Partners in Progress
WHEAT

Wheat Research at OSU 2013

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

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Partners in Progress WHEAT

Partnerships Enhance Wheat Research

Partners in Progress – Our long-standing partnership with the Oklahoma Wheat Commission (OWC) and the Oklahoma Wheat Research Foundation (OWRF) is a valuable asset for Oklahoma State University's wheat research and Extension programs. The partnership not only provides partial funding for our research programs, but also provides valuable input from producers that helps keep our research programs focused and relevant. It is 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. Partial funding for our research and Extension programs comes from wheat producers through the check-off program. We have been and continue to be accountable for the use of these funds.

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

At the beginning of the first section is a summary of accomplishments for fiscal year 2012-2013. The narrative that follows explains in more detail the progress made during the year.

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

Jonathan Edelson
Associate Director
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 the Oklahoma State University 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.

Variety Development Deeply Rooted at OSU

Variety development for wheat production is embroiled in a whirlwind of change. A whirlwind that is bending the branches of the wheat breeding program at Oklahoma State University, but the limbs will not break, nor will the tree fall, because rooted with the tree are the countless hours of hard work and dedication put forth from our OSU Wheat Improvement Team (WIT). The continued producer support through the OWC and OWRF also remain key for our public breeding program to persevere.

During this past year, we have continued to face challenging times with the significant drought, mild winter and late freeze situations all over the state. If you look at the data comprised in this report, you will see the analysis of wheat varieties that did well in the drought season of 2011-2012, and varieties that performed different in the 2012-2013 season because of the late freezes. However, one thing is for certain, yield potential was much more favorable than expected in the beginning of this crop season, not only in the variety trial data but also with production estimates statewide.

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

With the breeding program at OSU, we examine and study the end-use quality characteristics that are beneficial to our domestic and foreign customers. By finding those important traits that are beneficial to our buyers, we are working to capture more market share for the farmer using varieties created with our breeding program.

Quality starts with the seed placed into the soil. To have a product good for the end game, we must remember that good quality also has to start from the beginning. We encourage soil testing that is available through your local county Extension office. We also encourage producers to look at the importance of nitrogen applications for increased protein levels. Exporters and domestic grain companies are looking for higher protein wheat that has better attributes for baking. By focusing on some of these factors in an operation, it can help ensure good decisions are being made to deliver high quality wheat.

The OWC and OWRF, along with OSU's WIT and DASNR, continues to work on items beneficial to both the producer and buyer. We continue to make great strides with the breeding program at OSU, and we want to thank the producer support that continues to keep our public breeding program in operation. The OSU WIT prepares for planting by spending numerous hours on research and planning for a harvest that will give them the tools to help make our wheat producers more competitive, and therefore, we are glad to be *Partners in Progress*.

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Partners in Progress WHEAT

Genetic Improvement and Varietal Release of Hard Winter Wheat

Wheat Improvement Team

2012-2013 progress made possible through OWRF/OWC support

- Variety trial data published to www.wheat.okstate.edu within a few days of harvest of each location and generated more than 9,000 page views during harvest.
- Delivered wheat yield and phenology data to more than 8,000 Oklahomans through the 2013 Wheat Seed Book distributed by the *High Plains Journal* to all Oklahoma subscribers. The OWC was recognized as a funding agency on the cover of this publication.
- Provided 16 in-season wheat disease updates to wheat growers, consultants, extension educators and researchers via an electronic format.
- Increased the WIT's capacity to ascertain or develop novel resistance to a rising foliar disease called spot blotch, which is caused by the same fungus, *Bipolaris sorokiniana,* that produces common root rot.
- Validated a multiplex reverse transcriptase-PCR (rt-PCR) procedure to detect and differentiate among 1) wheat streak mosaic virus (WSMV), high plains virus (HPV) and Triticum mosaic virus (TriMV); and 2) multiple strains of barley yellow dwarf virus (BYDV), when both sets of viruses are present in the same sample.
- Evaluated more than 2,000 wheat experimental lines for reaction to multiple diseases, of which 60 percent were developed by the WIT.
- About 1,200 WIT experimental lines were evaluated for reaction to the wheat soilborne mosaic virus/wheat spindle streak mosaic virus (WSBMV/WSSMV) complex, and for a subset of 605 lines, the enzyme-linked immunosorbent assay (ELISA) was used to test for virus presence to better define the reaction of lines to both viruses.
- Determined additional reactions of 347 WIT experimental lines to leaf rust, 277 lines to tan spot and septoria, 347 lines to powdery mildew and 150 lines to BYDV.
- Tested for presence of Karnal bunt in 42 wheat grain samples from 13 counties, and based on the negative results, obtained a phytosanitary certificate allowing Oklahoma wheat to move without restriction into the export market.
- Determined genotypes of more than 150 WIT experimental lines and cultivars using three gene markers for a triplicate set of loci governing reproductive development and six gene markers for resistance to leaf rust, stripe rust and powdery mildew.
- Discovered that vernalization requirement duration in winter wheat was controlled by *Ta*VRN-A1 at the protein level; *Ta*HOX1, the first homeobox protein found in *T. aestivum*, also was found to be involved in the regulation of vernalization requirement duration in winter wheat through its interaction with *Ta*VRN-A1.
- Discovered that a major quantitative trait locus (QTL), *QHf.osu-1A*, for Hessian fly resistance was tightly linked with a gene encoding 12-oxo-phytodienoic acid reductase (*OPR*), an enzyme central to insect resistance pathways in higher plants.
- Developed a molecular marker for the Jagger *TaMFT-A1* allele found to be associated with nontemperature sensitive germination of after-ripened seeds, opening the door for more effective selection of genotypes better adapted to early planted management systems.

- **Wheat accessions that displayed the greatest phosphorus (P) uptake efficiency in low-P acid soils were shown to influence rhizosphere pH via excretion of oxalic and citric acids, and thereby extract P that would otherwise be tied up by iron and aluminum.**
- **Documented sub-economic infestations of Hessian flies in wheat fields throughout the major wheat growing regions of Oklahoma, with minimal impact on yields of WIT elite lines and cultivars.**
- **Used pheromone trap data to show that Hessian fly populations continue to persist in Oklahoma and should be accounted for when developing long-term insect management strategies.**
- **Determined elastic and viscous behaviors of gluten fractions isolated from WIT experimental lines and cultivars to obtain a more direct assessment of dough strength versus extensibility; Billings and Ruby Lee maintained their high standard for both indicators and for overall dough functionality.**
- **Released and licensed the 2-gene CLEARFIELD cultivar Doublestop CL+, signifying a new era in developing cultivars with enhanced competitiveness against feral rye, ryegrass and other problem weeds.**
- **Placed seven additional winter wheat candidates under preliminary seed increase or large-scale seed increase by Oklahoma Foundation Seed Stocks:**

OK09125	**TAM 303/Overley**
OK09520	**TAM 303/2*OK96717-99-6756**
OK10126	**OK Bullet/OK98680 reseln**
OK10728W	**OK Rising/OK98G508W-2-49**
OK10805W	**WD97-6740/KS98HW151-6//OK98G502W**
OK11754WF	**CIMMYT seln/Overley//Jagger-derivative**
OK109143CF	**Mason sib/OK03926C**

- **Leveraged financial support of OWRF/OWC with funding from either USDA-ARS or Oklahoma Genetics, Inc., to develop experimental materials with resistance to the Ug99 stem rust race, and to develop novel doubled haploid lines featuring stacked traits for insect and disease resistance.**
- **OSU-bred cultivars Duster and Endurance remained the top two planted wheat cultivars in Oklahoma for a third consecutive year.**

Nine faculty across three DASNR academic units form the dynamic WIT, which combines fundamental and applied components of wheat research to propel a common cause—to advance Oklahoma's wheat industry with new, improved cultivars and to provide the know-how that best captures their genetic potential. Now in its 15th year of uninterrupted service, pride is taken in elevating OSU's mission of "create, innovate and educate" to new heights.

Scientists serving on the WIT in 2012-2013 were **Jeff Edwards**, information exchange; **Bob Hunger** and **Art Klatt,** wheat pathology research and development of disease-resistant germplasm; **Liuling Yan,** gene discovery and genomic applications; **Chad Penn,** Phosphorus-use effinciency; **Kris Giles** and **Tom Royer,** Hessian fly monitoring and resistance; **Patricia Rayas-Duarte,** cereal chemistry; and **Brett Carver,** wheat breeding and cultivar development.

The 2012-2013 crop season was one of the best environments in many years for discerning straw strength potential deep into the OSU wheat improvement program. The past crop season also provided a unique opportunity to thoroughly ascertain field reactions to powdery mildew and multiple leaf spotting diseases. While the number of plant diseases, which is targeted in cultivar development, has not changed appreciably (14 in all), what has markedly changed is the degree of selection pressure applied to any certain disease, given the environmental and disease conditions naturally occurring in field nurseries. Hence, heavy emphasis continues to be placed on those diseases mentioned above, as well as BYDV and stripe rust, though the latter was not present in 2013.

Each year starts with more cultivar candidates than can ever be commercialized. The multiple late-winter freeze events that occurred in March to May 2013, took its toll on some earlier-maturing candidates that shined in previous years. The most notable loss was OK09634 (OK95616-98-6756/Overley). Its average yield rank in breeding nurseries was 3 out of 30 from 2009 to 2012, but fell to the 13 spot in 2013. Moreover, OK09634 performed poorly in the 2013 Oklahoma Small Grains Variety Performance Tests (OSGVPT).

In this report, you can read all about the work of the WIT, including instantaneous, reliable feedback on candidate line performance in one of the very few wheat variety testing programs in the USA that routinely integrates fungicide application with yield estimation, and the pursuit of multiple hard white (HW) cultivars, which rival the best of the hard red winter (HRW) cultivars.

Information exchange

Jeff Edwards
Dept. of Plant and Soil Sciences

The information exchange component of the WIT focused on timely information delivery and screening of advanced experimental lines in 2013. Wheat variety trial results were posted on the small grains Extension website (www.wheat.okstate.edu) within a few days of harvest, which allowed producers to access data quickly, regardless of their location. Farmers were notified of new data postings via email and Twitter feed, and the site was accessed 3,297 times during May through August 2013, with 9,191 individual page views. The print version of the OSGVPT was published in early July and distributed to more than 8,000 *High Plains Journal* subscribers in Oklahoma.

The WIT has significantly increased our web-based and social media efforts over the past few years. The blog www.osuwheat.com, for example, was created in the fall of 2012 to deliver technical information and updates in a concise, timely manner. In a little more than a year, the site has generated 19,000 page views with 3,000 of these views coming from overseas clientele. Other efforts include an Extension site, e-newsletter site, YouTube® channel, Facebook® page and several WIT member Twitter® accounts. In total, these sites received approximately 55,000 page views in 2012 alone.

