	44	63	42	54	55	34
OGI	Duster	47	89	-	68	34	53	12	43	40	26
OGI	Gallagher	34	81	61	65	45	67	27	48	41	19
OGI	Green Hammer	-	-	64	66	52	66	37	57	46	25
OGI	Iba	52	83	59	75	35	64	21	37	39	21
KWA	Joe	60	87	59	72	46	61	35	-	-	-
KWA	KS Venada	-	-	-	-	52	71	-	-	-	-
KWA	KS080093K-18	-	-	-	-	43	64	-	-	-	-
PlainsGold	Langin	65	94	-	-	35	64	-	-	-	-
KWA	Larry	50	85	-	66	26	53	28	36	-	-
LCS	LCH15ACC7-7	-	-	-	-	40	65	-	-	-	-
LCS	LCS Chrome	55	85	62	73	42	60	30	55	41	30
LCS	LCS Pistol	-	-	-	-	34	64	-	-	-	-
OGI	Lonerider	55	84	-	-	25	62	-	-	-	-
Dyna-Gro	Long Branch	55	82	-	49	22	53	-	35	31	-
OGI	NF 101	-	-	-	-	43	60	-	-	36	12
OGI	Ruby Lee	50	73	61	70	43	66	37	51	52	26
OGI	Showdown	58	85	70	68	31	57	28	45	42	38
OGI	Skydance	-	-	-	-	48	67	-	-	-	15
OGI	Smith's Gold	49	77	55	64	39	65	32	53	49	22
OGI	Spirit Rider	-	-	58	-	37	65	35	-	-	-
OGI	Stardust	-	-	61	-	21	50	24	-	-	-
AgriPro	SY Achieve CL2	-	-	72	78	35	62	35	-	-	-
AgriPro	SY Benefit	-	-	-	65	27	51	29	-	-	15
AgriPro	SY Flint	-	-	-	67	28	53	25	36	38	23
AgriPro	SY Grit	44	71	73	57	24	50	27	32	32	15
AgriPro	SY Monument	42	81	-	60	41	64	33	49	-	-
AgriPro	SY Razor	-	-	-	-	-	-	-	-	5	-
AgriPro	SY Rugged	53	86	65	73	41	56	40	50	50	15
Watley	TAM 112	51	87	-	-	12	48	-	-	-	-
AGSECO	TAM 114	46	71	-	-	38	64	-	-	-	-
Watley	TAM 204	53	79	-	58	10	50	-	33	38	-
WestBred	WB4269	49	80	62	83	40	62	32	68	52	18
WestBred	WB4303	45	75	72	85	44	67	37	65	40	-
WestBred	WB4418	-	-	-	-	36	56	-	-	-	-
WestBred	WB4515	-	-	74	58	24	54	24	54	31	-
WestBred	WB4595	-	-	-	-	40	66	-	-	-	-
WestBred	WB4699	-	-	-	-	47	70	-	-	-	-
WestBred	WB4792	-	-	-	-	52	70	-	-	-	-
WestBred	WB-Grainfield	56	89	-	63	19	48	16	-	-	-
KWA	Zenda	-	-	75	-	48	72	43	-	-	-
OSU Experimentals											
	OCW04S717T-6W	-	-	-	64	50	62	-	-	46	-
	OK149132C	-	-	-	61	29	57	-	51	50	-
	OK14P212	46	86	-	-	-	-	-	36	31	24
	OK14P736W	55	77	-	-	-	-	-	-	-	18
	OK15MASBx7 8-1	-	-	-	-	40	66	-	-	-	-
	OK16729W	-	-	-	-	51	71	-	-	-	
	OK168512	63	90	-	-	-	-	-	-	-	-
	OK16D101089	-	-	72	65	56	72	-	63	62	17
	Mean	**51**	**82**	**66**	**67**	**37**	**61**	**31**	**48**	**43**	**21**
	LSD (0.05)	**7**	**10**	**6**	**8**	**4**	**5**	**5**	**10**	**6**	**4**

Note: shaded values are not statistically different from the greatest value within a column (i.e., location).

Wheat Variety Trials – Protein Content

Amanda de Oliveira Silva, Robert Calhoun, Brett Carver and Jeff Edwards
Plant and Soil Sciences

Protein is just one of many attributes that determines end-use quality and marketability of winter wheat. In fact, some millers and bakers would argue functionality of wheat protein is more important than the quantity of protein. While varietal differences exist, variability in protein among environments is generally much larger than variability among varieties. Factors such as nitrogen fertility and drought stress, for example, can sharply impact final protein wheat content.

