



# *Wheat Research at OSU 2004*

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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# OSU's Cooperative Relationships

Partners in Progress—Wheat is one in a series of annual reports from the Division of Agricultural Sciences and Natural Resources (DASNR) highlighting the findings and impacts of research conducted by Oklahoma State University with the support of external agencies. Our cooperation with the Oklahoma Wheat Commission and the Oklahoma Wheat Research Foundation is fundamental in the funding of wheat research and distribution of the results.

For many years, DASNR has had a cooperative relationship with Oklahoma's wheat industry. In keeping with this spirit of cooperation, it is our intention that wheat research be directed as closely as possible to meet the needs of our state's producers.

At the beginning of each section of this report is a summary of accomplishments for fiscal year 2003-2004. The narrative that follows the highlights explains in more detail the progress made during the year. In other words, what did we

learn this year that we did not know last year?

While this report focuses on the progress of wheat research at OSU during the past year, it is the continued support of research over time that leads to such successes as variety releases and the development of new technologies. We value the wheat industry's commitment of continuously supporting agricultural research in DASNR.

History has proven that a united effort between OSU scientists and wheat producers, with the generous support of the Oklahoma Wheat Commission and the Oklahoma Wheat Research Foundation, is beneficial to Oklahoma agriculture. Progress in DASNR wheat research means progress for Oklahoma wheat producers, making us truly Partners in Progress.

D.C. Coston, 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.

# Plains Grains, Inc.

**“He who discovers the value reaps the reward”**

**Mark Hodges**

**Executive Director, Oklahoma Wheat Commission**

**Partners in  
Progress**  
**WHEAT**



Beginning in 1997, the Oklahoma Wheat Commission (OWC) started the move to a more quality based marketing approach of promoting Oklahoma wheat. The OWC's philosophy is not marketing wheat, but rather marketing

what end product that wheat will produce. Since that time, the OWC's marketing plan has evolved into a more intense focus on customers and meeting their needs. By providing "value" to the end user, Oklahoma wheat producers are extracting more value out of the wheat they produce, thereby increasing their own net profit.

By taking a more quality based approach in marketing Oklahoma wheat, we have to know much more about the non-visual quality factors that directly affect milling and baking. Our producers continue to try and find ways to limit the variability of those factors in their wheat shipments, whether it is to the miller or baker. Their ability to limit variability will increase the consistency of their product. Consistency has extremely high value to our customers, so the more consistency we can provide, the more value we can extract. This has been achieved in the past by direct rail shipments, which the OWC started promoting in 1997 (limiting origination to a defined geographical area guarantees consistency). Our focus now is to define where like milling and baking qualities exist (consistency) by intensive testing, then make that information available to our customer in a timely manner.

The evolution of this marketing approach has required us to utilize all the tools available to us to ensure we accurately define the Oklahoma wheat crop, and then work directly with the customer to facilitate the sale. This resulted in the development of a new private not-for-profit, Plains Grains, Inc. (PGI), established January 14, 2004. PGI is the combined marketing efforts of the OWC; Oklahoma Department of Agriculture, Food, and Forestry; and Oklahoma State University. PGI has been successful in developing a blueprint for not only defining the quality of this year's Oklahoma wheat crop, but continuing to be very active in the facilitation of sales. By late November, PGI was successful in meeting with grain buyers to facilitate 2 unit train shipments to Mexico, with others pending, and a 25,000 metric tons (just short of 1 million bushels) sale to Cuba. The added significance of the sale is it being the first ever direct shipment to Cuba with all grain originating from Oklahoma.

As PGI continues a coordinated effort to extract more value from Oklahoma wheat on behalf of Oklahoma wheat producers it will be imperative we expand our efforts. This expansion is needed to ensure we have the critical mass of "discovered value" so we might increase the "reap the reward" side of the equation as well. The research contained in this publication is the basis for discovering more value. This effort truly has been, and is, "Partners in Progress."

**Mark Hodges, Executive Director**

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# Genetic Improvement and Varietal Release of Hard Winter Wheat

Wheat Improvement Team

## *2003-2004 progress made possible through OWRF/OWC support*

- Placed 4 hard winter wheat candidate varieties under foundation seed increase, with the expectation to request DASNR approval for variety release in 2005. The possibilities include a CLEARFIELD-type hard red wheat (HRW) variety, 2 hard white (HW) varieties, and another HRW variety.
- From the 2004 Wheat Variety Trials—provided sufficient performance data for newer varieties such as Endurance, Deliver, and Overlay to warrant their consideration by wheat producers in future plantings.
- Demonstrated dramatic differences among varieties in their response to fungicide application, with yield increases ranging from 1 bushel per acre for Fannin to 17 bushels per acre for AP502CL.
- Developed 82 germplasm lines from crosses between Jagger, Tonkawa, 2137, or Chisholm with a South African wheat that is highly resistant to leaf rust. The majority of these lines also are resistant to wheat soilborne mosaic virus (WSBMV).
- To facilitate variety development, provided reactions to leaf rust and WSBMV of nearly 2,500 breeder lines to breeders across the Great Plains. Also determined reaction to powdery mildew and tan spot of selected OSU lines.
- Introduced several hundred foreign germplasms, mostly from CIMMYT, to incorporate new sources of leaf rust and stripe rust resistance for variety development.
- Produced the first set of base populations from which to select purelines expressing a more durable form of leaf rust resistance called “minor gene resistance.”
- With enhanced selection efforts, recorded significant strides in maintaining foliar disease resistance to leaf rust, stripe rust, WSBMV, and powdery mildew among breeder lines currently in the pipeline.
- Certified that Oklahoma wheat was produced in a state not known to be infected with Karnal bunt, thereby allowing wheat to move freely into international markets.

- Demonstrated that peanut isolates of *Rhizoctonia* spp. and *Sclerotinia rolsii* were more pathogenic on wheat and peanut than isolates obtained from wheat.
- Demonstrated in greenhouse studies a reduction in forage, grain yield, and kernel weight with bird cherry-oat infestation, even when the aphid was not carrying barley yellow dwarf virus.
- Identified effective sources of resistance within this program to multiple biotypes of the Russian wheat aphid.
- Identified sources of tolerance to bird cherry-oat aphid in adapted wheat materials using a novel seedling assay developed specifically for breeding programs.
- Provided further physiological characterization of a bacterial gene encoding an enzyme for mannitol synthesis inserted into the chloroplasts. This trans-gene alters photosynthetic properties and increases biomass compared to conventional wheat plants under water stress.
- Refined techniques to identify, for the first time, high-molecular-weight glutenin proteins associated with bread quality among advanced breeding lines.

Leading the charge to develop and disseminate winter wheat varieties custom-fit for Oklahoma's wheat industry is OSU's Wheat Improvement Team (WIT). The WIT operates on coordinated research and Extension programs directed by several OSU faculty, in cooperation with USDA-Agricultural Research Service (ARS) scientists in Stillwater. Faculty members and their areas of expertise are **Brett Carver**, wheat breeding and genetics; **Jeff Edwards**, wheat management and information exchange; **Bob Hunger**, **Jeanmarie Verchot-Lubicz**, and **Art Klatt**, wheat pathology and development of disease-resistant germplasm; **Dave Porter**, aphid resistance; **Bjorn Martin**, stress physiology; and **Patricia Rayas Duarte**, cereal chemistry. As our newest team member and OSU's Extension wheat specialist, Jeff Edwards, brings a fresh approach to optimizing management practices to extract every ounce of genetic potential out of released varieties. He is

no stranger to the wheat industry, from the mid-South to the Great Plains. Look for his inaugural report that includes a summary of the 2004 Wheat Variety Trials in the following section. The departure of Arron Guenzi leaves a temporary void in our research on gene discovery and transformation, but his research investments will continue to bring dividends in one of our critical focus areas, drought resistance. The WIT continues a close working relationship with one of its former members, Guihua Bai, who directs the USDA-ARS genotyping laboratory in Manhattan, Kansas.

In this report, you can read more about these and other significant breakthroughs: the pending release of several new winter wheat varieties that offer genetic solutions to Oklahoma producers of hard white wheat, hard red winter wheat, and CLEARFIELD wheat; the continued transfer of unique leaf rust resistance genes that vary widely

in their inheritance and their effect on the rust pathogen; a check-up on the disease resistance status in the breeding program; insertion of transgenes that provide alternative genetic solutions to disease and drought stress; immediate identification of WIT breeding materials resistant to the new Russian wheat aphid biotype; and application of protein fractionation techniques for pinpointing bread quality.

## **Wheat Variety Testing and Information Exchange**

**Jeff Edwards**  
**Plant and Soil Sciences**

Hard winter wheat variety rankings within the 2003-2004 variety trials varied by location, management system, and the time frame used for evaluation (i.e., 1-year vs. multiple-year averages). No one variety stood out as being dominant across the entire state, but some varieties such as 2174, Jagalene, and Ok102 were frequently among the highest yielding varieties. Furthermore, growers consistently had 4 to 5 varietal choices that were all statistically similar in grain yield potential, and with few exceptions (Thunderbolt, Custer, AP502CL, and Cutter) all varieties produced adequate fall forage. Visit <http://pss.okstate.edu/wheat/varietytrials/index.htm> for detailed variety trial information.

New varieties such as Endurance, Deliver, and Overlay were consistently near the top at most locations, and demand exceeded availability for these varieties in 2004. In contrast, the new Agripro variety, Fannin, fell short at most locations during the 2003-2004

production year. This was primarily a result of freeze damage and winter kill, so we are reevaluating this variety in the 2004-2005 production year to get a better grasp on its yield potential in Oklahoma's environment.