In addition to elite nurseries at Kingfisher and Cherokee (Figure 1), several advanced experimental lines were tested as part of the OSGVPT program in 2013. The extreme drought was an excellent proving ground to

Figure 1. The OSGVPT at Kingfisher, shown here in May 2013, is tested alongside the Oklahoma Elite Trial for final testing of experimental lines.

separate the wheat from the chaff, and data obtained from these sites was valuable in determining which lines were worthy of further pursuit. The experimental line OK09915C was tested at several sites across Oklahoma, as well as three CLEARFIELD qualification trials where it was compared to advanced lines from other states. OK09915C proved superior in our environment and was released as DoubleStop CL+.

Wheat pathology research and development of disease resistant germplasm

Bob Hunger
Dept. of Entomology and Plant Pathology

Evaluation of WIT experimental lines for reaction to diseases including the WSBMV/WSSMV complex, leaf rust, powdery mildew, tan spot and septoria is critical to developing improved wheat cultivars. Table 1 summarizes the number of lines that have been tested for reaction to these diseases over the last five years. These evaluations, which are conducted in both field and greenhouse/growth chamber settings, directly aid the selection of lines to populate breeder

Table 1. Number of WIT experimental lines tested for disease reaction in the last five years, either in the field or in greenhouse (GH) or growth chamber (GC) assays.

		Disease[a]					
Year	*Assay*	*SB/SS*	*LR*	*PM*	*TS*	*SEP*	*BYD*
2009	Field	1,500					
	GH/GC		400	400	400		
2010	Field	1,500					
	GH/GC		400	400	400	400	
2011	Field	1,400					
	GH/GC		324	67	262	262	
2012	Field	1,030		65			573
	GH/GC		427	618	170	105	
2013	Field	2,410		197	95	95	150
	GH/GC		347	150	277	277	
Total	Field & GH/GC	7,840	1,898	1,635	2,648	1,139	723

[a] SB/SS=complex of wheat soilborne mosaic and wheat spindle streak mosiac; LR=leaf rust; PM=powdery mildew; TS=tan spot; SEP=septoria; BYD=barley yellow dwarf.

trials in the variety development track. In other words, disease testing is not for the purpose of characterizing lines that are advanced in yield trials, but rather for determining which lines to yield test. OWRF funds support this testing and have allowed expansion of testing to include stripe rust, tan spot, septoria and most recently common root rot and spot blotch.

Disease testing was expanded in 2009 to introduce tan spot and septoria assays, two foliar diseases of significance in no-till situations where large amounts of wheat residue remain on the soil surface. About three years ago, testing was expanded to include stripe rust (Figure 2). Testing large numbers of experimental lines for stripe rust reaction is not anticipated because this testing currently is being done collaboratively with the USDA-ARS at Manhattan, Kan. However, having the ability to test for reaction to stripe rust has allowed facilitation of the genetic marker research conducted by Luiling Yan that targets stripe rust resistance genes. Even more recently, OWRF funding has allowed expansion of testing capabilities to common root rot and spot blotch (Figure 3), which are root and foliar diseases caused by the fungus *Bipolaris sorokiniana*. During the past year, Nathalia Graf Grachet, a graduate student in plant pathology, initiated testing protocols to determine reactions to spot blotch and common root rot. Although not yet ready for full implementation, Grachet has been able to reproduce both the foliar and seed/seedling blight stages of spot blotch and common root rot in growth chamber testing (Figure 4 and Table 2).

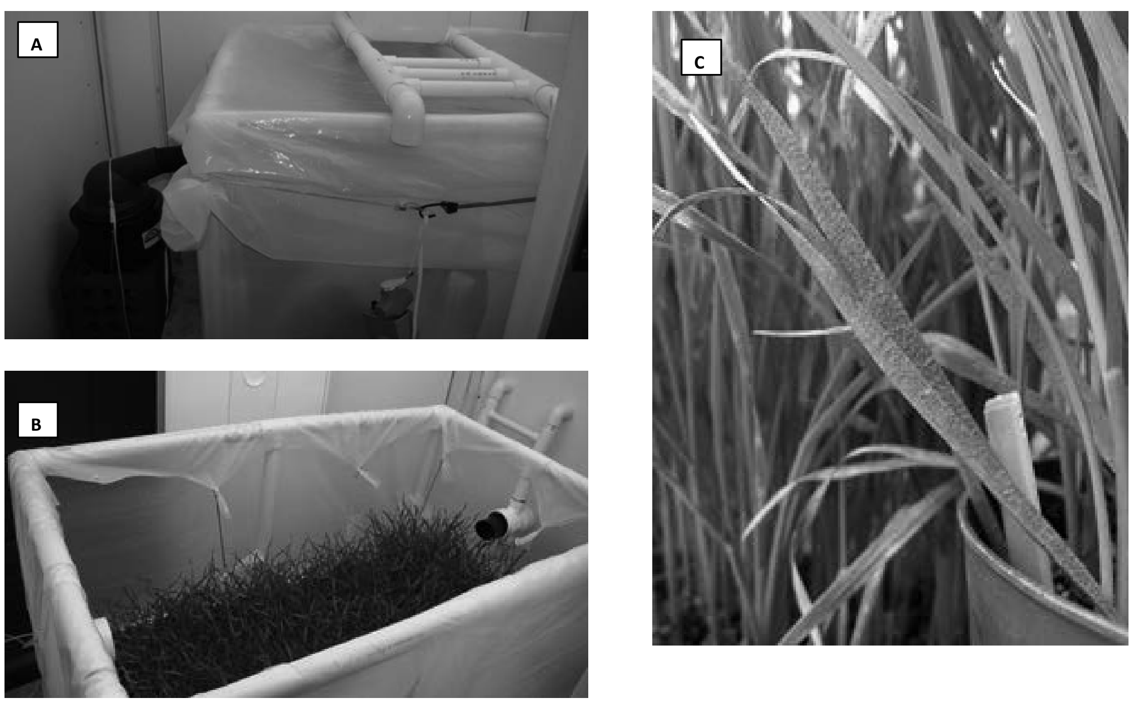

Figure 2. Growth chamber assay for stripe rust reaction, including (A) view of inoculation (humidity) chamber inside of growth chamber, (B) view of wheat seedlings inside of inoculation (humidity) chamber, and (C) symptoms observed on susceptible wheat seedlings 2 to 3 weeks after inoculating with spores of the stripe rust fungus.

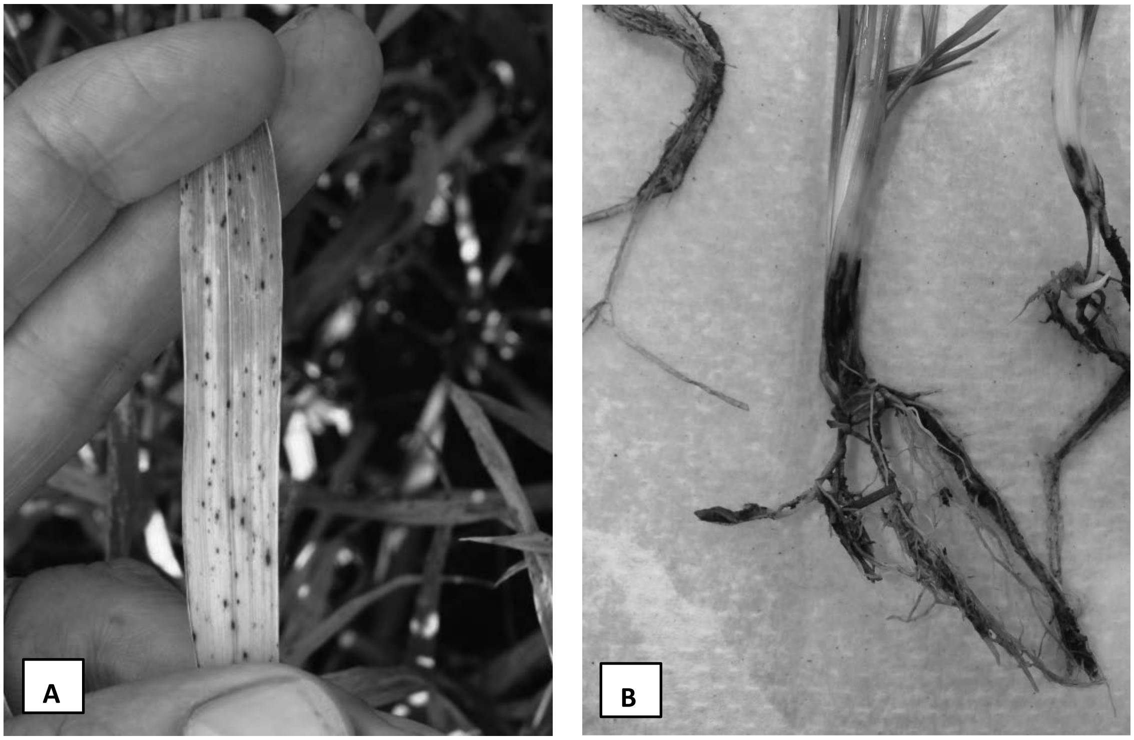

Figure 3. Symptoms of (A) common root rot and (B) spot blotch on field-grown wheat plants caused by the fungus *Bipolaris sorokiniana*.

Figure 4. Examples of results from inoculating (A) leaves of Ruby Lee & Gallagher and (B) seeds of Duster with the fungus *Bipolaris sorokiniana* that causes spot blotch (foliage) and common root rot (seeds/seedlings).

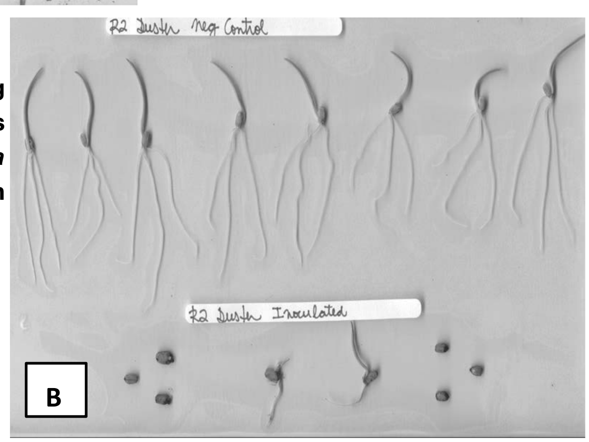

Table 2. Preliminary results of the reaction of hard red winter wheat cultivars to spot blotch and common root rot.