To reflect these management and environmental impacts on wheat protein content, data is reported by variety and location in Table 22. In Table 23, the wheat protein content by variety is reported as a deviation from the location mean, as this allows for easier comparison of wheat protein among varieties across locations. Doublestop CL Plus, for example, showed a positive deviation from the location mean in 95% of this year's trials, indicating a tendency for above-average wheat protein content. Iba, on the other hand, showed a negative deviation from the location mean in 90% of the trials, indicating a tendency for lower-than-average wheat protein content. Adequate nitrogen fertility as recommended by a recent soil test or sensor-based nitrogen management program can help ensure varieties with low average protein produce wheat or flour protein within the acceptable range for end-use customers.

However, protein quantity should not be used as a barometer for protein quality (i.e., dough strength and functionality). There are few exceptions to this, with Doublestop CL Plus being one example. Iba also is a prime example of how protein data can sometimes be misused, as the functionality of the protein in Iba is above average, which can offset lower absolute protein content. More information on end-use quality is available in Current Report CR-2165 Wheat and Flour Quality for Varieties Tested in the 2016 OSU Variety Performance Tests.

Procedures

Approximately 600-gram subsamples of wheat grain were collected from the OSU Wheat Variety Performance Test plots at harvest. These plots were well-fertilized and managed according to OSU Extension recommendations. Additional information on test locations and management practices is available in Current Report CR-2143 2018-2019 Oklahoma Small Grains Variety Performance Tests on the web at www.wheat.okstate.edu. Samples were stored in plastic containers for approximately one month following harvest. Samples were nondestructively analyzed for protein content on a 12% moisture basis using a Diode Array Near Infrared instrument (NIR) (model DA 7200, Perten Instruments, Sweden).

Additional Information on the Web

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

Website: www.wheat.okstate.edu
Blog: www.osuwheat.com
@OSU_smallgrains
OSU Small Grains
OSU Small Grains

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Table 22. 2018-2019 Oklahoma wheat variety performance test protein concentration summary.