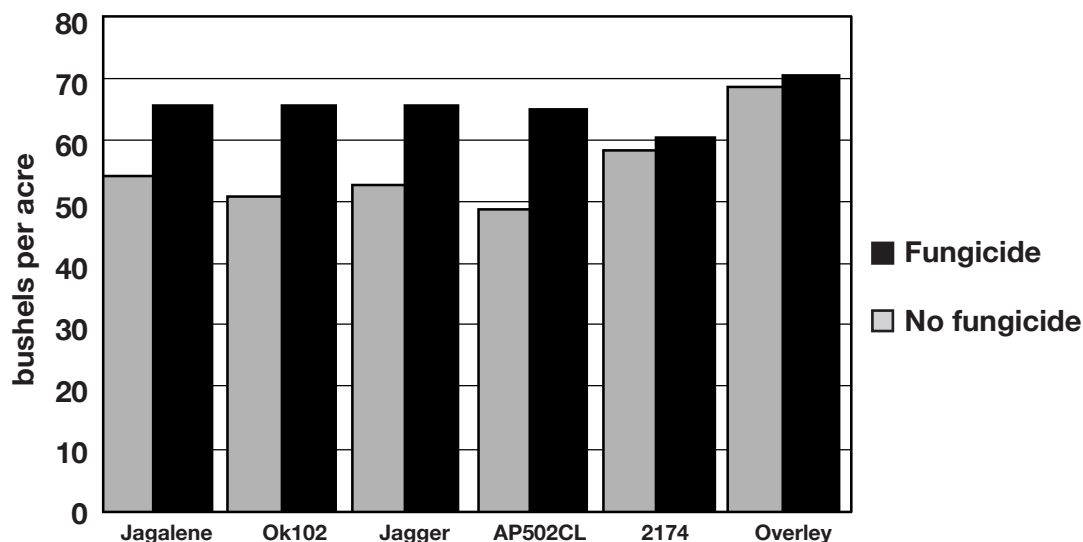
While older varieties such as Jagger still performed quite well at many locations, a trend of decreasing yield for some of these varieties became apparent in the previous year. For example, when a 3-year average is used for comparisons, Jagger is in the top yield-group at 75 percent of the north-central Oklahoma locations, but when the 1- to 2-year averages are compared, Jagger is only in the top yield group in 25 percent of the north-central Oklahoma locations. This trend could change, but 2003-2004 results clearly indicate that growers who are heavily dependent on Jagger should consider incorporating new varieties such as Endurance, Deliver, and Overlay into their rotations.

White wheats performed very well in relation to hard red varieties in 2003-2004. Varieties such as Platte, Trego, and Intrada were consistently top grain-yield performers, and Intrada was a top forage producer as well. Furthermore, the OSU experimental line OK00618W was at the top of the yield trial at Goodwell, indicating that new high-yielding germplasm is in the pipeline. Read further about this experimental line in Brett Carver's report.

Fungicide trials at Lahoma revealed large differences in the response of varieties to fungicide application (Figure 1). For example, fungicide application to 2174 and 2145 has consistently produced a 2 to 3 bushels per acre yield increase, whereas fungicide application to Jagalene has consistently produced around a 10 bushels per acre

yield increase. Further research will be conducted in conjunction with the 2004-2005 variety trials to monitor

the potential yield and seed quality increases for wheat varieties associated with fungicide application.



**Figure 1. Wheat yield response to fungicide application at Lahoma, Oklahoma, in 2004.**

## Wheat Pathology Research and Development of Disease Resistant Germplasm

**Bob Hunger**  
Entomology and Plant Pathology

Funds provided by the OWRF/OWC allowed us to test the 2003 Oklahoma wheat crop for the presence of Karnal bunt. Such testing is needed to obtain certification that Oklahoma wheat was produced in areas not known to be infested with Karnal bunt. Such certification is required by many international wheat trading partners.

Results from testing nearly 2,500 breeder lines for reaction to leaf rust and

wheat soilborne mosaic virus (WSBMV) were provided to breeders across the Great Plains. Additionally, more than 80 germplasm lines with a background of 2137, Jagger, Tonkawa, or Chisholm were developed that express leaf rust resistance due to the *Lr19* gene. *Lr19* confers a high level of resistance to all known races of leaf rust in North America, and was obtained from a South African spring wheat. A selected set of these lines is currently on variety-development track by the WIT.

Greenhouse studies demonstrated the increased effect of bird cherry-oat aphids (BCOA) carrying barley yellow dwarf virus (BYDV) on wheat as compared to BCOA without BYDV. However, concurrent field studies did not produce as striking results, so

these experiments are being repeated in 2005.

Vijay Choppakatla, a Ph.D. student funded by the OWRF, the Peanut Commission, and the OAES, began to study the relationship of wheat:peanut rotations on the incidence of root rots caused by two fungi, *Rhizoctonia* spp. and *Sclerotinia rolfsii*, that can parasitize both wheat and peanut crops. Initial results from greenhouse studies indicate that isolates of these fungi obtained from peanut are more virulent on wheat and peanut than isolates obtained from wheat. This project will continue and will include small field trials starting in 2004-2005.

In summary, funds provided by the OWRF/OWC were used to ensure the exportability of Oklahoma wheat by testing for the presence of Karnal bunt, to develop disease resistant wheat germplasm, to screen breeder lines for disease reaction, to investigate the effects of the aphid:BYDV complex on wheat, and to investigate the relationship between wheat:peanut rotations on disease incidence caused by *Rhizoctonia* spp. and *Sclerotinia rolfsii*.

#### **Jeanmarie Verchot-Lubicz Entomology and Plant Pathology**

Our studies of wheat soilborne mosaic virus (WSBMV) and wheat spindle streak mosaic virus (WSSMV) have shown that these viruses are internalized by their fungal vector *Polymyxa graminis*. This fungus invades root cells and undergoes its life cycle within the cell. We have recently

demonstrated that WSBMV encodes a movement protein that mediates fungal transmission of the virus, as well as promotes the spread of virus infection in plants. We have recently explained virus transmission by the fungus to plant hosts based on WSBMV. We reported that the WSBMV movement proteins and ribonucleic acids (RNAs) occur inside resting spores. We proposed a model to suggest that a ribonucleoprotein complex consisting of viral RNAs and movement proteins are released through the zoosporangial exit tubes transmitting virus to plant cells. Since *P. graminis* overtakes entire cells, it is worthwhile for the virus to move from cell to cell until it reaches one that is uninhabited by *P. graminis*. Then WSBMV starts its life cycle.

Evidence from studying WSBMV and WSSMV indicates that the movement protein also is involved in fungal transmission of the virus. Since virion particles have never been seen in association with *P. graminis*, and since many fungal infecting viruses do not have virion particles, it is reasonable to suggest that the movement proteins have been important in the emergence of new viral diseases from fungi into plants. Based on this research we believe that some viral movement proteins might have been acquired through evolution from fungal or algal hosts. Since *Polymyxa* spp. are so widely distributed, studying *Polymyxa*-virus interactions is likely to provide us with novel insights into the emergence of plant viral diseases. It is urgent that we learn more about mechanisms of virus transmission for developing novel control strategies.

**Art Klatt**  
**Plant and Soil Sciences**

We continued with transferring new sources of leaf and stripe rust resistance into high quality winter wheat materials adapted to Oklahoma. In 2004 alone, 450 new materials were introduced into the program. Many of these new materials were derived from the CIMMYT wheat improvement program and carry multiple minor genes for leaf and stripe rust resistance. This type of resistance has survived several race changes or changes in virulence in Mexico and in other parts of the world, and is now frequently called “durable rust resistance.” We are convinced that minor gene resistance (MGR) can be transferred into adapted winter wheats for Oklahoma. Other sources of rust resistance are the “synthetic” wheats developed at CIMMYT, which provide a genetic bridge to access novel resistance genes residing in distant relatives of Great Plains wheat. More than 400 single crosses and 350 three-way crosses were made during the past greenhouse cycle.

Potential parental materials and early-generation segregating populations were grown in South Texas to determine their reaction to a relatively severe outbreak of leaf rust in 2004. Materials identified as resistant were maintained in the crossing program in Stillwater. Resistant plants from segregating populations were selected and advanced for additional testing in South Texas and in Oklahoma. We now have suitable base populations ( $F_5$  generation) from which to select plants with the desired level of MGR expression in 2005. Some of these plants will be carried forward as purelines in the wheat improvement program.

Three years of research with CIMMYT have indicated significant potential for using spectral reflectance as an indirect breeding tool for grain yield and total biomass in spring wheat. Research on winter wheat materials in Oklahoma is ongoing, and similar results were obtained in the first year. This technology may potentially increase the efficiency and effectiveness of selection for yield and related traits.

**Gene Discovery,  
Transformation,  
and Stress Physiology**

**Bjorn Martin**  
**Plant and Soil Sciences**

Our work remains centered on evaluating physiological differences between conventional wheat and drought-resistant transgenic wheat that uniquely accumulates a specific sugar compound called mannitol. The transgenic wheat carries the bacterial *mtlD* gene that causes mannitol to accumulate either inside or outside the chloroplasts. Water and solute potentials did not differ in preliminary studies between conventional and transgenic plants, whether they were exposed to water stress or not. The transgenic wheat that accumulated mannitol inside the chloroplasts appeared to have a reduced  $\text{CO}_2$ -fixation rate compared to the transgenic wheat that accumulated mannitol outside the chloroplasts. Under water stress, however, the biomass-accumulation rate of both types of transgenic plants was better maintained than in conventional wheat. We have multiplied seed of transgenic

plants to be evaluated in yield trials in the field.

We have in the past year optimized techniques to use real-time DNA analysis to determine the number of copies of the transgene and to measure the messenger RNA expression level. We also have established calibration data for determining the ability of wheat tissue extracts to scavenge the destructive hydroxyl radical that forms in stressed plant tissue. The technique is based on quenching of fluorescence by mannitol in the extract. The fluorescence is emitted by a photoprotein as it reacts with hydroxyl radicals in the assay mixture.