Cultivar	*Leaf spot blotch severity (%)*	*Common root rot severity (% inhibition of root length)*
Iba	5	44
Duster	20	13
Endurance	20	34
Deliver	23	
Garrison	15	
Ruby Lee	30	
Garrison	15	
Ruby Lee	16	
Gallagher	26	
DoubleStop CL +	29	
Endurance	39	
Deliver	39	
Jagger	40	
Everest	42	
Iba	46	
Duster	49	
Billings	51	
Cedar	60	

OWRF funding also was used this past year by Jennifer Olson in the Plant Disease & Insect Diagnostic Lab to enhance the ability to detect WSMV, HPV and TriMV. Symptoms of the diseases caused by these three viruses are difficult to visually differentiate, but such differentiation is critical when rating cultivars and lines in the field for reaction to these diseases. Hence, Olson used frozen wheat samples previously tested by ELISA to validate a highly sensitive, molecular (RNA-based) test recently developed by Francisco Ochoa-Corona (OSU researcher). This technique allows for simultaneous detection of WSMV, HPV and TriMV. A result from Olson's validation testing is presented in Figure 5. The test results are visualized by running each sample

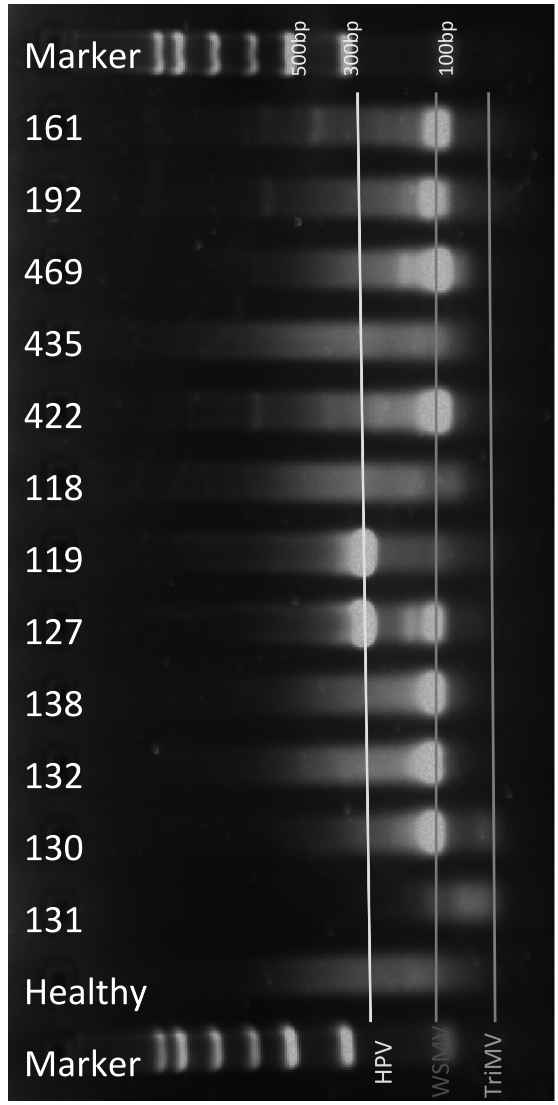

Figure 5. Detection of WSMV, HPV and TriMV using the multiplex rt-PCR method. Samples that test positive produce a fragment of a certain size that is visualized on an agarose gel and compared to a size marker. Two samples (119 and 127) have fragments that indicate they are positive for HPV as shown by the first line to the left. Numerous samples (161, 192, 469, 422, 127, 138, 132, 130) are positive for WSMV as indicated by the middle line. Two samples (130, 131) are positive for TriMV as indicated by the last line.

on an agarose gel and staining the fragments of nucleic acid. This method will be used in spring 2014 as needed to test for wheat viruses in support of the wheat improvement program.

Olson also is working to validate a test similar to the one just described for detecting and differentiating the BYDV/cereal yellow dwarf virus (CYDV) complex. There are at least five BYDV/CYDV viruses reported to cause disease on wheat, several of which are present in Oklahoma. Commercial test kits are available for only three of these viruses. A published method that is molecular based, highly sensitive and allows for simultaneous detection for all viruses in this complex is being verified. Additionally, this test easily pairs with the WSMV, HPV, TriMV multiplex test so there is minimal extra cost. These molecular tests will be used to confirm wheat samples are infected with BYDVs/CYDVs, and thereby facilitate selection of experimental lines for advancement.

Finally, funds provided by the OWC supported the testing of the 2013 Oklahoma wheat crop for the presence of Karnal bunt. Results from this testing were used to certify Oklahoma wheat was produced in areas not known to be infested with Karnal bunt, which allowed Oklahoma wheat to move freely into the export market.

Art Klatt
Dept. of Plant and Soil Sciences

Germplasm development efforts were aimed to identify advanced materials for introgression by the WIT. Major emphasis was given to adapted experimental lines with race nonspecific (RNS) resistance (adult plant resistance) to leaf and stripe rusts and to synthetic derivatives with biotic and abiotic stress resistance. Several major accomplishments were achieved during the 2012-2013 crop cycle. More than 400 cultivars and advanced lines were tested for leaf and stripe rust resistance based on RNS genes as determined by the following criteria: low field ratings for two or more years for leaf rust and one year for stripe rust, seedling susceptibility to leaf rust (to help ensure that adult plant resistance was RNS), and marker analysis indicating presence of Lr34, Lr46 and/or Lr68. Some advanced lines had good yield potential and most had resistance to WSBM and to powdery mildew. In all, 125 lines were identified with probable RNS resistance, and 45 advanced lines tested positive for all three markers.

An additional set of 260 hybridizations was made beyond those quantified later by WIT member Brett Carver, involving advanced lines from previous cycles of selection for RNS resistance or from synthetic derivatives. The overall objective was to generate a broader spectrum of regionally adapted, high-yielding materials.

Spring and winter wheat germplasm was introduced from the CIMMYT programs in Mexico and Turkey, and was tested for adaptation and disease resistance.

Gene discovery and genomic applications

Liuling Yan
Dept. of Plant and Soil Sciences

Almost all wheat cultivars grown in Oklahoma and surrounding states are a winter type that require a period of low temperature (vernalization) to initiate flowering for successful grain production. Based on the low-temperature duration required to reach a vernalization saturation point, i.e., to achieve the maximum vernalization effect, winter wheat cultivars can be classified into one of three groups. The weak winter type, such as Fannin, requires less than two weeks for full vernalization. A semi-winter type, such as Jagger, requires two to four weeks of cold exposure for full vernalization, and a strong winter type, such as 2174, requires four to six weeks of cold exposure for full vernalization.

We used a series of Jagger x 2174 progenies, also called recombinant inbred lines (RILs), to map a major quantitative trait locus (QTL) for vernalization requirement duration on the long arm of chromosome 5A. This genomic region encompasses the *vrn-A1* locus, and the corresponding QTL was designated *QVrd.osu-5A*. We have cloned this QTL, one that is crucial in discriminating among winter wheat cultivars, using the map-based cloning approach.

At a more fundamental level, we found that vernalization requirement duration is controlled by *Ta*VRN-A1 at the protein level. The amino acid alanine at position 180 in the amino acid sequence encoded by the dominant allele for three-week vernalization in Jagger was mutated to valine at the same position encoded by the recessive allele for six-week vernalization in 2174. More importantly, it was found this amino acid substitution at *Ta*VRN-A1, caused by a point mutation, determines the kind of interaction that occurs with another protein called *Ta*HOX1. The interaction between these two proteins has been confirmed by *in vitro* (Figure 6A) and *in vivo* assays (Figure 6B). *Ta*HOX1 is one of the homeobox (HOX) proteins that also control development and body segmentation in animals, whereas *Ta*VRN-A1 is one of the MADS-box proteins controlling flower initiation in plants.

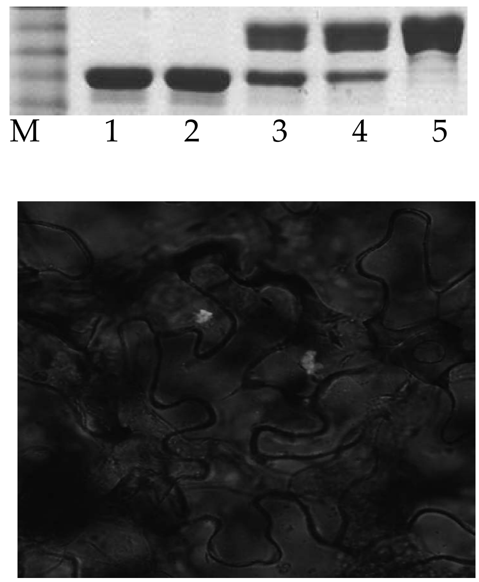

Figure 6. Physical binding of proteins *Ta*VRN-A1 and *Ta*HOX1.
(A) *In vitro* interaction between *Ta*VRN-A1 and *Ta*HOX1 proteins in pulldown assays. Lane 1: Purified Jagger vrn-A1a-HIS-tag; lane 2: Purified 2174 vrn-A1b-HIS-tag; lane 3: Interaction of *Ta*VRN-A1a-HIS-tag and *Ta*HOX1-MBP-tag; lane 4: Interaction of *Ta*VRN-A1b-HIS-tag and *Ta*HOX1-MBP-tag; lane 5: Purified *Ta*HOX1-MBP-tag. M: protein marker. Arrowheads represent the expressed or interacting proteins.
(B) *In vivo* interaction of *Ta*VRN-A1 and *Ta*HOX1 proteins in BiFC analysis. The green fluorescent proteins result from the in vivo interaction between *Ta*VRN-A1-YN and *TaHOX1-YC.* YN, YFP fragment at the N-terminal end expressed from pEG201-YN vector; YC, YFP fragment at the C-terminal end expressed from pEG202-YC vector.

The first example of a direct binding between MADS and HOX proteins involving homeosis in higher plants has been discovered. Key to this discovery, and what adds relevance to OSU wheat improvement, is that *Ta*VRN-A1 and *Ta*HOX1 proteins function in the same pathway controlling vernalization requirement duration in winter wheat cultivars. The regulatory role of *Ta*VRN-A1 in winter wheat development also was observed in previous field experiments. These combined studies demonstrate that *Ta*VRN-A1 cloned in greenhouse experiments can be directly utilized in field research. Molecular markers developed for both *Ta*VRN-A1 and *Ta*HOX1 will be particularly useful in establishing genetic models to discriminate among strong winter, semi-winter and weak winter cultivars, each with different sensitivities to photoperiod. Genetic models also will be useful in selection of adaptation to global shifts in temperature.