Licensee	Variety	Altus	Alva	Apache	Apache Fungicide	Balko	Buffalo	Cherokee	Chickasha	Chickasha IWM	Goodwell Irrigated	Homestead
		-% wheat protein-										
AGSECO	AG Gallant	11.1	11.2	-	-	10.6	9.3	11.9	13.0	12.1	12.9	-
AGSECO	AG Icon	12.3	11.8	-	-	10.7	10.1	13.7	13.6	13.1	13.5	12.9
AgriMAXX	AM Eastwood	9.6	11.2	12.0	10.5	10.3	-	13.5	13.7	12.1	12.3	11.8
OGI	Baker's Ann	11.0	-	-	-	10.3	-	13.6	13.7	13.0	13.6	-
OGI	Bentley	10.4	10.6	11.3	10.3	10.2	9.2	13.2	14.0	13.0	13.6	12.0
AgriPro	Bob Dole	11.2	11.0	-	-	-	10.5	13.1	13.3	12.3	14.5	12.5
PlainsGold	Canvas	9.4	-	-	-	-	-	-	13.6	13.0	12.1	-
CROPLAN	CP7826	10.2	11.1	11.6	10.9	10.2	-	13.4	14.3	12.9	15.6	11.9
CROPLAN	CP7869	10.5	-	-	-	-	-	-	14.7	12.8	13.0	-
CROPLAN	CP7909	10.2	-	-	-	-	-	-	12.4	11.6	12.1	-
PlainsGold	Crescent AX	9.6	-	-	-	-	-	-	12.8	12.5	12.2	-
OGI	Doublestop CL Plus	11.0	12.5	11.6	11.7	11.5	10.9	14.4	14.2	14.4	15.4	13.7
OGI	Duster	9.9	11.7	11.1	10.5	10.1	-	14.2	13.3	12.4	13.1	12.7
OGI	Gallagher	9.7	11.1	10.4	9.8	9.7	8.6	12.7	13.9	12.0	13.3	11.8
OGI	Green Hammer	11.0	-	11.6	11.2	-	-	14.3	13.5	13.9	-	13.6
OGI	Iba	10.1	10.8	11.6	10.5	10.1	9.4	12.4	13.2	11.9	12.2	11.6
KWA	Joe	10.7	10.6	-	-	9.6	-	12.4	12.8	12.1	12.5	11.7
KWA	KS Venada	10.4	-	-	-	-	-	-	12.6	13.2	13.4	-
KSU	KS080093K-18	10.8	-	-	-	-	-	-	13.4	13.4	12.9	-
PlainsGold	Langin	10.6	10.8	-	-	10.1	8.7	12.6	13.1	11.9	12.4	-
KWA	Larry	10.3	10.7	-	-	9.7	8.9	12.4	13.2	12.1	12.7	11.6
LCS	LCH15ACC7-7	10.7	-	-	-	-	-	-	13.4	12.3	12.9	-
LCS	LCS Chrome	11.3	11.2	11.7	11.4	11.0	10.1	13.2	14.5	13.6	13.3	12.6
LCS	LCS Pistol	10.3	-	-	-	-	-		-	14.3	12.9	13.0
OGI	Lonerider	10.1	11.4	-	-	9.9	9.8	13.8	15.0	13.0	13.4	-
Dyna-Gro	Long Branch	10.8	11.7	-	-	9.8	9.4	14.5	14.3	13.2	12.6	12.7
OGI	NF 101	10.9	-	11.2	10.5	-	-	-	12.8	12.6	13.7	-
OGI	Ruby Lee	10.3	11.7	10.9	11.1	10.9	-	13.2	12.7	12.9	14.1	11.6
OGI	Showdown	10.1	10.6	11.2	10.4	9.5	8.8	12.8	12.8	12.8	12.8	11.0
OGI	Skydance	11.1	11.9	10.7	10.7	-	-	-	13.3	13.3	14.5	-
OGI	Smith's Gold	10.1	11.7	10.7	10.5	10.2	9.3	13.4	13.4	13.1	13.4	12.1