## **Aphid Resistance**

**Dave Porter**

**USDA-ARS, Plant and Soil Sciences**

New virulent biotypes of Russian wheat aphid (RWA) continue to be identified in the United States. Currently only one biotype (RWA-1) has been detected in Oklahoma. RWA-1 is the original population of RWA that migrated into the U.S. in 1986. However, with the identification of a new biotype found in Colorado last year, RWA-2, and other virulent biotypes recently collected in Texas and Colorado, it is likely only a matter of time until these new biotypes make their way into Oklahoma wheat fields.

We will be ready when this happens. Testing and selection of superior breeding lines with high levels of resistance to RWA-1 and RWA-2 have

resulted in the identification of several high performance candidates that are already on variety-development track. Two such lines, OK03825 and OK03826, are derivatives of Custer with resistance to both RWA-1 and RWA-2. Additional work is ongoing to identify new sources of resistance to the newly detected virulent biotypes of RWA found in other states.

A newly developed seedling screening technique was used to test and characterize several collections of wheat for reaction to bird cherry-oat aphid (BCOA) feeding damage. This seedling test is useful to identify wheat lines with tolerance to BCOA feeding. Several promising wheat lines with good levels of BCOA tolerance were identified. These wheat lines will undergo additional testing to confirm the tolerance and to understand the genetic control of this trait. In the meantime, crosses have been made with these BCOA tolerant lines to transfer this important trait into advanced lines in the breeding program.

Additional work is ongoing to move greenbug resistance genes in superior wheat lines through the breeding program for potential release as new cultivars. The pending release of OK02909C (described in Brett Carver's report) provides the latest example. Screening of breeding lines for resistance to RWA and greenbug continued this year. The goal of this line of research is to have a steady stream of aphid resistance genes available in superior wheat lines that can be moved through the breeding program and released to Oklahoma producers.

## **Cereal Chemistry**

**Patricia Rayas Duarte**  
**Biochemistry and Molecular Biology**

For the first time in the history of the OSU wheat breeding program, we scanned for the presence of high molecular weight glutenin subunits among advanced breeding lines using 1-dimensional sodium-dodecyl-polyacrylamide gel electrophoresis. Long-term research shows that specific glutenin subunits are related to dough functionality and bread baking characteristics. Knowing which subunits are present allows us to better interpret small-scale test results of breeding lines relative to dough strength and potential loaf volume. Another critical impact is that we can use this information to make more informed decisions in choosing parents for future crosses. Very few crosses are made, therefore, few breeding populations are formed without consideration of the end-use quality potential resulting from those crosses and populations. This technology gives us a better read on quality potential in the marketplace.

## **Wheat Breeding and Variety Development**

**Brett Carver**  
**Plant and Soil Sciences**

The 2003-2004 crop year put a final coat of paint on a 4-year expansion-overhaul of the wheat breeding program. We now operate at a level

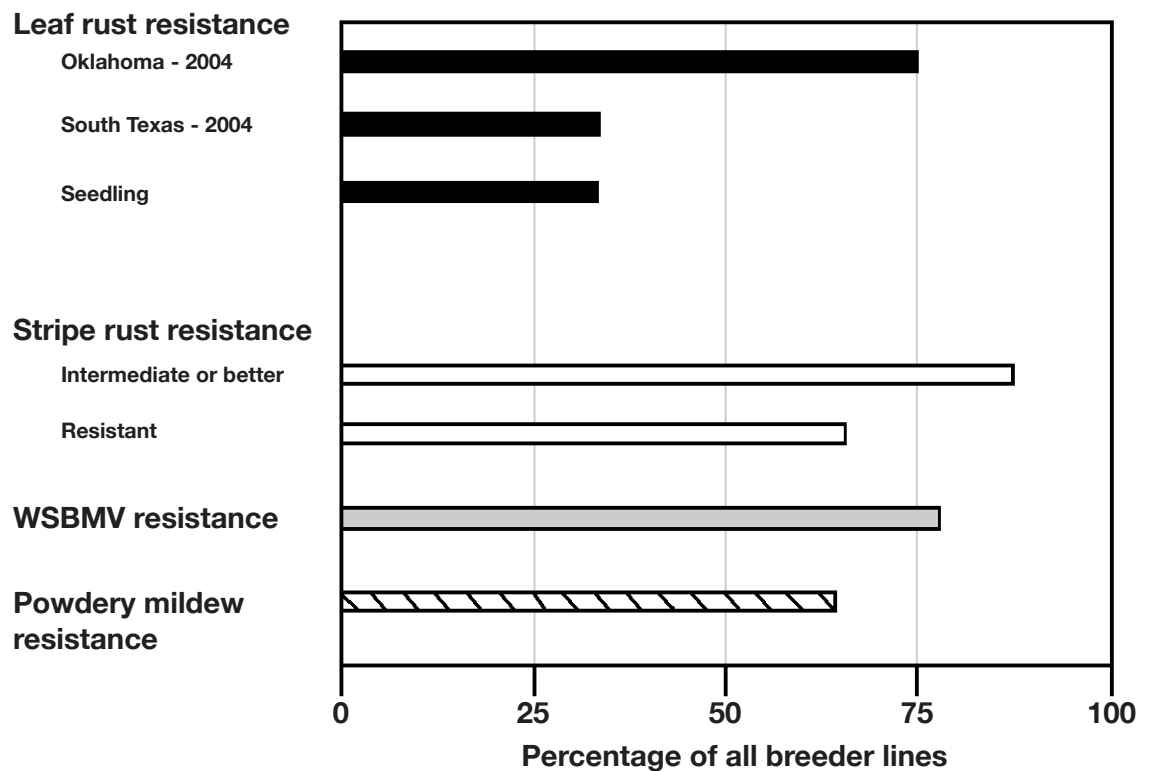
fully capable of servicing the state's varietal needs, yet at a level sustainable with current resources. The numbers for 2004 stacked up like this: more than 950 unique hybrid crosses produced; 620  $F_1$  populations increased for further selection; 2,140 bulk populations screened in grazed and grain only systems; 29,500 head rows searched for disease resistance and seed quality; 1,680 preliminary lines evaluated from head to root in dual-purpose and grain only systems; and 470 breeding lines tested statewide for a multitude of agronomic and quality traits. Not only have these numbers increased over the past 4 years (15 to 20 percent per year), so have the pieces of information gathered in all phases of the program to make selection decisions keenly focused on Oklahoma's wheat industry. Expansion of the breeding program could not have been possible without the continued investment of wheat producers through the Oklahoma Wheat Commission and the Oklahoma Wheat Research Foundation.

With that expansion has come output, in the form of 2 new hard red winter (HRW) wheat varieties named Endurance and Deliver. Endurance gives producers statewide an edge on grain production without taking it on the chin should they decide to graze their winter pasture. Moreover, this variety allows extended winter grazing because its arrival at first hollow stem stage is about 2 weeks later than early varieties. With Deliver, we took away the awns, but left the performance level that producers and processors expect. Deliver has a tremendous track record in the breeding program for protection

against Oklahoma's toughest diseases – wheat soilborne mosaic, stripe rust, leaf rust, and Septoria leaf blotch – and for its “show wheat” characteristics out of the combine.

Perhaps nothing has grabbed the WIT's attention more than the flurry of foliar diseases across the southern Great Plains in recent years. With no let up in the 2003-2004 crop year for leaf rust, stripe rust, and powdery mildew, the time was right for a check-up on our more advanced breeding lines (about 150) already planted for 2005 testing. The results (Figure 2) reinforce the WIT's dedication to carry forward lines

resistant to those diseases, including wheat soilborne mosaic virus. More than one-half of our breeding lines carry an effective level of resistance to any of the 4 diseases based on reactions surveyed in the state in 2004. Leaf rust readings also were collected in Texas in 2004, a much more severe environment than what is typically encountered in Oklahoma, where about one-third of these lines still showed a favorable reaction. Resistance in the seedling stage might be considered “icing on the cake” that reinforces the type of resistance targeted in the adult plant.



**Figure 2. Foliar diseases resistance was a high priority among 150 advanced lines carried forward from 2004.**

The WIT will not rest with the release of Endurance and Deliver. Four years has passed since the release of Intrada, Oklahoma's first hard white (HW) wheat variety. A replacement clearly lies in sight, but in different directions. Our first option is OK00618W, which originated from one of the first hard white crosses performed at OSU between two experimental wheats later to be named Intrada and Platte. OK00618W is positioned specifically for the Panhandle. Expect the same superb test weight patterns as with Intrada but at a substantially higher yield level. Our second option, OK98G508W-4C04, stretches farther into central Oklahoma and has parentage similar to Trego. Both candidates are well adapted to dual-

purpose and grain only management systems. Foundation seed is currently being produced, anticipating a release of one of these lines in early 2005.

The horizon has room for yet another candidate variety, equipped with the CLEARFIELD genetic system for weed control, named OK02909C. The 2003-2004 crop year pushed this line to the top of the heap at the Expanded Wheat Pasture Center near Marshall, where it surpassed all advanced breeding lines for grain yield after grazing. Expect to learn more about this candidate in the OSU Wheat Variety Trials scheduled for 2005, and as the WIT prepares a case for its release. Table 1 summarizes the action taken on these and other candidate varieties tested in 2004.