Hessian fly is one of the most destructive pests of wheat in the USA and worldwide. More than 32 Hessian fly resistance genes *(H1-H32)* have been identified, but many of them were identified in diploid and tetraploid wild species and none have been cloned, restricting their direct utility as resistance gene sources for hexaploid wheat. Plants display many defense mechanisms in response to mechanical tissue damage by insects. Jasmonic acid (JA) and its conjugates, jasmonates, play a central role in regulating defense responses of plants to insect herbivores. However, little was known about how wheat plants use defense systems to recognize Hessian fly or other feeding insects. A major QTL *QHf.osu-1A* for Hessian fly resistance in the Jagger x 2174 mapping population has been discovered. *QHf.osu-1A* is allelic to several resistance genes including *H9, H10, H11, H16* and *H17* previously reported in tetraploid wheat. The gene responsible for *QHf.osu-1A* found in the study can be accessed by the WIT to develop Hessian fly-resistant cultivars adapted to Oklahoma.

Interestingly, it was found *QHf.osu-1A* was tightly linked with a gene encoding 12-oxo-phytodienoic acid reductase (OPR) that is central to insect resistance pathways in higher plants. It is thus intuitive to hypothesize that the OPR gene is a candidate gene for this QTL. These novel results in bread wheat are exciting and have initiated positional cloning of *QHf.osu-1A*. Realizing that it takes several years to clone a QTL in wheat using the map-based cloning approach, it was decided not to wait until this QTL was cloned, but to release the discovery to the research community to accelerate utilization of this genetic resource in wheat breeding programs.

Seed germination is an important trait in winter wheat that accounts for approximately 75 percent of the wheat worldwide. The initial goal of this study was to identify genetic loci associated with temperature-sensitive seed germination in winter wheat. After a major QTL for temperature-sensitive germination was mapped, the focus was on allelic variation in *Ta*MFT-A1 for winter wheat. *Ta*MFT-A1, *MOTHER OF FT (Flowering locus T)* and *TFT1 (Terminal Flower 1)* genes were previously reported to be associated with seed dormancy and pre-harvest sprouting in spring wheat. Allelic variation in *Ta*MFT-A1 was found and associated with germination of after-ripened seeds in the Jagger x 2174 progenies, when tested at low, optimum and high temperatures. The sequence of the complete *Ta*MFT-A1 gene revealed 87 single-nucleotide polymorphisms (SNPs), and 12 insertions/deletions (indels) with sequences from 1 to 20 base pairs, between the Jagger and 2174 alleles. The Jagger *Ta*MFT-A1 allele is a novel haplotype associated with nontemperature sensitivity, and it occurs widely among cultivars collected from different geographical areas. This study not only validated the function of *Ta*MFT-A1 in winter wheat, but also led to the development of a new PCR-based marker with greater efficiency and lower cost to track the presence, or absence, of the Jagger *Ta*MFT-A1 haplotype in wheat.

In the 2012 PIP report, research with a key disease resistance gene, *Lr34*, was extensively reported. Research continues in this area for the ultimate purpose of improving disease resistance in Oklahoma wheat cultivars. The strategy still includes capitalizing on the novel *Lr34* haplotype present in Duster and a transformation system applicable to locally adapted cultivars.

Phosphorus-use efficiency

Chad Penn
Dept. of Plant and Soil Sciences

Highly accessible geologic P sources are projected to dramatically decrease over the next 20 to 50 years. This potential shortage implores the need for increased P-use efficiency (PUE) among major staple crops, including wheat. Our previous research examined the PUE of several winter wheat accessions and specifically quantified and distinguished between P-uptake efficiency (the ability of a plant to take up P from a low-P soil) and PUE (the ability of a plant to produce biomass with low concentrations of P within its tissue). The latest funding period focused on and compared the three P-uptake-efficient accessions (MO4*5109, OK91G107 and P03207A-1) with the three P-uptake-inefficient cultivars (SD0616165, Iba and Duster).

The accessions were grown in custom-designed rhizo-cells (Figure 7) for the purpose of examining root excretions that may contribute to increased PUE. A mesh screen was used to prevent wheat roots from entering the low-P acid soil below (5 mm deep), yet allow those roots to have contact and interact with the soil. Above the screen, acid-washed lab-grade sand was used to physically support the plant.

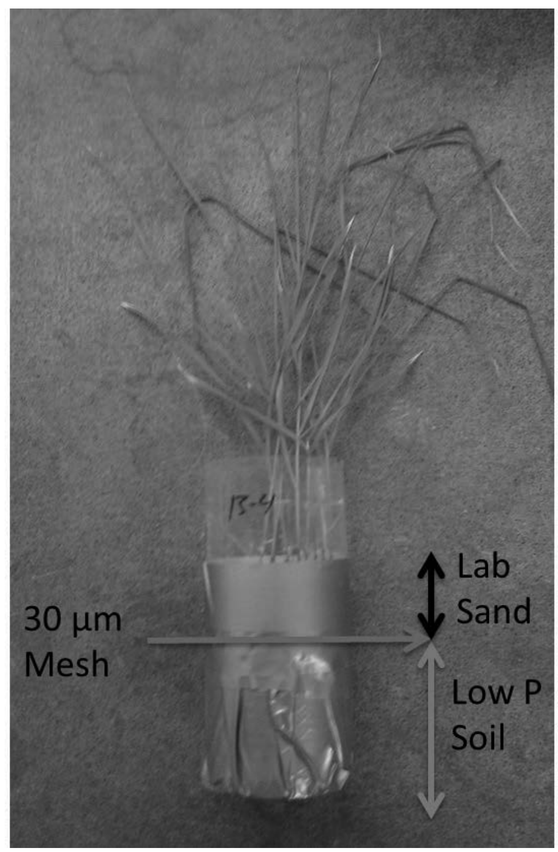

Figure 7. Rhizo-cell used to detect and measure minute quantities of root excretions, which may contribute to increased PUE.

Sufficient N and K were supplied to the plants. After 28 days, plant roots and shoots were harvested, weighed and analyzed for total P uptake. The soil was sliced into two depths (0 to 3.75 mm and 3.75 to 5 mm) and analyzed for P forms, pH and root exudates, such as organic acids and phytase enzyme. Although the soil used was very acidic (pH 4.8), the level of exchangeable Al was very low. This allowed the examination of the impact of P-uptake efficiency mechanisms without the confounding effects of Al toxicity. Chemical properties of the soil used in the study are shown in Table 3.

The plant roots tended to influence the soil up to a distance of 2 mm from the surface of the root. Considering P only moves very small distances in the soil via diffusion, this underscores why root architecture and a large root surface area are important to P uptake. Accession MO4*5109 produced the greatest biomass under the low-P conditions, although a significant difference could not be detected from the other accessions (Table 4). MO4*5109 and OK91G107 also showed the greatest levels of P uptake. As expected, P uptake was well associated with biomass.

Oxalic acid and citric acid were found to be statistically related to increased P-uptake efficiency. While excretion of these organic acids has been observed in other plant species, it is highly variable between accessions within species. This mechanism is especially important since acid soils are often dominated with Al- and Fe-bound P that is typically not plant available. In

Table 3. Chemical characteristics for Lucien sandy loam (acid) series soil.

pH	*NO_3-N*	*Extractable P*	*Total P*	*Exch. Al*	*K*	*SO_4-S*	*Ca*	*Mg*	*Fe*	*Zn*	*B*	*Cu*
		mg kg^{-1}										
4.8	19	6[a]	1,906[b]	0.3	106	19.5	673	214.5	30.3	0.9	0.2	1.0

[a] Mehlich 3 extractable P.

[b] Measured according to method EPA 3050.

Table 4. Plant mean biomass and phosphorus (P) uptake for six wheat accessions.

Accession	*Mean Biomass (mg)*	*P uptake (mg)*
MO4*5109[a]	728	0.62
OK91G107[c] (Al-susceptible isoline of Chisholm)	696	0.64
P03207A-7[a]	501	0.30
SD06165[a]	429	0.34
Iba[c]	414	0.32
Duster[b]	384	0.30

[a] Field tolerant to acidity, but lacks a key Al-resistance gene.

[b] Field tolerant to acidity, and carries a key Al-resistance gene.

[c] Al susceptible.

addition, phytase enzyme excreted by the roots may have aided in increasing P plant availability through the help of the organic acids interacting with soil Al and Fe which would bind strongly to P. Development of accessions that excrete these organic acids will improve P-uptake efficiency in low-P acid soils.

Hessian fly monitoring and resistance

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The research during the 2012-2013 growing season aimed to survey Hessian fly populations in Oklahoma and to evaluate the reaction of elite WIT materials. Our primary service to the WIT is to identify sources of Hessian fly resistance to natural fly populations and utilize those sources in developing new cultivars adapted to Oklahoma. Pheromone sticky traps were used from the previous field season to identify locations where flies were most active to deploy replicated studies for 2012-2013. In addition, traps were deployed throughout the state at wheat research sites to verify fly activity during the growing season.

Flies were captured throughout most of the state, and for the second consecutive year, counts were highest near the two replicated sites, Marland and Blackwell. Adult flies were captured in low numbers during the fall, but significantly higher numbers were found during the spring (Figure 8). As in previous years, counts in pheromone traps were no indication of infestation levels in nearby replicated trials. Flies either avoided the plot area, or more likely, the pheromone traps were effective at trapping out active adults in the area. The subeconomic fly infestations in our replicated trials continue a trend of lowering intensities (number of larvae per tiller) throughout

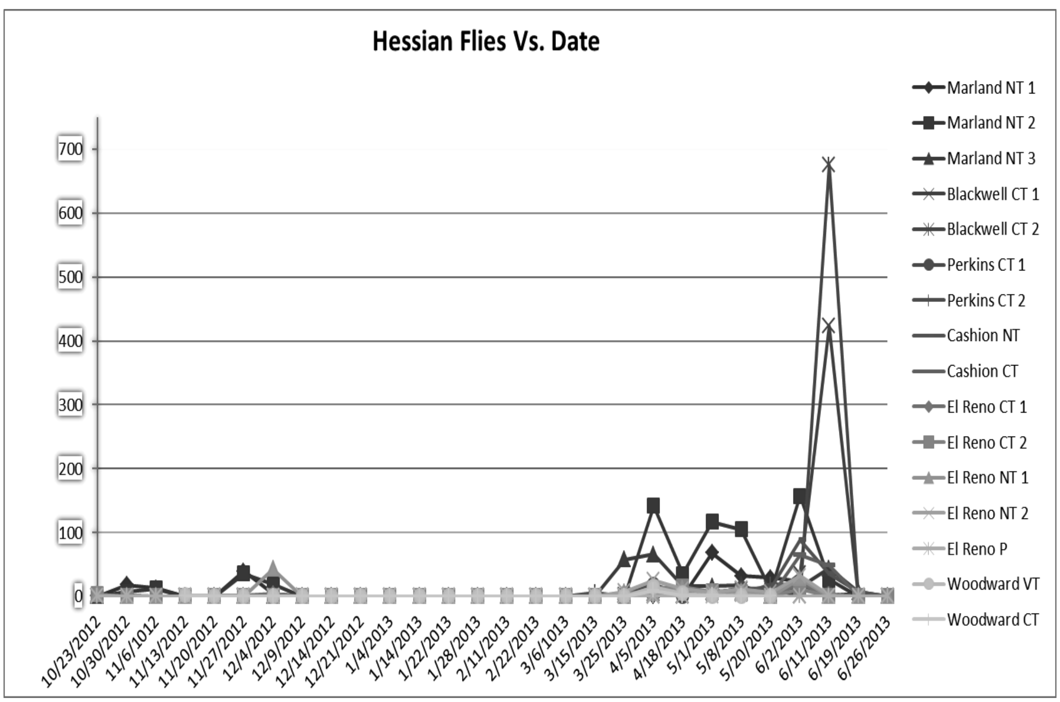

Figure 8. Total number of adult Hessian flies caught in pheromone traps (2 traps/location) in Oklahoma during the 2012-2013 growing season.

the region over the past seven years. Biotyping data from Kansas indicate biotype GP is the most common in Oklahoma. The trap catch data indicate Hessian fly populations still persist in Oklahoma and need to be accounted for when developing long-term insect management strategies.