OGI	Spirit Rider	10.2	-	-	-	-	-	-	14.1	12.1	13.0	12.5
OGI	Stardust	11.4	-	-	-	-	-	-	14.3	14.0	13.6	12.4
AgriPro	SY Achieve CL2	10.6	-	-	-	-	-	-	13.6	13.1	13.6	12.5
AgriPro	SY Benefit	10.1	-	10.9	10.4	-	-	-	12.4	12.1	12.2	11.0
AgriPro	SY Flint	10.5	-	10.7	10.5	-	-	-	12.8	12.1	13.1	11.5
AgriPro	SY Grit	10.9	10.5	11.5	10.4	9.6	9.1	13.2	14.0	13.5	12.6	12.4
AgriPro	SY Monument	-	11.1	-	-	10.2	-	13.2	-	-	12.9	11.7
AgriPro	SY Razor	11.1	-	11.4	11.3	-	-	-	12.8	13.1	-	-
AgriPro	SY Rugged	10.5	11.3	11.3	10.7	10.1	9.9	13.3	13.4	12.8	12.3	11.7
Watley	TAM 112	10.6	11.7	-	-	10.0	8.9	13.1	12.1	12.2	12.8	-
AGSECO	TAM 114	10.9	10.2	-	-	9.7	8.6	12.5	13.1	12.1	13.6	-
Watley	TAM 204	10.9	12.0	-	-	10.4	9.4	14.1	14.3	12.1	13.2	12.2
WestBred	WB4269	10.3	11.4	10.6	10.5	10.9	9.9	12.8	12.6	11.7	12.4	11.5
WestBred	WB4303	11.2	11.3	11.2	10.7	11.0	10.5	12.5	13.1	12.9	13.9	12.0
WestBred	WB4418	10.3	-	-	-	-	-	-	14.0	12.7	12.8	-
WestBred	WB4515	10.6	-	-	-	-	-	-	14.5	13.3	14.1	11.9
WestBred	WB4595	10.4	-	-	-	-	-	-	12.4	11.4	12.3	-
WestBred	WB4699	9.7	-	-	-	-	-	-	12.3	10.5	12.2	-
WestBred	WB4792	10.3	-	-	-	-	-	-	12.5	12.3	12.2	-
WestBred	WB-Grainfield	9.5	10.4	-	-	9.5	9.7	12.4	13.0	12.2	12.5	11.3
KWA	Zenda	10.1	-	-	-	-	-	-	12.3	12.1	13.0	-
OSU Experimentals												
	OCW04S717T-6W	-	-	-	-	-	-	-	14.2	13.6	-	13.5
	OK149132C	11.1	11.4	-	-	-	-	-	13.6	12.5	13.9	-
	OK14P212	11.0	10.9	12.4	10.2	9.6	9.5	14.0	-	-	12.7	12.1
	OK14P736W	11.1	10.6	12.5	10.7	10.6	9.4	13.1	13.0	12.1	12.1	-
	OK15MASBx7 8-1	-	-	-	-	-	-	-	-	-	-	-
	OK16729W	11.1	-	-	-	-	-	-	-	-	12.2	-
	OK168512	-	11.6	-	-	10.2	9.3	13.7	-	-	13.1	-
	OK16D101089	10.6	-	-	-	-	-	-	12.9	12.6	-	-
	Mean	**10.6**	**11.2**	**11.3**	**10.7**	**10.2**	**9.5**	**13.2**	**13.4**	**12.6**	**13.1**	**12.1**
	LSD (0.05)	**1.1**	**0.5**	**0.6**	**0.7**	**0.3**	**0.8**	**0.6**	**0.6**	**0.6**	**0.5**	**0.4**

Note: shaded values are not statistically different from the greatest value within a column (i.e., location).