**Table 1. Candidate HRW wheat varieties tested in 2003-2004.**

Selection	Action	Pedigree	Comments
OK00618W	Advance	Intrada/Platte	HW with superlative yield and test weight in the Panhandle. Inconsistent baking quality outside area of adaptation.
OK98G508W-4C04	Advance	Rio Blanco/ KSWGRC10	HW with broader adaptation, lower test weight, and larger kernel size than OK00618W. Same yield. Excellent stay-green.
OK00611W	Continue	KSWGRC39/Jagger	HW for central Oklahoma with sprouting resistance and high test weight. Yield fell off in 2004. Resistant to WSBMV, stripe rust, and low pH. Intermediate leaf rust resistance.
OK02909C	Advance	TAM 110-FS4/2174	CLEARFIELD HRW, with statewide adaptation. Excellent stay-green but moderately susceptible to leaf rust. Exceptional yield recovery after grazing. Larger kernels and lower test weight than 2174. Biggest blemish is WSBMV susceptibility.
OK00514	Advance	KSWGRC39/Jagger	HRW sister to OK00611W. Premium milling and baking quality and best fit for grain only systems in central Oklahoma. Durability of leaf rust resistance in question. Yielding ability unquestioned.
OK00614	Terminate	OK90604/ Rio Blanco	Excellent foliar disease package and test weight, but lodging too risky to carry forward. Yield hit the floor in 2004.
OK99212	Continue	Tomahawk/ 2174/Tonkawa	Premium HRW quality with dual-purpose dominance. Forage spreads like ivy. Foliar disease package better-than-average. Will hold for 1 year for further yield comparisons.

# Development of a Biocontrol System for Wheat Leaf Rust

Michael Anderson  
Plant and Soil Sciences

Bob Hunger  
Entomology and Plant Pathology

## *2003-2004 progress made possible through OWRF/OWC support*

- Application of the biocontrol agent reduced rust by 80 percent in greenhouse trials.
- Several formulations were tested in the greenhouse. The best control was obtained when using the bacterial growth media.
- Time course studies indicated that the biocontrol agent was stable and effective on the leaf surface for at least 7 days before rust spore inoculation.
- When tested in the field, no reduction was evident for 2003 and 2004. Reasons for this could be: insufficient leaf coverage, lack of rain fastness in the formulation, or application issues arising from the complicated dynamics of rust infection processes in the field.

Leaf rust is a major disease in wheat producing areas that results in significant economic loss to producers and rural economies in Oklahoma and throughout the Midwest. Historical losses have been as high as 50 percent of the wheat crop, but because of the introduction of modern resistant varieties, these losses have declined substantially in recent years. Over the last 14 years, Oklahoma lost an average of 2.5 percent of the total crop to leaf rust, representing about 4.5 million bushels per year. However, this average is misleading, because in certain years losses were significantly higher. For example, in 1985 an estimated 12 million

bushels, representing 12 percent of the wheat crop, were lost to the disease. In the same year, Texas lost an estimated 73 million bushels, representing 28 percent of their total production. Although resistant cultivars have reduced the danger to historic epidemics, this disease continues to be one of the great threats to the economic sustainability of wheat production in Oklahoma.

Frequent, large-scale mutation creates tremendous genetic diversity within the rust spore population over time and geographic location. The rust spore population has diversified in time to produce many races capable of overcoming most, if not all, plant

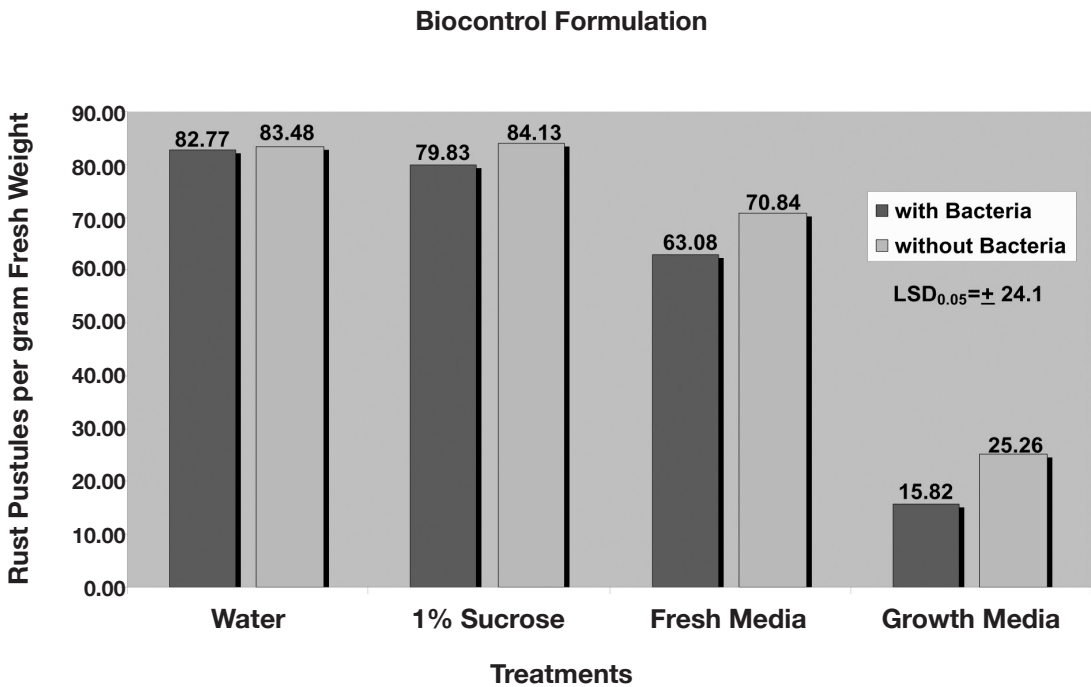
resistance mechanisms. Resistance to rust infection is the major barrier that keeps farmers from returning to historical epidemic losses. However, because of the tremendous diversity within the rust population, these resistance genes are frequently overcome within 2 or 3 years of their introduction. Limiting losses to leaf rust depends on the ability of plant breeders and pathologists to quickly identify new resistance genes and incorporate these genes into adapted wheat cultivars. So far this system has worked remarkably well, but we need to investigate additional control options to guard against a potential historic breakdown in the current rust protection system.

Microorganisms are known to produce antibiotics that inhibit plant pathogens. The use of microorganisms to control plant diseases is known as biocontrol. At least 3 examples of successful reduction of rust disease using biocontrol have been documented. These include: application of compounds known as exopolysaccharides from *Xanthomonas campestris* to control coffee rust, application of *Pseudomonas putida* to wheat rust, and application of a *Bacillus subtilis* strain to bean rust. The latter reduced rust pustules by 95 percent probably due to the release of a thermostable compound that inhibited rust development. We discovered a novel *Bacillus* spp. strain that completely inhibits rust spore germination. The same agent inhibits the growth of other fungi by the secretion of a series of thermostable antibiotics. To date, we have identified and characterized 3 antibiotics from this strain with known antifungal activity.

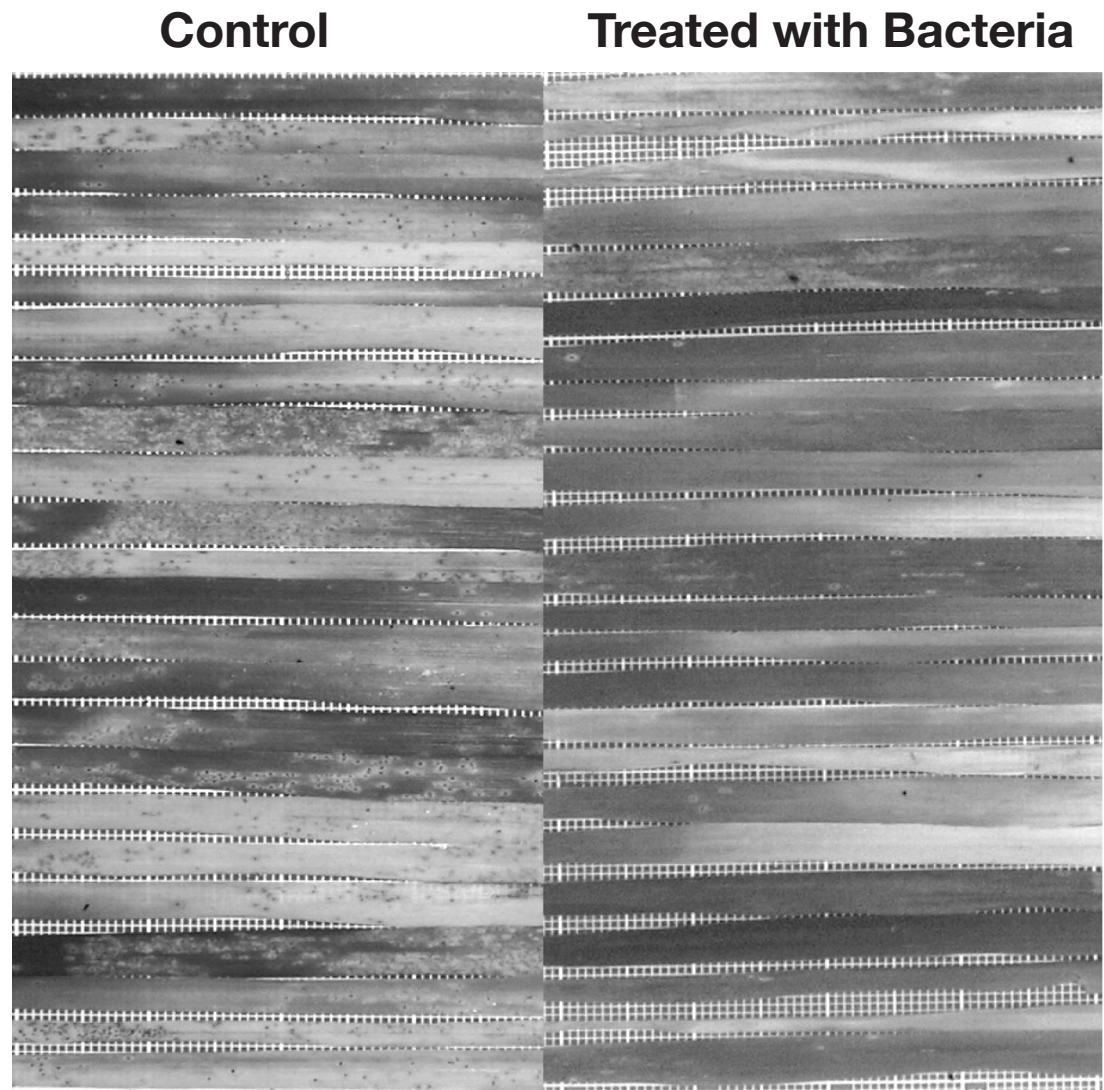
Applying our bacterium to wheat leaves was effective in eliminating almost all subsequent rust spore germination. Recently, we applied the bacterium to wheat shoots growing in the greenhouse using several different formulations. The formulations included a detergent to aid in spreading nutrients to encourage bacterial growth with corresponding controls. Application was conducted using the dip method, which ensured that the entire leaf surface was covered. Results indicated that up to 80 percent control can be expected from the application of the growth media and bacteria (Figure 1) after a single exposure to leaf rust spores. Further experiments were conducted to determine the effective stability time for the biocontrol agent on the leaf surface under greenhouse conditions. The rust spores in a single application were applied 3 days before, during, 1 day after, 3 days after, 7 days after, and 14 days after application of the biocontrol agent. It was determined that the biocontrol agent was stable and effective on the leaf surface for at least 7 days under greenhouse conditions (Figure 2).