The reaction of WIT experimental lines entered in the 2013 Oklahoma Elite Trial to natural fly populations was evaluated near Blackwell and Marland. At both locations, plots were well established and relatively high yields resulted (Tables 5 and 6). However, natural fly infestations were low again for this growing season, well below economic injury levels. When fly populations are this low, it is not possible to separate the impact of resistance and fly infestations on grain yield.

Wheat producers in Oklahoma have high yielding options that also come with durable Hessian fly resistance. About 40 percent of the experimental lines entered into the 2014 Oklahoma Elite Trial contain an effective level of Hessian fly resistance. Regional fly populations appear to have been driven down because of strategic deployment of resistant cultivars. We recommend a continued proactive approach to managing Hessian fly through rotation of locally adapted cultivars that periodically provide protection against fly buildup.

Table 5. Grain yield and Hessian fly infestation in the 2013 Oklahoma Elite Trial at Marland.

Entry	*bu/A*	*Larvae/tiller*
OK1080031	72	0.03
OK09729	70	----
OK08328	70	----
OK1059060	70	0.05
OCW00S063S-1B	67	0.11
OK09520	65	0.02
OK08229	64	----
OK05511-RHf2	62	0.03
Gallagher	61	----
OK109143CF	62	0.04
Billings	60	0.09
OK1080029	60	0.04
OK09528	60	----
Doublestop CL+	59	0.01
Endurance	58	0.03
OK0986044	58	0.01
OK09634	58	0.02
Garrison	57	0.04
OK09125	57	0.05
OK09208	57	0.02
OK09935C	56	0.04
Iba	56	0.08
OK10728W	53	0.01
Ruby Lee	53	0.02
Cedar	51	----
OK0986050	52	----
OK1059016	50	0.01
OK09316	49	0.02
Duster	46	0.01
LSD (0.05)	19	0.07

Table 6. Grain yield and Hessian fly infestation in the 2013 Oklahoma Elite Trial at Blackwell.

Entry	*bu/A*	*Larvae/tiller*
OK1059016	60	----
OK09125	55	----
OK08328	52	----
OK1080031	51	0.09
OK09208	50	----
OK08229	49	----
OK09634	48	0.01
OK09528	48	----
OK10728W	48	0.01
OK1059060	44	0.06
Billings	44	0.02
OK09935C	44	----
Cedar	44	----
Iba	43	0.03
Garrison	43	0.03
OK09316	42	0.10
OK109143CF	41	0.13
OCW00S063S-1B	41	0.04
Endurance	40	----
Ruby Lee	39	0.01
OK0986050	38	0.02
OK05511-RHf2	38	0.01
OK0986044	38	----
Duster	37	----
OK09520	37	0.04
Gallagher	36	----
OK1080029	36	0.01
OK09729	32	0.03
Doublestop CL+	36	0.10
LSD (0.05)	17	0.10

Cereal chemistry

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OWRF/OWC funding was used to leverage a multi-institutional collaboration to develop a new method for predicting wheat protein functionality. This method, often called a compression-recovery (CORE) gluten test, has been experimentally applied to WIT experimental materials over several crop seasons. The method consists of compressing the gluten extracted from wheat flour, followed by a period of recovery. In the compression step, extensibility of the gluten can be evaluated, as it is deformed and flows as a viscous material. Gluten, which is easier to deform, is considered more extensible. In the recovery step, the capacity to which gluten can return to its original shape reveals its elasticity. Thus, gluten with higher recovery can mean greater elasticity, which may be translated as having greater strength than gluten with lower recovery.

Key to any bread dough is some degree of balance between its viscous and elastic properties, better yet, its extensibility and strength. Andrew Ross wrote in “Wheat: Science and Trade,” the dough must be “strong enough to withstand the rigors of processing (mixing, fermentation, dividing, molding), and for leavened bread, … strong enough to hold the fermentation gases during proofing and yet deformable or extensible enough to rise easily and form the familiar aerated internal structures (crumb).” Hence, extensibility and strength are extremely important for describing the functionality of bread dough.

The CORE test is based on fundamental properties and theory, and it generates data in physical units. This offers an advantage over current dough testing methods, whose measurements cannot be directly compared from one instrument to another because they do not measure fundamental properties and do not report in universal physical units. Applying the CORE test to gluten samples from the WIT program has allowed the measurement of balance between strength (elasticity) and extensibility (deformation). Examples of the test are provided in Figure 9 for three common OSU cultivars. The gluten present in Billings recovers faster from compressive deformation, indicated by the steeper rise in the CORE curve shown, and it regained more of its original state via elastic recovery (height of the curve, Figure 9) than Endurance or Duster.

Finally, the comparison of protein content, which is a measure of the potential to form gluten in one dimension (quantity), to two other dimensions representing strength and extensibility, have allowed the identification of experimental lines with similar dough properties. Such comparisons have proven valuable to describe how far or how close experimental materials are to a balanced value and their relationship to protein content.

Wheat breeding and cultivar development

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Perhaps the best way to describe the sequence of selection decisions between 2012 and this last crop season is the breeding program was virtually turned upside down. Too often experimental lines, which excelled in the heat and drought of 2012, plummeted following the repeated freezes of 2013. Very rarely

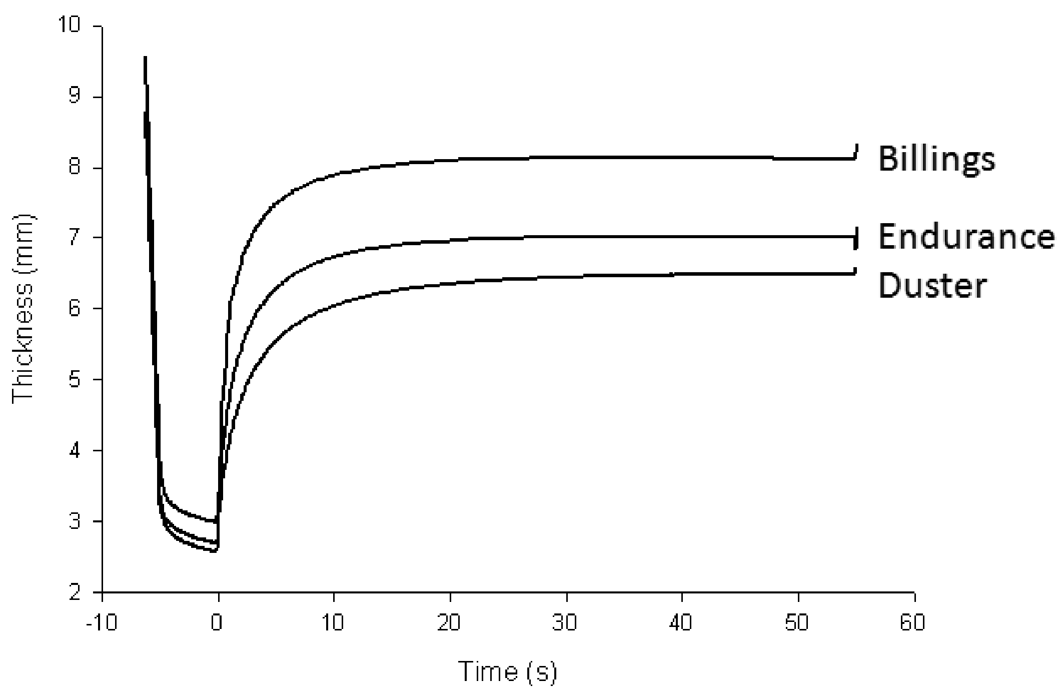

Figure 9. Compression-recovery curves for gluten fractions isolated from Billings, Endurance and Duster, in which gluten thickness (mm) vs. time (s) was recorded during 5 s compression at constant force and 55 s recovery. The CORE test has proven to be practical and effective compared with other currently used methods for evaluating protein functionality, such as a farinograph or amylograph. Figure previously published in *Journal of Plant Registrations*.

did an experimental line excel in both years, but those lines with unusual consistency were highly prioritized in making advancement decisions for the 2013-2014 crop year. More common was the practice of selecting experimental lines that showed the least drop off in performance from the early maturity favoring environment in 2012. Much like what was experienced in 2010 vs. 2011, the contrast in environmental conditions from 2012-2013 represented bookend conditions to base selection. One consistency, however, was obvious: in each year, greater yield was realized with the ability to grain-fill and mature rapidly. What differed dramatically was the optimum time for initiating stem elongation (first-hollow-stem stage, FHS). In 2012, early stem elongation (relative to the germplasm base) was definitely favored for advancement but not as much in 2013. Relatively late FHS stage was the prevailing result in 2013, where ever selection was based strictly on yield patterns.

Genetic footprints of 2013

Environmental conditions to which the OSU wheat improvement program was exposed in 2013 will leave a favorable and lasting impact on three key trait complexes: disease resistance, grain-filling capacity (following delayed stem elongation) and lodging resistance. Disease reaction once again dominated trait selection at all levels of inbreeding, from early generations, such as $F_{4:5}$ headrows to later generations such as $F_{4:10}$ advanced lines. What continues to be so extraordinary is the low-level presence of leaf rust. Leaf rust reactions have not been highly relevant to advancement decisions since 2009. The prevailing pathogens in 2013 produced severe leaf blight and premature senescence, including those causing powdery mildew, Septoria leaf blotch, spot blotch, Staganospora nodorum blotch, tan spot—and to some extent—a nonpathogenic condition called physiological leaf spot. These diseases, other than powdery mildew, often are difficult to distinguish and their effect can create blight and poor canopy health.