Table 22. 2018-2019 Oklahoma wheat variety performance test protein concentration summary. (cont'd)

Licensee	*Variety*	*Hooker*	*Keyes*	*Kildare*	*Kingfisher*	*Lahoma*	*Lahoma Fungicide*	*Lamont*	*Thomas*	*Union City*	*Walters*
		% wheat protein									
AGSECO	AG Gallant	14.8	12.7	-	-	11.9	11.6	-	-	-	-
AGSECO	AG Icon	15.4	12.5	13.1	11.7	14.1	13.8	14.5	14.2	12.9	-
AgriMAXX	AM Eastwood	14.4	12.9	11.6	10.1	14.4	13.2	14.0	13.6	13.8	12.6
OGI	Baker's Ann	14.9	-	12.5	-	13.9	13.6	14.7	-	-	-
OGI	Bentley	13.8	12.9	12.0	10.3	13.0	12.9	13.2	13.2	13.2	12.0
AgriPro	Bob Dole	-	-	11.9	12.1	12.9	12.8	13.0	-	-	-
PlainsGold	Canvas	-	-	-	-	13.2	12.5	-	-	-	-
CROPLAN	CP7826	17.2	14.0	13.0	12.5	13.5	13.0	13.7	15.0	12.7	11.8
CROPLAN	CP7869	-	-	-	-	13.6	12.7	-	-	-	-
CROPLAN	CP7909	-	-	-	-	12.2	11.3	-	-	-	-
PlainsGold	Crescent AX	-	-	-	-	11.8	11.8	-	-	-	-
OGI	Doublestop CL Plus	15.5	14.5	13.4	12.7	13.7	13.9	13.9	14.6	12.6	13.5
OGI	Duster	14.8	12.1	-	11.6	13.5	12.8	14.9	13.9	12.7	11.9
OGI	Gallagher	15.8	12.9	12.1	11.2	12.5	12.3	14.1	13.7	12.8	11.3
OGI	Green Hammer	-	-	13.4	13.2	13.9	14.4	14.6	14.0	13.1	13.3
OGI	Iba	13.7	11.9	11.7	11.2	12.8	11.9	13.3	13.3	12.7	11.3
KWA	Joe	13.4	12.3	11.9	11.2	12.8	12.3	12.6	-	-	-
KWA	KS Venada	-	-	-	-	12.9	13.0	-	-	-	-
KSU	KS080093K-18	-	-	-	-	13.4	12.9	-	-	-	-
PlainsGold	Langin	13.3	11.4	-	-	12.4	12.1	-	-	-	-
KWA	Larry	13.8	12.8	-	10.3	13.3	12.2	12.9	13.2	-	-
LCS	LCH15ACC7-7	-	-	-	-	12.8	12.2	-	-	-	-
LCS	LCS Chrome	14.8	13.4	12.9	12.4	13.7	13.6	13.9	14.1	12.4	12.0
LCS	LCS Pistol	-	-	-	-	13.9	12.8	-	-	-	-
OGI	Lonerider	14.5	13.3	-	-	14.6	12.7	-	-	-	-
Dyna-Gro	Long Branch	13.5	11.9	-	11.4	14.0	13.1	-	13.4	13.7	-
OGI	NF 101	-	-	-	-	12.6	12.9	-	-	12.8	11.8
OGI	Ruby Lee	15.1	13.7	12.2	11.0	12.4	13.4	13.0	12.9	11.8	13.1
OGI	Showdown	13.9	12.2	12.2	10.5	12.9	12.0	13.5	12.9	13.0	11.0
OGI	Skydance	-	-	-	-	13.6	13.6	-	-	-	13.5
OGI	Smith's Gold	14.0	12.5	12.7	10.9	13.4	12.6	14.3	13.1	12.9	11.5
OGI	Spirit Rider	-	-	12.9	-	13.9	13.5	14.1	-	-	-
OGI	Stardust	-	-	12.9	-	14.3	13.3	14.4	-	-	-
AgriPro	SY Achieve CL2	-	-	12.6	10.7	13.9	13.2	14.0	-	-	-
AgriPro	SY Benefit	-	-	-	10.2	12.5	11.7	12.1	-	-	11.3
AgriPro	SY Flint	-	-	-	11.3	12.4	12.1	12.9	12.4	12.6	12.0
AgriPro	SY Grit	15.0	13.0	11.8	10.1	13.4	13.0	13.6	13.1	13.1	12.3
AgriPro	SY Monument	14.4	12.4	-	11.0	13.0	12.6	13.2	13.7	-	-
AgriPro	SY Razor	-	-	-	-	-	-	-	-	11.9	-
AgriPro	SY Rugged	13.9	12.1	12.0	11.4	13.5	13.1	13.8	14.1	12.7	11.2
Watley	TAM 112	14.3	12.6	-	-	14.0	12.6	-	-	-	-
AGSECO	TAM 114	14.5	13.1	-	-	13.1	12.5	-	-	-	-
Watley	TAM 204	14.7	12.6	-	11.1	15.0	12.7	-	14.7	13.4	-
WestBred	WB4269	13.8	12.5	12.1	10.8	12.8	12.0	13.4	12.9	12.1	11.7
WestBred	WB4303	16.0	13.6	12.6	10.6	13.4	13.9	13.3	13.3	13.0	-
WestBred	WB4418	-	-	-	-	14.3	13.1	-	-	-	-
WestBred	WB4515	-	-	12.0	11.9	13.8	13.3	14.1	12.9	13.5	-
WestBred	WB4595	-	-	-	-	12.8	12.1	-	-	-	-
WestBred	WB4699	-	-	-	-	12.2	11.6	-	-	-	-
WestBred	WB4792	-	-	-	-	12.1	11.9	-	-	-	-
WestBred	WB-Grainfield	13.8	12.0	-	9.9	13.2	12.3	13.1	-	-	-
KWA	Zenda	-	-	11.6	-	12.2	12.5	12.5	-	-	-
OSU Experimentals											
	OCW04S717T-6W	-	-	-	10.6	13.5	14.0	-	-	12.3	-
	OK149132C	-	-	-	12.5	13.3	12.5	-	12.8	13.2	-
	OK14P212	14.5	12.8	-	-	-	-	-	14.2	13.5	11.0
	OK14P736W	13.8	12.4	-	-	-	-	-	-	-	11.8
	OK15MASBx7 8-1	-	-	-	-	13.1	12.2	-	-	-	-
	OK16729W	-	-	-	-	12.3	12.1	-	-	-	-
	OK168512	13.6	12.2	-	-	-	-	-	-	-	-
	OK16D101089	-	-	12.3	11.1	12.4	12.8	-	13.5	12.4	12.0
	Mean	**14.5**	**12.7**	**12.4**	**11.2**	**13.2**	**12.7**	**13.6**	**13.6**	**12.8**	**12.0**
	LSD (0.05)	**0.5**	**0.8**	**0.6**	**1.0**	**0.5**	**0.4**	**0.5**	**0.7**	**0.6**	**0.6**