In the springs of 2003 and 2004, we applied the biocontrol agent to field plots at the OSU Plant Pathology Farm. Results indicated there were no differences in rust disease or differences in grain yield due to application of the biocontrol agent. The discrepancies between the greenhouse results, which represent the potential level of control, and the field results need further investigation. The differences can be attributed to either inadequate leaf coverage by the spraying system in the field, lack of stability under field conditions (rain, etc.), or lack

of effectiveness under continuous inoculation events as occurs under field conditions. Use of improved formulations could be effective in enhancing the level of activity in the field. Field plots and greenhouse studies are currently in progress to resolve these questions. Ultimately, we hope to design a strategy to reduce dependence on plant resistance and provide additional alternatives for the control of this formidable disease.



**Figure 1. Formulation study of biocontrol effectiveness in the greenhouse.** The biocontrol bacterium was grown in an optimized formulation referred to as the original growth media. While growing, the antifungal bacterium excreted into the growth media several antibiotics that inhibit rust spore germination. The bacteria were removed from the original growth media containing the antibiotics and added to 1 of 4 formulations: water, 1 percent sucrose solution, and fresh media (without antibiotics). Fresh media was the same as the original growth media, but was never used to grow the bacterium and therefore lacked antibiotics. The fourth treatment referred to as growth media was made by adding bacteria back to the original growth media that contained the antibiotics. Each of the four formulations were tested without bacteria for a total of 8 treatments. These media formulations allowed us to distinguish between the activities of bacterium alone versus the activities of the secreted antibiotics. The formulations were applied to the leaves. After air drying, the leaves were inoculated with rust spores to initiate infection. Fourteen days later, the leaves were harvested, photographed, and rust pustules counted. Results indicated that the antibiotics in the original growth media were effective in significantly reducing infection by more than 80 percent. Leaves inoculated with the bacteria alone, without the antibiotics, showed no significant net inhibition.



**Figure 2. Wheat plants were treated (right panel) or not treated (control, left panel) with bacteria plus growth media and then inoculated 7 days later with rust spores. Results show few pustules in leaves treated with bacteria plus growth media even with a 7 day exposure prior to inoculation. This indicates that the anti-rust activity is stable for at least 7 days under greenhouse conditions.**

# Economic Thresholds for Aphids on Wheat Forage

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in cooperation with

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Francis Epplin, Agricultural Economics;

and Norm Elliott, USDA-ARS, Stillwater

## *2003-2004 progress made possible through OWRP/OWC support*

- For every bird-cherry oat aphid (BCOA) per wheat tiller prior to putting cattle out to pasture, an average of 13 pounds of dry matter forage are lost per acre.
- Depending upon expected forage production in wheat pastures, between 10 and 30 BCOA per tiller cause a 25 percent reduction in usable forage.
- Based on daily weight gain expectations for cattle on wheat pasture, this 25 percent reduction in usable forage causes \$6.67 to \$12 in losses per acre.
- If aphids are allowed to increase above 30 BCOA per tiller prior to grazing, they can affect forage yields and may significantly affect daily beef gains.
- In dual-purpose systems, early aphid infestations also will significantly reduce grain yields.
- The additional presence of barley yellow dwarf virus during autumn does not significantly affect forage yields, but causes severe yield losses in dual-purpose systems.

Grazed wheat production systems in the Southern Plains require that fields are planted in early- to mid-September to optimize forage production and subsequent weight gain for cattle. Planting wheat early frequently leads to increased populations of aphids, primarily greenbug and bird-cherry-oat aphid (BCOA). Economic losses attributable to aphids have only been calculated for grain production systems. In Oklahoma, annual losses from aphid pests in wheat grain systems vary from one-half to \$135 million. However, based on our field research, infestations of both greenbugs and BCOA also can reduce forage yields and quality. Based on several years of

field sampling, BCOA is very common during autumn and appears to be the biggest threat to forage production in wheat grazing systems. We have been concerned that producers who graze their wheat pastures may be ignoring the effects of BCOA on wheat forage because plants remain green and look healthy when light to moderate infestations occur. Another critical missing component of effective aphid management has to do with the lack of management recommendations for the aphid-barley yellow dwarf virus (BYDV) complex.

In an effort to evaluate these concerns, the effect of BCOA with and without BYDV on winter wheat forage production and

resulting yields were evaluated. Separate fall and spring BCOA infestations were evaluated in 1 by 1 meter caged plots over a 2-year period.

Our results demonstrated that increasing fall infestations of BCOA reduce forage yields, protein levels, and digestibility. According to our data, for every BCOA per wheat tiller prior to putting cattle out to pasture, an average of 13 pounds of dry-matter forage are lost per acre. Crude protein levels are slightly reduced as BCOA levels per tiller increase, however, not below critical levels. Increasing levels of BCOA during the fall or spring significantly reduce yields. As expected, grain yields in plots with BCOA-BYDV complex were the most significantly reduced. Grain yields in plots infested by BCOA and/or BYDV during the spring were reduced compared to controls, but not as much as plots with autumn infestations.

Our initial calculations of expected losses caused by BCOA in grazing systems are based on the assumption that prices for standing fall-winter wheat forage are not routinely reported. However, some wheat producers lease their pasture to livestock owners, and in informal surveys, farmers report an average lease rate of \$0.32 per pound of beef gain for winter wheat pasture<sup>1,2</sup>. In these lease arrangements, payments from livestock owners to wheat producers are based on net live weight gain attributable to the wheat pasture. These lease arrangements are made based on price expectations and are typically not changed if the price of cattle increases or decreases beyond the expected levels.

One reasonable method to estimate the value per acre of the forage lost to BCOA is to determine the dry matter loss per acre, divide by 10 or 12 to obtain an estimate of the pounds of weight gain or loss per acre, and then multiple by \$0.32. For example, if

the forage when the animals were placed on wheat is 1,000; 1,250; or 1,500 pounds per acre, and if these values were reduced by 25 percent, the estimated forage lost to aphids is 250, 312, and 375 pounds per acre. Based upon the assumption that 12 pounds of forage are required per pound of gain, the estimated weight gain loss is 21, 26, and 31 pounds. Given the lease value of \$0.32 per pound of gain, the loss per acre is \$6.67, \$8.33, and \$10. If a pound of gain requires only 10 pounds of forage, the cost estimate is \$8, \$10, and \$12 per acre for 250, 312, and 375 pounds per acre loss.

Based on the above calculations, as BCOA approach levels that cause a 25 percent reduction in forage yields, most insecticide choices that prevent further aphid increases would be economically justified. One of the obvious shortcomings of this method is that it assumes that the pasture is sufficiently stocked so that all the forage can be used. If the stocking rate is too low, the excess forage will be lost and be of no value. In well-managed grazing systems we expect that effective and timely aphid control would preserve valuable forage.

Currently, we are continuing to incorporate our data into pest management decision models that will allow Oklahoma wheat producers to cost-effectively manage aphids in pasture only, dual-purpose, and grain only systems.

<sup>1</sup> Doye, D., D. Kletke, and B.L. Fisher. 2003. Oklahoma Pasture Rental Rates: 2002-2003. Current Rep. CR-216. Oklahoma Cooperative Extension Service, Stillwater.

<sup>2</sup> Krenzer, E.G., Jr., A.R. Tarrant, D.J. Bernardo, and G.W. Horn. 1996. An Economic Evaluation of Wheat Cultivars based on Grain and Forage Production. *Journal of Production Agriculture*, 9:66-73.

# Developing Pesticide-free Storage and Handling Systems for Wheat

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in cooperation with

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and Ron Noyes\*, Biosystems and Agricultural Engineering

## *2003-2004 progress made possible through OWRF/OWC support*

- Biologically based Spinosad can protect stored wheat from insects for up to 2 years.
- Bin studies using reduced risk products, diatomaceous earth and methoprene, were established at the OSU Stored Product Research and Education Center (SPREC).
- Computer-controlled aeration system and temperature monitoring installed and running at SPREC.
- Studies with physical exclusion of insects from grain bins show promise for fine mesh screening.
- Ethyl formate, a natural product, shows promise as an organic grain fumigant.

Funding that began in the summer of 2003 helped to complete work in progress and establish new stored wheat research in early 2004. The overall objective of this project is to research and demonstrate non-chemical methods to store grain with minimal or no insect infestation, or to utilize reduced risk materials for stored grain protection that might be considered either organic or essentially

chemical-free as alternatives to the use of traditional chemical insecticides. Here we report on the completion or progress of 5 studies conducted under this project. Most of the work done under this project was performed at the OSU Stored Product Research and Education Center (SPREC).