For a disease that only occasionally cracked the top 10 less than 10 years ago, powdery mildew has now become a key trait in several decision platforms, e.g., which lines to use as parents or which lines to release for commercial production. On the average rate of about every other year, powdery mildew resistance is given almost as much priority as reactions to the WSBMV/WSSMV complex, BYDV or stripe rust, depending on natural disease development in the field. In 2013, the WIT collected mildew ratings on experimental lines May 1-May 26. Likewise in the more compressed grain-filling period in 2012, powdery mildew readings still spanned nearly three weeks. Very few diseases remain active for that duration, causing significant damage throughout the canopy but at the same time significant opportunity to identify genetic pockets of resistance. There is a molecular marker to tell if one of the components of resistance is the gene *Pm1a,* which is derived from multiple sources, the most recognizable being 2174. Interestingly, the moderate resistance present in Duster and Garrison is not conferred by that gene; thus, other viable options are available, including powdery mildew resistance that has been incorporated into high-yielding derivatives from the susceptible cultivar Billings. Of the candidate cultivars, only OK09520 is weak against powdery mildew, while OK10805W and OK10728W are exceptionally strong. Gene *Pm1a* is present in OSU breeding materials at a frequency of about 15 percent. Frequencies of other key resistance genes are unknown but sufficiently high to ensure an effective level of resistance comparable to Duster in more than 85 percent of advanced elite lines scheduled for testing in 2013-2014.

Tremendous breeding effort also has been given to the leaf spotting diseases. Their effect was highly visible in 2013 as captured in Figure 10. Supplemented with tan spot reactions arduously collected by WIT member Hunger in custom-designed greenhouse assays, field conditions in 2013 allowed broad-spectrum selection for resistance to multiple leaf spotting conditions. This effort will invariably continue, either in the field or on a more targeted path in the greenhouse, as the WIT is determined to improve upon the leaf spotting tendencies of Duster and Billings and their progenies. One obvious improvement can be seen in the 2012 release Iba, for which 2013 Kansas State University tests, confirmed its moderate resistance to tan spot. Severity of symptoms, as a percentage of the susceptible check TAM 101, was 17 percent for Iba (as well for Armour), 44 percent for Cedar, and 103 percent for Everest. Of the candidate cultivars, OK09125 and three white wheat candidates (OK10728W, OK10805W and OK11754WF) offer superior protection specifically to tan spot based on Hunger's seedling assay. Garrison remains one of OSU's more resistant releases for tan spot reaction.

The reoccurrence of late winter freeze events in 2013 cast another genetic footprint on the OSU wheat improvement program. High yielding ability was invariably driven by the capacity to recover from partial, or

Figure 10. Leaf spotting symptoms found in breeding nurseries at Lahoma May 23, 2013. The plot to the left produced typical symptoms affecting greater than 60 percent of the flag leaves with greater than 60 percent damaged tissue. Leaf spotting was less evident in the adjacent plot to the right. These conditions allowed the WIT to eliminate progenies with undesirable levels of leaf spotting at a key stage of the breeding cycle, i.e., when lines are extracted for subsequent statewide testing.

in the case of far western Oklahoma, complete canopy desiccation. This is a condition not too unlike what is imposed in a grazed environment, though the timing of canopy destruction following the 2013 freeze events would have been much later in development, relative to the onset of stem elongation, than typically experienced under grazing. Experimental lines recovered differentially to the late freezes, but sometimes not entirely reflective of their maturity. As one obvious example, Billings and Ruby Lee reached the FHS stage relatively early among most current cultivars in 2013. On a scale of 0 (very early) to 5 (very late), 2013 ratings for dormancy release averaged 1.9 for Ruby Lee and 2.3 for Billings, compared with 4.3 for Endurance, across four locations in Oklahoma. Despite their similar developmental pattern, Billings recovered far less to five late-winter/spring freeze events than did Ruby Lee, as captured in Figure 11. This response pattern was intrinsic to our advancement decisions, either directly by ratings of freeze recovery or indirectly via selection for yield. It is not certain the reason for Ruby Lee's exceptional recovery from spring tiller loss or abortion, but it is nearly certain that this response parallels Ruby Lee's favorable recovery from grazing.

Stem integrity, and straw strength, were likely impacted by these freeze events, which in turn impacted final grain yield. However, conditions in 2013 allowed direct assessment of straw strength in the absence of any noticeable freeze damage. This was especially true where grazing in northern Oklahoma delayed plant development in some breeding nurseries and provided a likely escape from harmful effects of the freeze. Ample spring rainfall and high winds combined to expose lodging tendencies, leaving yet another significant and much needed genetic footprint on the wheat improvement program. If there is one trait complex that needs immediate attention as progressive steps are made in improving yield potential, it is straw strength. Duster and Billings provided step increases in yielding ability in two divergent genetic backgrounds. One common weakness is the tendency to lodge at high plant population densities

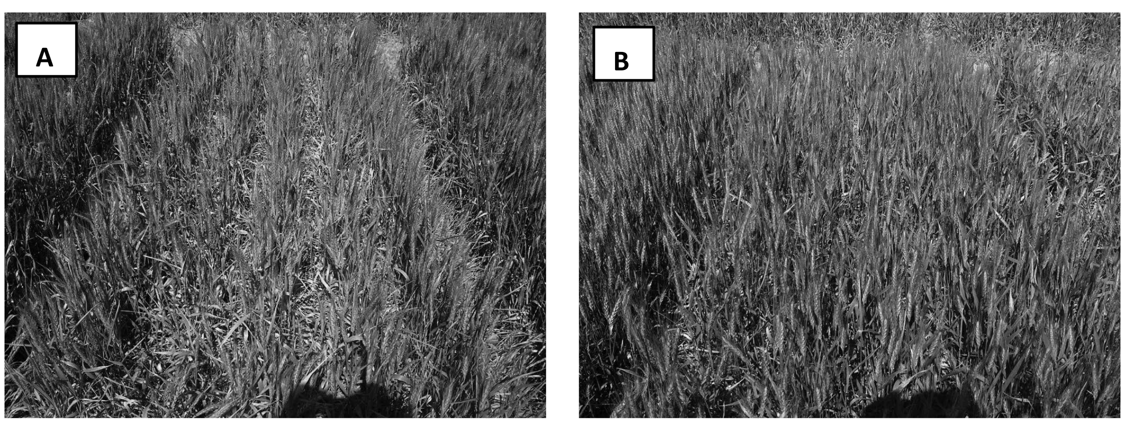

Figure 11. Recovery from multiple freeze events April-May 2013 at the Oklahoma Panhandle Research and Extension Center (with irrigation) for (A) Billings and (B) Ruby Lee May 31, 2013. Yields in bu/A were 26 (Billings) and 36 (Ruby Lee), with the highest yielding line in this nursery (Oklahoma Elite Trial) producing 43 bu/A. Both varieties appeared to initiate stem elongation at a similar time during the third week of March 2013.

and/or with abundant spring moisture.

Recently the candidacy of experimental lines with exceptional straw strength was considered, but withdrawn due to other recently exposed weaknesses – namely OK08229 (susceptible to 2012 stripe rust races), OK08328 (low protein content) and more recently, OK09634 (late-winter freeze susceptibility). With heavy emphasis on lodging resistance, more experimental lines are emerging through the pipeline with OK Bullet or OK Rising parentage. Candidate cultivars OK10126 (from OK Bullet) and OK10728W (from OK Rising) are two worthy examples. The effect of OK Bullet parentage is readily visible in the photographs in Figure 12 taken for two groups of half-sibs with OK Bullet as the common parent. Retaining OK Bullet's straw strength, while obviating weaknesses in winterhardiness and powdery mildew reaction, remain high priorities in the OSU wheat improvement program.

Products of the Graze*n*Grain breeding system

The WIT typically employs a modified bulk-pedigree selection method in cultivar development, whereby early generation populations are selected and advanced as bulk populations for three consecutive generations. More than 50,000 purelines are derived as headrows from F_4 populations, and a subset of these lines is tested statewide in replicated yield trials for at least three generations.

Superimposed on this selection method is the **Graze*n*Grain** breeding system, which incorporates a dual-purpose management selection environment at key points of the 10- to 13-year breeding cycle. This feature distinguishes the OSU wheat

Figure 12. Family of experimental lines with OK Bullet parentage (left) vs. a family without OK Bullet (right), tested in the 2013 Dual-Purpose Observation Nursery at Stillwater. Photograph taken June 4, 2013.

improvement program as possibly the only one in the world which actually selects for adaptation to dual-purpose conditions, rather than simply testing finished lines ex post facto in a dual-purpose environment. With a proven track record, Endurance and Duster have earned their status as stalwarts in the dual-purpose system, but there is evidence to suggest other newer releases may have even greater potential. Ruby Lee has demonstrated as much grazing recovery and yield responsiveness as Endurance in the dual-purpose breeding nursery site at Marshall, but with earlier maturity and other strengths. Supporting grain yield data from 2012 and 2013 are reported in Table 7.

Attributes considered to be improved indirectly by the **Graze*n*Grain** breeding system are stand establishment and canopy closure, tillering capacity, drought and cold tolerance, resistance to BYDV (or to its primary vector, bird cherry oat aphid) and to Hessian fly, winter dormancy retention and stem carbohydrate remobilization. Our most recent release, Doublestop CL+, fits this billing well, though with lower BYDV tolerance than Endurance and Duster and no apparent Hessian fly resistance.

Doubled haploid bypass of the Graze*n*Grain breeding system

At times, an alternate breeding method is used that creates inbred experimental lines within one year of executing the cross, using a specialized mating system and tissue culture that essentially bypasses two of the four principle stages of variety development (Figure 13). The production of doubled haploids has its disadvantages and limitations, and thus only a small proportion (less than 1 percent) of the available crosses are ever considered for this approach. However, turning the 10-year breeding cycle over at a faster rate improves the potential rate of gain on a per-annum basis and puts the wheat improvement program on par with other breeding programs where the cycle time is greatly shortened (as with maize).

Given that background, yielding ability of the first two sets of doubled haploid materials exceeded expectations. Superiority to Gallagher has already been found in doubled haploids derived from crosses with Gallagher conducted in only the last three years. The only testing that remains is yield validation in more environments and confirmation of functionality suitable for HRW and HW

Table 7. Grain yield following grazing in a dual-purpose management system at Marshall, 2012 and 2013.