Note: shaded values are not statistically different from the greatest value within a column (i.e., location).

Table 23. Wheat protein content relative to the location mean (expressed as a deviation) for varieties and experimental lines in the 2018-2019 Oklahoma wheat variety performance tests.

		Altus	*Alva*	*Apache*	*Apache Fungicide*	*Balko*	*Buffalo*	*Cherokee*	*Chickasha*	*Chickasha IWM*	*Goodwell Irrigated*	*Homestead*
	Location mean	10.6	11.2	11.3	10.7	10.2	9.5	13.2	13.4	12.6	13.1	12.1
Licensee	**Variety**	-------------------------------% wheat protein relative to location mean----------------------------------										
AGSECO	AG Gallant	0.5	0.0	-	-	0.4	-0.2	-1.3	-0.4	-0.5	-0.2	-
AGSECO	AG Icon	1.7	0.6	-	-	0.5	0.6	0.5	0.2	0.5	0.4	0.8
AgriMAXX	AM Eastwood	-1.0	0.0	0.7	-0.2	0.1	-	0.3	0.3	-0.5	-0.8	-0.4
OGI	Baker's Ann	0.4	-	-	-	0.1	-	0.4	0.3	0.4	0.5	-
OGI	Bentley	-0.3	-0.6	-0.1	-0.4	0.0	-0.3	0.0	0.6	0.4	0.5	-0.1
AgriPro	Bob Dole	0.6	-0.2	-	-	-	1.0	-0.1	-0.1	-0.3	1.4	0.4
PlainsGold	Canvas	-1.2		-	-	-	-	-	-	0.2	0.4	-1.0 -
CROPLAN	CP7826	-0.4	-0.1	0.3	0.2	0.0	-	0.2	0.9	0.3	2.5	-0.2
CROPLAN	CP7869	-0.1	-	-	-	-	-	-	1.3	0.2	-0.1	-
CROPLAN	CP7909	-0.4	-	-	-	-	-	-	-1.0	-1.0	-1.0	-
PlainsGold	Crescent AX	-1.1	-	-	-	-	-	-	-0.6	-0.1	-0.9	-
OGI	Doublestop CL Plus	0.4	1.3	0.3	1.0	1.3	1.4	1.2	0.8	1.8	2.3	1.6
OGI	Duster	-0.8	0.5	-0.2	-0.3	-0.1	-	1.0	-0.1	-0.2	0.0	0.6
OGI	Gallagher	-0.9	-0.1	-0.9	-0.9	-0.5	-0.9	-0.5	0.5	-0.6	0.2	-0.3
OGI	Green Hammer	0.4	-	0.3	0.5	-	-	1.1	0.1	1.3	-	1.5
OGI	Iba	-0.5	-0.4	0.3	-0.3	-0.1	-0.1	-0.8	-0.2	-0.7	-0.9	-0.5
KWA	Joe	0.1	-0.6	-	-	-0.6	-	-0.8	-0.6	-0.5	-0.6	-0.4
KWA	KS Venada	-0.2	-	-	-	-	-	-	-0.8	0.6	0.3	-
KSU	KS080093K-18	0.2	-	-	-	-	-	-	0.0	0.8	-0.2	-
PlainsGold	Langin	0.0	-0.4	-	-	-0.1	-0.8	-0.6	-0.3	-0.7	-0.7	-
KWA	Larry	-0.3	-0.5	-	-	-0.5	-0.6	-0.8	-0.2	-0.5	-0.4	-0.5
LCS	LCH15ACC7-7	0.1	-	-	-	-	-	-	0.0	-0.3	-0.2	-
LCS	LCS Chrome	0.7	0.0	0.4	0.7	0.8	0.6	0.0	1.1	1.0	0.2	0.5
LCS	LCS Pistol	-0.3	-	-	-	-	-	-	0.9	0.3	-0.1	-