Spinosad, a product of Dow AgroSciences, is a bacterial fermentation product and has insecticidal properties for many insects. Because it is derived from a naturally occurring bacterium,

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\* Retired

it represents a reduced risk alternative to traditional insecticides such as organophosphates and pyrethroids, and the USDA has accepted its use for organic food production. Prior work showed that Spinosad could kill stored grain insects. In our study at SPREC, we utilized 12 bins that held 170 bushels per bin and filled them with 2002-crop year wheat treated with one of the following: 1 ppm Spinosad, 6 ppm Reldan, a combination of 1 ppm Spinosad plus 3 ppm Reldan, and untreated controls (3 bins per treatment). Reldan is a currently labeled organophosphate grain protectant for wheat that is a target of alternative research. Following exposure to multiple species of stored grain insects, the bins treated with Spinosad failed to support infestations and grain was maintained in good quality for up to 2 years of storage, while bins with other treatments suffered large infestations and drastic losses in quality. Spinosad clearly can be an effective grain protectant while being a very low risk and an alternative to traditional chemicals.

Bin experiments were established in 2004 to evaluate the low-risk material methoprene, which is an insect growth regulator (IGR), and the inert desiccant dust, diatomaceous earth (DE). The IGR treatment was applied to bins as a complete treatment with and without aeration cooling and also as a top-dress only. The DE was applied to bins as a complete treatment, which would be least preferred in practice due to cost and loss of test weight, and as 2 different layered treatments intended to pose a barrier to invading insects while having minimal effect on test weight. Results of both studies will be determined in 2005. A computer-controlled automated aeration and

grain temperature management system was installed on the experimental bins at SPREC and used as part of the IGR study. Through automatic actuation of fans during certain cool nights, bins with automatic aeration achieved grain temperatures about 30°F cooler than untreated bins by September 2004. This work demonstrates the effectiveness and economy of summer aeration to cool grain and reduce insect infestation early in the storage season.

Laboratory and field trials were conducted in 2004 on the use of sealing and screen mesh applied to bin vents for physical exclusion of several insect species from stored wheat. In the laboratory, we tested stainless steel screens that were 40-mesh, 80-mesh, and 150-mesh for their ability to prevent passage of adults and immatures of 4 species of pest insects between containers of uninfested and infested wheat. Screens of 80-mesh and 150-mesh had a significant effect of preventing passage of insects. A small-scale field study was conducted with 15 bins that each held 57 bushels of wheat and were sealed with silicone caulk and had either open roof vents or vents screened with 127-mesh nylon screen or 150-mesh steel screen. Bins were exposed to naturally occurring insect pressure for 2 months and the grain was sampled for insects. Both the nylon and steel screens prevented entry of the lesser grain borer compared to unscreened bins. Continued studies with vent screening will examine the effects of screening on bin aeration, and may result in a chemical-free preventive measure for excluding insects from stored wheat.

Chemical fumigant gases such as phosphine and methyl bromide are dangerous and cannot be used for organically produced grains. Ethyl

formate is a naturally occurring volatile in some grains, fruits, and vegetables that is insecticidal; it is exempt from a requirement of a tolerance by the Environmental Protection Agency and it is considered GRAS (generally regarded as safe) as a food additive. Laboratory studies found that the most tolerant life stages of key stored grain pests could be killed with exposure to ethyl

formate. Mortality could be increased by increasing temperature and by being used in a combination treatment with a partial vacuum. Ethyl formate formulated with carbon dioxide will be tested in the future under commercial conditions. Ethyl formate may offer a low risk, natural product alternative to traditional chemical insecticides for commodity disinfestation.

# Notill versus Conventional Wheat – Second Year Results

Deena Morley and Tom Peeper  
Plant and Soil Sciences

## *2003-2004 progress made possible through OWRP/OWC support*

- Compared to conventional tillage, notill wheat substantially increases wheat forage production.
- Notill production decreased wheat grain yields the first year, but by the second year, yields with notill were much closer to yields with conventional tillage.
- Recent price increases for fuel and steel will likely increase interest in notill wheat.

Driving across Oklahoma it is easy to see that more and more wheat growers are trying notill wheat. The first growers to adopt notill wheat were primarily interested only in growing wheat to run stockers. They have found, as we have, that early seeded wheat grows well in notill and cattle do not bog down nearly as bad in notill fields as in conventional tilled fields. When the fall is relatively wet the difference is very obvious.

Over the years, many of the problems with notill have been resolved. Today, notill seeding equipment is much better, herbicides are available for winter grass weed control, the cost for summer weed control has gone down, and most combines have good straw choppers and chaff spreaders. These technological advances have made notill easier to adopt. Recent increases in diesel prices also will give notill a big push next year. As the advantages of notill become obvious, more growers, who want both grazing and grain, are trying notill.

Therefore, in the summer of 2002, after considerable discussion with several wheat growers and the Oklahoma Wheat Commission,

a cooperative on-farm project was initiated to look at forage and grain production with various production systems. Each production test was carried out using both conventional and notill. The first 2 production systems involved planting wheat only for cattle. Each year it is planted the first week of September, grazed from fall until March, and then cut for hay in late April or early May. In one of the production systems, German foxtail millet is planted soon after the wheat hay is removed and the millet is cut for hay when it heads out. The millet is followed by early seeded wheat again.

The next 2 production systems are wheat pasture plus grain. The difference in these 2 is whether the emphasis would be on wheat pasture or a more traditional approach of grazing plus grain. To emphasize wheat pasture, we planted the first week of September. For the more traditional approach, we planted September 20 through 24. These plots were grazed until early March. The stockers were then removed by our farmer-cooperators and the wheat was cut for grain.

Our last production system is to grow wheat for grain only. These plots are seeded from October 10 to 15 and electric fences are used to keep calves out of the wheat.

We started the experiments by either cutting wheat for hay in May 2002 or grain in June 2002. Millet was grown on appropriate plots in the summer of 2002 and again in 2003 and 2004. Wheat forage is estimated by clipping small areas in November before the stockers are turned out onto the fields. Wheat was again either cut for hay or grain in 2003 and 2004. These experiments are continuing this fall with the same treatments on the same plots. All plots receive 100 lbs of Nitrogen (N) and 24 pounds of Phosphorus (P). Grazed plots are also topdressed with 65 pounds per acre of N. Certified Ok101 wheat is planted at all sites at 90 pounds per acre. Millet plots also receive additional N fertilizer.

## Results to Date

First, look at the 2 systems set up for forage production only. Averaged over 3 locations (near Cherokee, Hunter, and Loyal) and 3 years, the foxtail millet hay yields have been 3,860 pounds per acre per year in conventional tillage and 4,220 in notill. That is about a 9 percent yield advantage for notill (Table 1). Looking at the wheat pasture available in November, when no millet was planted in the summer, forage growth in notill has exceeded forage growth in conventional till by 33 percent. Therefore, it is easy to see why growers interested only in wheat pasture are quickly adopting notill. Planting millet in the summer has reduced fall wheat pasture and the effect seemed stronger in the fall of 2002 than in 2003, probably because of differences in rainfall.

The first year, grain yields were lower with notill. However, the second

harvest showed that the yield gap was closing. For example, with wheat planted September 4 through 6 and grazed from November to early March, the first year notill reduced grain yield by 7.7 bushels per acre. In the second year, notill and conventional till yields were about equal. With October seeded wheat, notill reduced yield 8 bushels per acre the first year, but the second year notill and conventional till yields were about equal. We have often heard that it takes about 3 years for notill fields to "level out" and start yielding as good as conventional till. We are waiting to see what happens with the 2004-2005 crop. Also, there are distinct differences among the sites that may be related to pH and soil type. Additional data analysis is required to sort that out.

Test weight has not been good either year. In 2003, test weights were a little lower in notill plots, whereas in 2004, the notill plots had slightly higher test weights. Due to light test weights, grade also has not been good. However, for purposes of determining what the impact of notill will be, it is important to note that by the second year, notill is not negatively affecting test weight or grade.

Where do we go from here? It is obvious there is a place for notill wheat in Oklahoma, particularly for the stocker operator. We plan to obtain data on the third wheat crop in 2005. We, along with our cooperators, are aware that long-term notill wheat may increase foliar diseases and grass weeds. Therefore, we incorporated winter canola into the experiments this year to determine whether a rotation with winter canola provides an advantage for weed and pest management in the wheat. Also, Francis Epplin, agricultural economics, and his assistants will be completing a thorough economic analysis of the data, to compare notill and conventional tillage.