Variety	*Two-year grain yield*	*2012 yield*	*2013 yield*	*Total data points*
Ruby Lee	47	44	50	26
Everest	46	45	47	10
Gallagher	45	49	41	18
Endurance	44	38	50	31
Iba	44	41	47	23
Duster	42	44	41	49

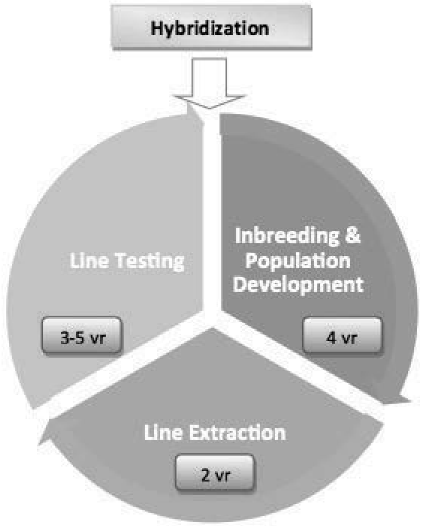

Figure 13. Wheat cultivar development from purelines can be represented as four stages spanning 10 to 13 years from hybridization to final testing and release. Rarely are experimental lines deemed worthy as parents for the next cycle of hybridization within six years of their development, a period often called the breeding cycle interval. Shortening this interval is a crucial component to improving the rate of gain in wheat breeding programs.

wheat. Experimental lines derived via doubled haploid techniques are already recycled back into the breeding program to serve as parents for future cultivar development, effectively cutting the cycle time by more than one-half.

The numbers

Field evaluation, molecular and greenhouse assays, and end-use quality testing were conducted in 2012-2013 to allow selection and advancement of 2,960 breeding lines in preliminary (F_6), intermediate (F_7) and advanced inbreeding generations (F_8 and beyond) in 2013-2014. About 15 percent of those belong to the HW class, with the balance being HRW, or in rare cases, soft red winter (SRW) (less than 1 percent). CLEARFIELD materials constitute 7 percent of the total number of breeding lines in the F_6 generation and beyond moving into the 2014 season. Doubled haploid lines account for 13 percent of the total, our highest proportion yet, though very few crosses are represented by those lines. Many of the doubled haploid progeny feature Gallagher, Garrison or a recent cultivar candidate OK09634 as a parent. Finally, of the 2,960 breeding lines, 27 advanced lines were chosen as cultivar candidates to move into various stages of breeder seed increase in 2014. Of those 27, seven candidates are in the possession of Oklahoma Foundation Seed Stocks (OFSS). Two of those are HW, one is a soft white and one is a two-gene CLEARFIELD line in a SRW background. The other three candidates are HRW. Some of these candidates will be highlighted later in this report.

The OSU hybridization component of the breeding program had great success in 2013, producing 960 unique crosses (compared with only 740 in 2012) strictly for the purpose of cultivar development. The annual goal is about 1,000 crosses, excluding the additional crosses conducted by Klatt and other collaborators. About 18 percent of these crosses will potentially lead to populations that contain genes fixed for white kernel color or otherwise segregate for kernel color. Less than 25 percent of these hybridizations was limited to elite in-house parentage, underscoring the emphasis placed on germplasm introgression from external sources. As is the usual case, introgression was principally focused on disease and insect resistance. About 30-35 percent of the total breeding effort is dedicated toward improving disease resistance, while at least maintaining current yield levels. It would be preferred to decrease that effort somewhat, in favor of putting more direct selection pressure on increasing yield potential.

The end of the genetic pipeline

CLEARFIELD genetics remain a fixture among WIT breeding lines following OSU's latest release of the two-gene HRW cultivar DoubleStop CL+. One example is the candidate cultivar, OK109143CF, a two-gene line with the pedigree Mason sib/ OK03926C. It performed well enough in 2013 to warrant regional testing in the soft winter wheat uniform nurseries coordinated by USDA-ARS. OK109143CF provides excellent protection against powdery mildew, BYDV and the leaf spotting complex. It has excellent straw strength and moderate dough strength, especially for a soft wheat. This line would only be targeted for areas that normally produce SRW wheat. More CLEARFIELD lines are in the pipeline, but the majority of WIT breeding populations are now fixed for *AHASL1D* but segregate for *AHASL1B*, which greatly simplifies future selection and fixation of the two-gene genotype. This component of our breeding efforts is facilitated by WIT member Edwards, whose Extension efforts focus on delivering educational information relevant to CLEARFIELD technology to multiple publics.

Selection and advancement decisions in 2013 have produced an entirely different lineup for candidate cultivar testing in the 2014 OSGVPT. The 2013 harvest turned the tables on red vs. white wheat. Candidates are summarized in Table 8, where three can be found to have a white bran coat. OK10728W is the best all-around HW candidate with statewide adaptation, tan spot resistance, and resistance to shattering and lodging. It also fits the **Graze*n*Grain** mold, though BYDV reaction and early dormancy release are weaknesses. OK10805W is nearly the mirror image of OK10728W, with much later maturity and better BYDV resistance. The 2014 OSGVPT and USDA-ARS regional nurseries will be needed to further separate these two HW candidates.

OK11754WF is a high-yielding soft white candidate and, due to the nature of its functionality, will be considered independent of the two HW candidates. It appears to be better adapted to northern Oklahoma, and shows very early dormancy release like one of its parents, Overley. Other strengths are tan spot resistance and lodging resistance. Like OK109143CF, it will be placed in soft winter wheat uniform nurseries coordinated by USDA-ARS to determine its best positioning and potential avenues for commercial use. OK11754WF and OK10728W were given such high priority in 2013 to justify a breeder-seed increase in Yuma, Ariz., amounting to 20 bushels for OK11754WF and 56 bushels for OK10728W.

Of the remaining HRW candidates, OK09125 holds greatest interest and will undergo a second year of breeder seed increase by OFSS. With consistently high yield, OK09125 was one of the rare exceptions on yield charts from the last two crop seasons. Unfortunately, it tends to produce below-average test weight. In addition to showing exceptional tenacity with grazing, OK09125 excelled in the 2013 USDA-ARS Southern Regional Performance Nursery, where it ranked in the top four entries among 40 candidates submitted by public and private breeding programs throughout the Great Plains. OK09125 has a strong

Table 8. Six advanced experimental lines undergoing further testing in the OSGVPT and their yield ranks (out of a minimum of 30 entries total) in statewide replicated breeder trials from 2010-2013. Two entries with the same rank may have been tested in different nurseries but across the same environments.

Candidate	*Class*	*2010*	*2011*	*2012*	*2013*
OK09125 (TAM 303/Overley)	HRW	2	15	2	1
OK09520 (TAM 303/2*OK96717-99-6756)	HRW	4	5	2	15
OK10126 (OK Bullet/OK98680 reseln)	HRW	17	10	3	1
OK10728W (OK Rising/OK98G508W-2-49)	HW	5	2	5	12
OK10805W (WD97-6740/KS98HW151-6//OK98G502W)	HW	3	4	16	3
OK11754WF (CIMMYT seln/Overley//Jagger-derivative)	SW	--	14	2	20
Gallagher (check)	HRW	1	5	1	2

reputation of good drought tolerance but is not as resilient under severe stripe rust infection.

A new and shining star in the program has the selection number OK10126, featuring perhaps the best straw strength (with short stature), even among a strong slate of candidate cultivars. Consider it an OK Bullet with upgraded yield potential, unusually good green-leaf retention and leaf hygiene based upon resistance to multiple diseases, most notably stripe rust, tan spot and leaf rust. Outstanding end-use quality is yet another feather in its cap.

Wheat Variety Trials

Jeff Edwards

Dept. of Plant and Soil Sciences

At the time of writing this report, 2013 Oklahoma wheat production is estimated to be approximately 114 million bushels, which is roughly 26 percent less than 2012 production (Table 9). The production decrease was due to the combination of lower yields and fewer harvested acres. Given the challenges faced in the 2012-2013 wheat production year, most would consider the average yield and total production to be much better than expected.

There have been several dry starts for wheat planting in Oklahoma, but the fall of 2012 might go down as the driest of the dry. A few timely rains in late August and early September allowed early and mid-September sown wheat to emerge and get a rapid start on forage production. This was the last substantial rain most of western Oklahoma received until early 2013. As a result, much of the October-sown crop remained partially emerged in dry soil until after the first of the year.

Wheat that had emerged in September had consumed available water by early November and turned brown by December. Many fields were assumed dead, as there was no green tissue remaining above the soil surface (e.g. Marshall dual-purpose [DP] trial). This left little to no grazing potential for many dual-purpose wheat producers. The Stillwater forage trial, for example, had less than 500 lbs/A (estimated) of available forage in early December, which is the normal forage measurement timing.

Rain was not plentiful in early 2013, but there was enough to allow the wheat crop to rebound. Wheat seed that had been lying in the soil germinated and early emerging fields that had turned brown from drought were resuscitated and brought back to life. Wheat in southwestern Oklahoma and the Panhandle struggled throughout the season, surviving but never really thriving. Given these extreme circumstances, the grain yield at the Chattanooga, Altus and Hooker sites are nothing short of amazing. Although wheat finally emerged at the Alva, Balko, Buffalo, Cherokee, Gage, Keyes and Lamont sites, the stands were far too variable for use in comparing the yield potential of wheat varieties.

Drought was not the only weather-related issue Oklahoma wheat producers dealt with in 2013. There were multiple rounds of freeze events in late March

Table 9. Oklahoma wheat production for 2012 and 2013 as estimated by OK NASS, June 2013.

	2012	*2013*
Harvested Acres	4.3 million	3.8 million
Yield (bu/A)	36	30
Total bushels	154.8 million	114 million

and early April. Wheat in southwest Oklahoma and the Panhandle was affected by different freeze events but both sustained 30 to 80 percent tiller loss and were largely written off in the weeks following the freezes. Outside of far southwestern Oklahoma, cooler than normal conditions and some replenishment of soil moisture allowed regeneration of tillers. This, along with extended grainfill duration, allowed many wheat fields to recover and produce greater than expected grain yields (e.g. Apache variety trial). The cooler than normal spring temperatures were beneficial for wheat grainfill, but also delayed harvest by about one month, as compared to 2012, and about two weeks as compared to the long-term average.

It was a fairly quiet year regarding foliar disease. Pockets of the state suffered from heavy powdery mildew infestation in March and April, and some wheat producers chose to split-apply fungicides to combat this disease. There also were areas affected by glume blotch, tan spot, and septoria, but there was not much leaf or stripe rust present.