OGI	Lonerider	-0.5	0.2	-	-	-0.3	0.3	0.6	1.6	0.4	0.3	-
Dyna-Gro	Long Branch	0.2	0.5	-	-	-0.4	-0.1	1.3	0.9	0.6	-0.5	0.6
OGI	NF 101	0.3	-	-0.2	-0.2	-	-	-	-0.6	0.0	0.6	-
OGI	Ruby Lee	-0.3	0.5	-0.4	0.4	0.7	-	0.0	-0.7	0.3	1.0	-0.5
OGI	Showdown	-0.5	-0.6	-0.2	-0.3	-0.7	-0.7	-0.4	-0.6	0.2	-0.3	-1.1
OGI	Skydance	0.5	0.7	-0.6	0.0	-	-	-	-0.1	0.7	1.4	-
OGI	Smith's Gold	-0.5	0.5	-0.6	-0.2	0.0	-0.2	0.2	0.0	0.5	0.3	0.0
OGI	Spirit Rider	-0.4	-	-	-	-	-	-	0.7	-0.5	-0.1	0.4
OGI	Stardust	0.8	-	-	-	-	-	-	0.9	1.4	0.5	0.3
AgriPro	SY Achieve CL2	0.0	-	-	-	-	-	-	0.2	0.5	0.5	0.4
AgriPro	SY Benefit	-0.5	-	-0.4	-0.3	-	-	-	-1.0	-0.5	-0.9	-1.1
AgriPro	SY Flint	-0.1	-	-0.6	-0.3	-	-	-	-0.6	-0.5	0.0	-0.6
AgriPro	SY Grit	0.3	-0.7	0.2	-0.3	-0.6	-0.4	0.0	0.6	0.9	-0.5	0.3
AgriPro	SY Monument	-	-0.1	-	-	0.0	-	0.0	-	-	-0.3	-0.4
AgriPro	SY Razor	0.5	-	0.1	0.6	-	-	-	-0.6	0.5	-	-
AgriPro	SY Rugged	-0.1	0.1	-0.1	0.0	-0.1	0.4	0.1	0.0	0.2	-0.8	-0.4
Watley	TAM 112	0.0	0.5	-	-	-0.2	-0.6	-0.1	-1.3	-0.4	-0.3	-
AGSECO	TAM 114	0.3	-1.0	-	-	-0.5	-0.9	-0.7	-0.3	-0.5	0.5	-
Watley	TAM 204	0.3	0.8	-	-	0.2	-0.1	0.9	0.9	-0.5	0.1	0.1
WestBred	WB4269	-0.4	0.2	-0.7	-0.3	0.7	0.4	-0.4	-0.8	-0.9	-0.7	-0.6
WestBred	WB4303	0.6	0.1	-0.1	0.0	0.8	1.0	-0.7	-0.3	0.3	0.8	-0.1
WestBred	WB4418	-0.3	-	-	-	-	-	-	0.6	0.1	-0.3	-
WestBred	WB4515	0.0	-	-	-	-	-	-	1.1	0.7	1.0	-0.2
WestBred	WB4595	-0.2	-	-	-	-	-	-	-1.0	-1.2	-0.8	-
WestBred	WB4699	-0.9	-	-	-	-	-	-	-1.1	-2.1	-0.9	-
WestBred	WB4792	-0.3	-	-	-	-	-	-	-0.9	-0.3	-0.9	-
WestBred	WB-Grainfield	-1.2	-0.8	-	-	-0.7	0.2	-0.8	-0.4	-0.4	-0.6	-0.8
KWA	Zenda	-0.5	-	-	-	-	-	-	-1.1	-0.5	-0.1	-
OSU Experimentals												
	OCW04S717T-6W	-	-	-	-	-	-	-	0.8	1.0	-	1.4
	OK149132C	0.5	0.2	-	-	-	-	-	0.2	-0.1	0.8	-
	OK14P212	0.4	-0.3	1.1	-0.5	-0.6	0.0	0.8	-	-	-0.4	0.0
	OK14P736W	0.5	-0.6	1.2	0.0	0.4	-0.1	-0.1	-0.4	-0.5	-1.0	-
	OK15MASBx7 8-1	-	-	-	-	-	-	-	-	-	-	-
	OK16729W	0.5	-	-	-	-	-	-	-	-	-0.9	-
	OK168512	-	0.4	-	-	0.0	-0.2	0.5	-	-	0.0	-
	OK16D101089	0.0	-	-	-	-	-	-	-0.5	0.0	-	-