**Table 1: Effect of conventional tillage (CT) versus no till (NT) and seeding date on forage and grain production where the production systems were: forage only, dual-purpose, or grain only. Average of three locations (Cherokee, Loyal, and Hunter).**

Tillage Practice	Planting dates and Production objective	Millet Forage <sup>*</sup> Lbs/A	Wheat Forage <sup>**</sup> Lbs/A	Wheat Hay Lbs/A	Wheat <sup>***</sup> Yield Bu/A '02-'03 '03-'04	Wheat Test Wt. '02-'03 '03-'04	Wheat Grade '02-'03 '03-'04	Wheat Protein % '02-'03 '03-'04
CT	Wheat planted Sept. 4-6 Graze + Wheat hay		1610 ('02) 1720 ('03)	5020 ('03) 9700 ('04)				
CT	Millet planted May 14-22 Wheat planted Sept. 4-6 Graze + Wheat hay + Millet hay	4250 ('02) 3690 ('03) 3645 ('04)	1300 ('02) 1575 ('03)	5040 ('03) 8980 ('04)				
CT	Wheat planted Sept. 4-6 Graze + Grain		2290 ('02) 1770 ('03)		46.1(G) 52.6(U)	58.7 57.9	2.0 2.4	11.7 12.9
CT	Wheat planted Sept. 20-24 Graze + Grain		1025 ('02) 725 ('03)		51.0(G) 55.9(U)	58.9 57.6	1.9 2.7	12.3 13.1
CT	Wheat planted Oct. 11-15 Grain only				43.0 47.3	58.2 57.0	2.3 3.0	11.7 13.2
NT	Wheat planted Sept. 4-6 Graze + Wheat hay		2370 ('02) 2140 ('03)	5930 ('03) 8995 ('04)				
NT	Millet planted May 14-22 Wheat planted Sept. 4-6 Graze + Wheat hay + Millet hay	4880 ('02) 3090 ('03) 4700 ('04)	1370 ('02) 1940 ('03)	4890 ('03) 8740 ('04)				
NT	Wheat planted Sept. 4-6 Graze + Grain		2830 ('02) 2140 ('03)		38.4(G) 43.6(U)	57.1 58.5	2.8 2.2	11.7 12.2
NT	Wheat planted Sept. 20-24 Graze + Grain		970 ('02) 900 ('03)		43.5(G) 47.2(U)	58.2 59.0	2.5 1.9	12 12.6
NT	Wheat planted Oct. 11-15 Grain only				35.0 47.6	58.4 58.3	2.1 2.3	12 12.4

<sup>\*</sup> Millet forage is pounds of dry matter per acre, including weeds present

<sup>\*\*</sup> Wheat forage present when stockers were turned onto the field in November (pounds of dry matter per acre)

<sup>\*\*\*</sup> G = Yield from grazed part of each plot and U = Yield from ungrazed part of each plot.

# Development of a Weather-based Model for Predicting First Hollow Stem in Winter Wheat

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## *2003-2004 progress made possible through OWRF/OWC support*

- Ten years (1995-2004) of first hollow stem (FHS) observations from Marshall and Stillwater were assembled and grouped by variety into 3 categories based on occurrence of FHS.
- For each category, ranges of 28 to 29 days between the earliest and latest FHS dates were observed over the 10-year period.
- Daily weather/soil data from the Marshall and Stillwater Mesonet sites were assembled over this 10-year period; variables for analysis include air and soil temperatures, solar radiation, rainfall, and evapotranspiration.
- To aid in model development, software was designed to calculate cumulative variables from these daily data.

Past research<sup>1</sup> has shown the importance of first hollow stem (FHS), a particular growth stage of winter wheat, as an indicator of when to remove cattle from grazed wheat fields in order to maximize economic return. FHS is the stage at which hollow stem (about half an inch in length) can first be identified above the crown; this stage occurs prior to the growing point reaching the soil surface. Ten years of FHS observations have shown that this

stage occurs in the February to March time frame in Oklahoma, depending on variety and the preceding weather conditions. Research has shown that grain yield decreases dramatically (a daily decrease of 1.25 bushels per acre) as cattle are left on grazed wheat fields after the occurrence of FHS in ungrazed sections. For example, during the 1991-1992 season, a producer who would have allowed cattle to graze until March 15, a typical date used in Oklahoma, would have lost about 19 bushels per acre of wheat grain.

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\* Retired

The purpose of this multi-year project is to develop a weather-based model to predict FHS in winter wheat, with a view toward implementation of this model on the Oklahoma Mesonet (<http://agweather.mesonet.org>), the statewide-automated weather station network whose products are available in near real time. Such a product would constitute an important management tool for producers who use winter wheat as a dual-purpose crop because it would provide guidance as to when to remove cattle from grazed fields so potential wheat yield is not endangered.

To develop any model, observations are needed of the quantity one is trying to predict. In this case, we started with 10 years of FHS observations (calendar dates of first appearance) from wheat variety trials at Marshall (four seasons: 1994-1995 through 1997-1998) and Stillwater (six seasons: 1998-1999 through 2003-2004). For purposes of this research study, wheat varieties are grouped into three categories with respect to appearance of FHS (early, middle, and late). Early varieties are represented by Jagger; middle, by Custer and Ok101; and late, by Ike, 2174, and Ok102.

Figures 1 through 3 show the dates of FHS occurrence at Marshall and Stillwater over the 10-year period for the early FHS group (Figure 1), the middle FHS group (Figure 2), and the late FHS group (Figure 3). The early FHS varieties had an average FHS date of March 2, while the middle FHS varieties had an average date of March 8, and the late FHS varieties, an average date of March 16. Note, however, the wide variability about these average dates (ranges of 28 to 29 days between the earliest and latest FHS dates over the 10 years). Thus, if a producer used the "calendar date"

method of removing cattle, in any given year he or she could be off as much as 2 to 3 weeks. For example, in 1998 for the late FHS varieties, if a grower removed cattle via the "calendar method," using March 16 as the date, FHS that year would have occurred 16 days earlier. Based on the research noted above, that would represent a grain yield loss of about 20 bushels per acre.

Since the occurrence of FHS is weather-dependent and varies greatly from year to year, if there were a weather-based model to better predict the FHS date in any given year, a producer would have a management tool for removing cattle that might improve upon the "calendar date" method. For each category of wheat variety, we seek to develop an optimal weather-based model to predict the calendar date of FHS appearance.

Over the past year of this project, Mesonet weather and soil data from the Marshall and Stillwater towers were used (and software written) to assemble "cumulative" weather and soil-based variables from a range of "start dates" (December 1, January 1, and February 1). The idea is to explore which are the important weather/soil factors over a given period of time in the development of FHS and what that period of time optimally is. The chosen factors (variables) are calculated from daily Mesonet air and soil temperatures, daily solar radiation, daily rainfall, and daily evapotranspiration of the wheat plant. Air and soil temperatures are used to calculate daily degree days (a measure of heat accumulation above a threshold temperature – currently, we are investigating 32°F, since this is what the literature suggests). These daily quantities are then accumulated from a given start date.

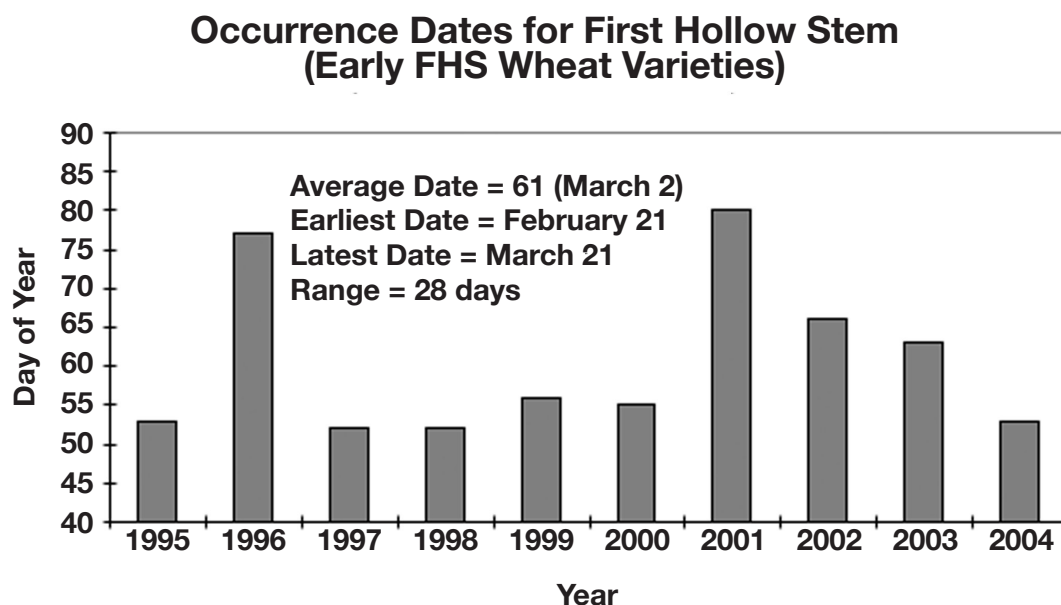
Over the next year of the project, the focus will be on model development with a goal of developing optimal models for each FHS wheat variety category. We will investigate different “start dates” as well as different threshold temperatures for degree-day calculation. The “optimal” model for a given wheat variety category will be the model that minimizes the standard deviation (in days) of the difference between predicted and actual FHS dates. We also will seek a model that minimizes the over-prediction of the FHS date, since that is detrimental to wheat grain yield.

In 2005, in conjunction with Jeff Edwards in Plant and Soil Sciences, we also will continue the FHS scouting program, which was active this past season. In addition to intensive scouting at Goodwell, we had volunteer observations from

Oklahoma Cooperative Extension Service educators at El Reno and Altus, as well as observations from the Noble Research Foundation at Ardmore. Stillwater data also will continue to be collected. We intend to use these FHS data sets on testing the models in other areas of the state.

After optimal weather-based models are developed and tested, we plan to integrate them with the Oklahoma Mesonet for real-time access over the Internet by producers. Optimistically, assuming success in model development, such a product might be ready in time for the 2005-2006 growing season (FHS dates in 2006).

<sup>1</sup> Redmon, L.A., E.G. Krenzer, Jr., D.J. Bernardo, and G.W. Horn, 1996. Effect of Wheat Morphological Stage at Grazing Termination on Economic Return. *Agronomy Journal*, 88:94-97.