Yellow and purple leaves were tell tale signs that a late spring flush of aphids had transmitted BYDV to several Oklahoma wheat fields. Armyworms were present late in the season, but generally did not reach threshold levels prior to maturity and few fields were sprayed. Winter grain mites took advantage of slow-growing, drought-stressed wheat and were a frequently reported problem in southwest Oklahoma, but the wheat curl mite takes top billing among mite pests in 2013. The wheat curl mite transmits WSMV and HPV. These two diseases are fairly common in the Panhandle, but do not typically affect wheat in central Oklahoma. In 2013, fields as far east as Kingfisher tested positive for WSMV and several central Oklahoma fields were affected. Growers affected by WSMV should take care to ensure that any volunteer wheat or corn is dead at least two weeks prior to planting to reduce the risk of this disease in 2013-2014.

Methods

Conventional plots were eight rows wide with 6-in. row spacing. No-till plots were seven rows wide with 7.5-in. row spacing. Plots were 20 feet long and wheel tracks were included in the plot area for yield calculation. Conventional till plots received 50 lbs/A of 18-46-0 in-furrow at planting. No-till plots received 5 gals/A of 10-34-0 at planting. The Marshall DP trial and forage trials were sown at 120 lbs/A. All other locations were sown at 60 lbs/A. Grazing pressure, N fertilization, and insect and weed control decisions were made on a location-by-location basis and reflect standard management practices for the area.

The addition of a new plot combine allowed harvest operations to run a little smoother in 2013. The purchase was made possible by $260,000 in one-time additional funding from the OWC and the Oklahoma Agricultural Experiment Station. The new machine is a Wintersteiger Delta with a 5.7-ft header powered by a 80 HP turbo charged Perkins diesel. The combine is manufactured in Austria and includes an on-board weighing system that records plot weight, moisture and test weight. The increased capacity of the larger machine and the on-board weighing system will reduce labor requirements and allow for more rapid

Winterstieger Delta.

publication of results on the website. The orange Hege 140 machine will still be out harvesting plots as well, and the ability to go to two sites will greatly increase timeliness during harvest.

How can I become a certified seed grower?

Seed certification is the process required to produce high quality pedigreed seed and is open to all who wish to participate. Certified seed is a limited generation seed production system. Foundation seed produces registered seed, registered seed produces certified seed and certified seed produces grain.

There are several basic requirements to become a certified seed producer.

1. **Start clean.** All planting and harvesting equipment and storage facilities must be clean to prevent contamination from other crops, varieties or weed seeds.
2. **Plant eligible seed and retain proof of eligibility.** Foundation or registered seed must be planted for the crop to be eligible for certification. If you are going to produce registered seed, you will need to purchase foundation seed. If you are going to produce certified seed you will need to purchase registered seed.
3. **Eligible ground.** The seed you plant needs to be planted on eligible (clean) ground, i.e. ground that has not produced a like crop in the past year, unless it was planted to a class of certified seed in the past year. For example, if you are going to produce certified Duster, you will need to purchase registered Duster and plant it on ground that was not in wheat the previous year. This ensures there will be no contamination by other varieties of wheat.
4. **Field inspection application.** Contact Oklahoma Crop Improvement Association (OCIA) office for an application for field inspection and submit it by the appropriate deadline. This will start the paper work process to complete seed certification. You will need to send in a seed tag or other documentation with the application. This creates a paper work trail so the seed source can be identified.
5. **Prepare your field for inspection by OCIA.** This involves roguing any contaminants, such as rye or off-type plants, and controlling any noxious weeds, such as field bindweed. Isolation also needs to be determined at this time. In wheat, there needs to be 10 feet between a certified seed field and other wheat.
6. **Field inspections.** The inspector will contact you prior to harvest to make

you aware that he will be in the area and confirm that your field is ready for inspection. After inspection is completed, you will receive a copy of the field inspection report.

7. **Seed conditioning.** The primary purpose for seed conditioning is to remove all impurities (broken seed, chaff, weed seed, etc.) from your seed. Conditioning must be done by an OCIA approved conditioner listed in the directory or with your own seed cleaning equipment.
8. **Laboratory analysis.** After cleaning has been completed, a sample of seed must be submitted for testing. This will provide you with all the necessary information for the label requirements, and ensure the seed meets OCIA standards. Sample bags are provided by the OCIA office.
9. **Official tags/labels.** Once the seed has passed both field and laboratory inspections, tags or labels can be ordered from the OCIA office. Both bagged and bulk seed sales require official OCIA tags to be legally sold. It also is a requirement of the State Seed Law that all seed sold be labeled properly.

Specific crop standards and other information are available from the OCIA office or at www.okcrop.com.

Before the seed is sold, you will need to purchase a seed dealers license from the Oklahoma Department of Agriculture (ODA). Contact the ODA office for further instructions and information.

Oklahoma Dept. of Agriculture, Food & Forestry Plant Industry & Consumer Services
2800 N. Lincoln Blvd.
Oklahoma City, OK 73105
(405) 522-5885

Oklahoma Crop Improvement Association
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Additional information on the Web

A copy of this publication, as well as additional variety information and more information on wheat management, can be found at www.wheat.okstate.edu

Website

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2013 Oklahoma Wheat Variety Trial Yield Summary

Variety	*Afton*	*Altus*	*Apache*	*Apache Fungicide*	*Chattanooga*	*Chickasha*	*Goodwell Irrigated*	*Homestead*	*Hooker*
	grain yield (bu/A)								
Armour	50	10	36	39	18	74	35	59	25
Billings	39	9	40	42	23	65	39	52	27
Brawl CL+	-	16	-	-	-	77	48	-	28
Byrd	-	16	-	-	-	70	47	57	27
Centerfield	-	9	-	-	-	69	45	-	-
CJ	47	11	36	46	23	65	39	-	-
Deliver	-	14	-	-	-	75	43	-	-
Doans	45	15	37	44	24	76	39	53	26
DoubleStop CL+	54	25	-	-	-	79	45	64	-
Duster	40	17	41	49	28	65	47	50	33
Endurance	48	21	43	54	22	74	46	51	32
Everest	55	8	36	41	17	81	43	58	24
Gallagher	49	7	42	44	25	72	46	66	22
Garrison	49	17	42	50	31	70	45	61	31
Greer	40	16	46	51	21	63	42	58	30
Iba	36	14	47	57	36	71	54	58	30
Jackpot	49	11	42	52	24	60	44	57	25
Jagger	31	10	37	41	16	64	37	53	31
LCH08-109	-	7	-	-	-	50	28	-	-
LCH08-80	-	17	-	-	-	81	56	-	-
LCS Mint	-	18	-	-	-	69	56	-	-
Mace	-	-	-	-	-	-	41	-	28
OK Bullet	-	16	-	-	-	67	39	-	-
Pete	-	8	-	-	-	67	33	-	-
Razor	-	12	-	-	-	58	39	-	-
Ruby Lee	56	10	40	46	25	72	46	57	24
T153	51	7	39	41	12	70	37	46	28
T154	57	8	36	43	18	70	39	50	30
T158	50	12	45	46	24	74	43	56	31
TAM 113	-	16	-	-	-	55	47	-	28
WB-Cedar	68	8	34	37	13	73	35	41	25
WB-Duece CL+	-	5	-	-	-	52	24	-	-
WB-Grainfield	-	22	-	-	-	83	55	-	-
WB-Redhawk	-	7	37	39	15	58	38	63	31
WB4458	-	13	-	-	-	67	46	-	-
Winterhawk	39	15	-	-	-	80	55	-	-
OK08328	-	23	-	-	-	-	-	-	-
OK09125	-	22	49	55	24	68	46	61	31
OK09528	-	-	-	-	-	80	40	-	-
OK09634	31	10	40	43	14	61	36	60	-
OK09729	-	-	-	-	-	74	41	-	-
OK09935C	-	15	-	-	-	64	37	-	-
Mean	47	13	40	46	22	69	42	56	28
LSD (0.05)	10	4	6	8	5	8	8	6	5

2013 Oklahoma Wheat Variety Trial Yield Summary (continued)

Variety	Kildare	Kingfisher	Lahoma	Lahoma Fungicide	Marshall Dual Purpose	Marshall Grain Only	Thomas	McLoud
	grain yield (bu/A)							
Armour	57	47	63	73	49	59	13	48
Billings	44	40	58	64	39	49	10	56
Brawl CL+	-	-	66	70	-	-	-	-
Byrd	51	40	66	81	-	-	-	-
Centerfield	-	-	60	67	-	-	-	-
CJ	-	-	63	65	47	52	12	49
Deliver	-	-	53	58	-	-	-	-
Doans	33	39	51	57	45	44	13	56
DoubleStop CL+	56	37	63	67	50	49	-	59
Duster	34	44	55	67	46	45	13	58
Endurance	43	42	61	65	49	52	17	61
Everest	57	34	65	72	49	57	17	60
Gallagher	46	40	66	77	42	53	16	53
Garrison	55	39	56	70	43	52	14	59
Greer	65	44	65	75	48	55	11	48
Iba	45	46	63	68	51	55	12	60
Jackpot	60	42	64	75	49	48	15	61
Jagger	63	37	57	75	45	54	15	51
LCH08-109	-	-	58	70	-	-	-	-
LCH08-80	-	-	63	73	-	-	-	-
LCS Mint	-	-	65	73	-	-	-	-
Mace	-	-	62	69	-	-	-	-
OK Bullet	-	-	-	-	45	-	-	-
Pete	-	-	53	64	-	-	-	-
Razor	-	-	62	64	-	-	-	-
Ruby Lee	59	40	69	79	51	52	16	50
T153	57	36	57	70	44	55	20	55
T154	53	34	67	74	52	55	18	47
T158	53	43	66	71	50	52	16	55
TAM 113	-	-	59	70	-	-	-	-
WB-Cedar	56	36	65	76	48	54	18	54
WB-Duece CL+	-	-	56	62	-	-	-	-
WB-Grainfield	-	-	69	74	-	-	-	-
WB-Redhawk	64	32	60	66	45	51	-	48
WB4458	-	-	66	68	-	-	-	-
Winterhawk	-	-	62	69	-	-	18	-
OK08328	-	-	-	-	-	-	-	-
OK09125	64	49	71	74	44	54	14	-
OK09528	45	-	64	72	-	48	-	-
OK09634	55	40	63	68	40	47	18	47
OK09729	-	-	64	66	-	-	-	-
OK09935C	-	-	-	-	-	-	-	-
Mean	53	40	62	70	47	52	15	54
LSD (0.05)	7	5	8	7	5	6	3	10

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