Table 23. Wheat protein content relative to the location mean (expressed as a deviation) for varieties and experimental lines in the 2018-2019 Oklahoma wheat variety performance tests. (cont'd)

		Hooker	*Keyes*	*Kildare*	*Kingfisher*	*Lahoma*	*Lahoma Fungicide*	*Lamont*	*Thomas*	*Union City*	*Walters*
	Location mean	14.5	12.7	12.4	11.2	13.2	12.7	13.6	13.6	12.8	12.0
Licensee	**Variety**	% wheat protein relative to location mean									
AGSECO	AG Gallant	0.3	0.0	-	-	-1.3	-1.1	-	-	-	-
AGSECO	AG Icon	0.9	-0.2	0.7	0.5	0.9	1.1	0.9	0.6	0.1	-
AgriMAXX	AM Eastwood	-0.1	0.2	-0.9	-1.1	1.2	0.5	0.4	0.0	1.0	0.6
OGI	Baker's Ann	0.4	-	0.1	-	0.7	0.9	1.1	-	-	-
OGI	Bentley	-0.7	0.2	-0.4	-0.9	-0.2	0.2	-0.4	-0.4	0.4	0.0
AgriPro	Bob Dole	-	-	-0.5	0.9	-0.3	0.1	-0.6	-	-	-
PlainsGold	Canvas	-	-	-	-	0.0	-0.2	-	-	-	-
CROPLAN	CP7826	2.7	1.3	0.6	1.3	0.3	0.3	0.1	1.4	-0.1	-0.2
CROPLAN	CP7869	-	-	-	-	0.4	0.0	-	-	-	-
CROPLAN	CP7909	-	-	-	-	-1.0	-1.4	-	-	-	-
PlainsGold	Crescent AX	-	-	-	-	-1.4	-0.9	-	-	-	-
OGI	Doublestop CL Plus	1.0	1.8	1.0	1.5	0.5	1.2	0.3	1.0	-0.2	1.5
OGI	Duster	0.3	-0.6	-	0.4	0.3	0.1	1.3	0.3	-0.1	-0.1
OGI	Gallagher	1.3	0.2	-0.3	0.0	-0.7	-0.4	0.5	0.1	0.0	-0.7
OGI	Green Hammer	-	-	1.0	2.0	0.7	1.7	1.0	0.4	0.3	1.3
OGI	Iba	-0.8	-0.8	-0.7	0.0	-0.4	-0.8	-0.3	-0.3	-0.1	-0.7
KWA	Joe	-1.1	-0.4	-0.5	0.0	-0.4	-0.4	-1.0	-	-	-
KWA	KS Venada	-	-	-	-	-0.3	0.3	-	-	-	-
KSU	KS080093K-18	-	-	-	-	0.2	0.2	-	-	-	-
PlainsGold	Langin	-1.2	-1.3	-	-	-0.8	-0.6	-	-	-	-
KWA	Larry	-0.7	0.1	-	-0.9	0.1	-0.5	-0.7	-0.4	-	-
LCS	LCH15ACC7-7	-	-	-	-	-0.4	-0.5	-	-	-	-
LCS	LCS Chrome	0.3	0.7	0.4	1.2	0.5	0.9	0.3	0.5	-0.4	0.0
LCS	LCS Pistol	-	-	-	-	0.7	0.1	-	-	-	-
OGI	Lonerider	0.0	0.6	-	-	1.4	0.0	-	-	-	-
Dyna-Gro	Long Branch	-1.0	-0.8	-	0.2	0.8	0.4	-	-0.2	0.9	-
OGI	NF 101	-	-	-	-	-0.6	0.2	-	-	0.0	-0.2
OGI	Ruby Lee	0.6	1.0	-0.2	-0.2	-0.8	0.7	-0.6	-0.7	-1.0	1.1
OGI	Showdown	-0.6	-0.5	-0.2	-0.8	-0.3	-0.7	-0.1	-0.7	0.2	-1.0
OGI	Skydance	-	-	-	-	0.4	0.9	-	-	-	1.5
OGI	Smith's Gold	-0.5	-0.2	0.3	-0.3	0.2	-0.1	0.7	-0.5	0.1	-0.6
OGI	Spirit Rider	-	-	0.5	-	0.7	0.8	0.5	-	-	-
OGI	Stardust	-	-	0.5	-	1.1	0.6	0.8	-	-	-
AgriPro	SY Achieve CL2	-	-	0.2	-0.5	0.7	0.5	0.4	-	-	-
AgriPro	SY Benefit	-	-	-	-1.0	-0.7	-1.0	-1.5	-	-	-0.7
AgriPro	SY Flint	-	-	-	0.1	-0.8	-0.6	-0.7	-1.2	-0.2	0.0
AgriPro	SY Grit	0.5	0.3	-0.6	-1.1	0.2	0.3	0.0	-0.5	0.3	0.3
AgriPro	SY Monument	-0.1	-0.3	-	-0.2	-0.2	-0.1	-0.4	0.1	-	-
AgriPro	SY Razor	-	-	-	-	-	-	-	-	-0.9	-
AgriPro	SY Rugged	-0.6	-0.6	-0.4	0.2	0.3	0.4	0.2	0.5	-0.1	-0.8
Watley	TAM 112	-0.2	-0.1	-	-	0.8	-0.1	-	-	-	-
AGSECO	TAM 114	0.0	0.4	-	-	-0.1	-0.2	-	-	-	-
Watley	TAM 204	0.2	-0.1	-	-0.1	1.8	0.0	-	1.1	0.6	-
WestBred	WB4269	-0.7	-0.2	-0.3	-0.4	-0.4	-0.7	-0.2	-0.7	-0.7	-0.3
WestBred	WB4303	1.5	0.9	0.2	-0.6	0.2	1.2	-0.3	-0.3	0.2	-
WestBred	WB4418	-	-	-	-	1.1	0.4	-	-	-	-
WestBred	WB4515	-	-	-0.4	0.7	0.6	0.6	0.5	-0.7	0.7	-
WestBred	WB4595	-	-	-	-	-0.4	-0.6	-	-	-	-
WestBred	WB4699	-	-	-	-	-1.0	-1.2	-	-	-	-
WestBred	WB4792	-	-	-	-	-1.1	-0.8	-	-	-	-
WestBred	WB-Grainfield	-0.7	-0.7	-	-1.3	0.0	-0.4	-0.5	-	-	-
KWA	Zenda	-	-	-0.8	-	-1.0	-0.2	-1.1	-	-	-
OSU Experimentals											
	OCW04S717T-6W	-	-	-	-0.6	0.3	1.3	-	-	-0.5	-
	OK149132C	-	-	-	1.3	0.1	-0.2	-	-0.8	0.4	-
	OK14P212	0.0	0.1	-	-	-	-	-	0.6	0.7	-1.0
	OK14P736W	-0.7	-0.3	-	-	-	-	-	-	-	-0.2
	OK15MASBx7 8-1	-	-	-	-	-0.1	-0.5	-	-	-	-
	OK16729W	-	-	-	-	-0.9	-0.6	-	-	-	-
	OK168512	-0.9	-0.5	-	-	-	-	-	-	-	-
	OK16D101089	-	-	-0.1	-0.1	-0.8	0.1	-	-0.1	-0.4	0.0

AG RESEARCH