**Figure 1. Occurrence dates for FHS at Marshall (1995-1998) and Stillwater (1999-2004) for an early FHS variety (Jagger).**

### Occurrence Dates for First Hollow Stem (Middle FHS Wheat Varieties)

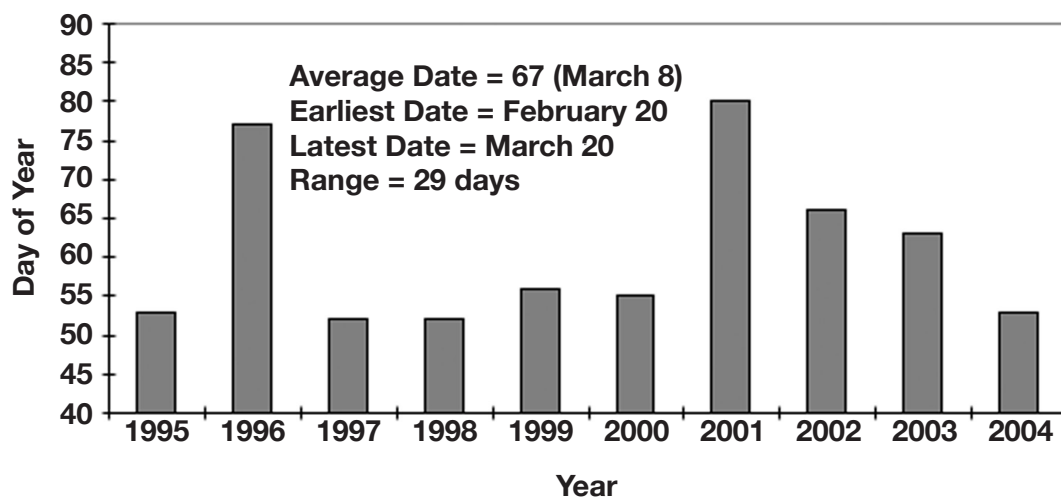


Figure 2. Occurrence dates for FHS at Marshall (1995-1998) and Stillwater (1999-2004) for middle FHS varieties (Custer, Ok101).

### Occurrence Dates for First Hollow Stem (Late FHS Wheat Varieties)

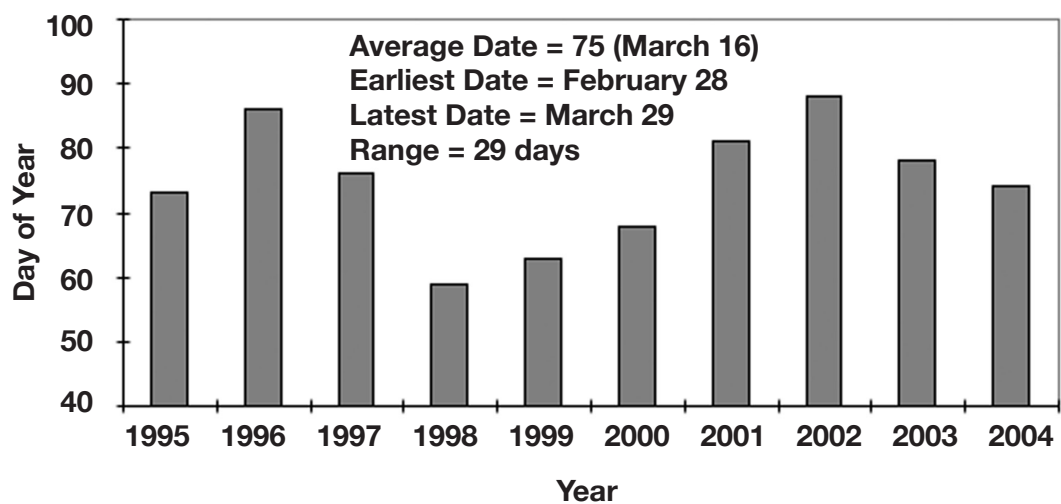


Figure 3. Occurrence dates for FHS at Marshall (1995-1998) and Stillwater (1999-2004) for late FHS varieties (Ike, 2174, Ok102).

# Value-added Product Development from Wheat Milling Industry By-products

Nurhan Turgut Dunford  
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*2003-2004 progress made possible through OWRF/OWC support*

- Wheat germ oil and straw contain a substantial amount of policosanol (PC).
- Bran fractions of Trego and Intrada wheat varieties have significantly higher PC content than that of the other wheat varieties.
- Wheat germ oil and wheat straw may be alternative sources for obtaining PC to be used in dietary supplements and pharmaceuticals.

Commonly, wheat is grown for its flour (protein and starch). Numerous research studies have been conducted on the composition and properties of wheat flour. However, by-products of the wheat milling industry have not yet been fully exploited. Various forms of bran, wheat germ, and the “clean-out” of the cleaning house or screen room are by-products of the wheat milling operations. As these products may represent about 25 percent of the original grain, they are of considerable economic significance to the miller.

Policosanol (PC) is a mixture of high molecular weight aliphatic primary alcohols. Wheat germ oil (WGO) has been reported to improve human physical fitness and this effect is attributed to its high PC, specifically its high octacosanol (OC) content. There are numerous research studies indicating that 5 to 20 mg per day PC consumption is effective in lowering total cholesterol (by 17 to 21 percent),

and low-density lipoprotein (LDL) (21 to 29 percent) levels, and increasing high-density lipoprotein (HDL) (8 to 15 percent). This is accomplished both by inhibiting cholesterol synthesis and increasing LDL processing. There also is scientific evidence that PC has additional beneficial effects on smooth muscle cell proliferation, reducing platelet aggregation, and LDL peroxidation. Policosanol formulations also are being used as “antifatigue drugs.” One study carried out with tail-suspended rats indicated that OC could counteract some effects of simulated weightlessness on rats, suggesting that OC enriched foods might benefit astronauts during space travel.

Today, there are several companies producing dietary supplements containing PC as their main ingredient. Currently, beeswax and sugar cane are the main sources of PC. Although WGO contains PC, to our knowledge there is no commercial product containing

wheat PC. The main objective of this research is to determine PC and OC concentrations in WGO, various wheat fractions, and wheat varieties grown in Oklahoma.

Wheat fractions (germ, bran, shorts, flour) used in this study were obtained from ADM Milling Corp. (Enid, Oklahoma). Thirty-one hard red and white winter wheat varieties also were examined. These varieties were Intrada, Above, Cutter, Jagalene, TAM 302, Coronado, Custer, Kalvesta, Enhancer, Ok101, Thunderbolt, Cisco, Chisholm, Trego, Avalanche, Jagger, Dumas, Triumph 64, AP502CL, Lakin, OK94P549-11, TAM 110, Venango, Cossack, TAM 111, G1878, Ok102, WT3P1, 2174, 2137, and 2145. All of these wheat varieties were grown at the Oklahoma State University Agronomy Research Station under identical growing conditions and management. Wheat grain samples for each variety were milled to separate bran and endosperm fractions. Each fraction was analyzed for its PC content and composition. A gas chromatograph coupled with a mass spectrometer system were used for PC analysis.

PC compositions of wheat fractions and WGO are given in Table 1. The solid fraction that precipitated at the bottom of the container containing WGO (crude WGO-solids) had the highest amount of total PC. The PC content of the clear WGO (oil above the precipitate) was about 17 times smaller than that of the WGO solids/precipitate. Wheat straw contained significantly higher total PC content as compared to that of the other wheat milling fractions (wheat

bran, germ, shorts, flour). This result was expected since PC is a part of the protective and waterproofing surface layer, which acts as an interface between plant tissue and the growth environment. The very low (less than 1 mg per kg) PC content of wheat flour can be explained by the association of PC with plant surface layers and other lipophilic plant components rather than inner starchy endosperm. Wheat bran contains a significantly higher amount of PC than the germ. This might be due to the higher oil content of wheat germ extract (about 11 percent weight per weight). Sugar cane is one of the commercial sources for extraction of PC to be used for supplements. The total PC content of sugar cane peel is about 270 mg per kg. This study shows that wheat straw contains about 160 mg per kg, which is the same order of magnitude as the sugar cane PC content. The PC content of wheat varieties varied in the range of 3 to 56 mg per kg. Table 2 shows the PC content and composition of Oklahoma grown wheat varieties containing more than 19 mg per kg PC in the bran fraction. Trego had the highest PC content (about 56 mg per kg) among the 31 wheat varieties examined in this study. The PC content of Intrada bran was also quite high (about 37 mg per kg). Currently, we are working on development of an efficient method for extraction and concentration of PC from the bran fraction of Trego and Intrada varieties.

The experimental results of this study indicate that WGO and wheat straw may be a source for obtaining PC to be used in dietary supplements and pharmaceuticals.

**Table 1: Policosanols content and composition of wheat fractions and wheat germ extracts<sup>1</sup>.**

Sample	Policosanols Amount (mg/kg)					
	C22	C24	C26	C28	C30	Total PC <sup>2</sup>
Crude WGO-solids	47±3	215±10	164±11	127±8	55±3	628±17
Crude WGO-clear oil	2.8±0.3	9.5±0.9	8.1±1.2	8.8±0.4	5.8±0.5	38±2
Wheat Straw	2.6±0.3	10.7±0.9	4.8±0.6	140±5	3.1±0.7	164±5
Wheat Bran	2.73±0.02	10.68±0.01	4.87±0.03	4.39±0.02	n.d.*	29.97±0.06
Wheat Germ	2.8±0.5	1.4±0.2	n.d.*	2.9±0.3	2.5±0.3	10.0±0.7
Wheat Shorts	0.21±0.02	0.82±0.01	0.45±0.03	0.39±0.01	0.22±0.03	3.29±0.08
Wheat Flour	n.d.*	n.d.*	n.d.*	0.17±0.01	n.d.*	0.17±0.01

\* not detected

<sup>1</sup> Docosanols (C22), tetracosanols (C24), hexacosanols (C26), octacosanols (C28), triacontanols (C30), and policosanols (PC).

<sup>2</sup> Total of 9 PC (C20, C21, C22, C23, C24, C26, C27, C28, and C30).

**Table 2: Policosanols content of bran fractions of Oklahoma grown wheat varieties<sup>1</sup>.**

Wheat Variety	Policosanols Amount (mg/kg)					
	C20	C22	C24	C26	C28	Total PC <sup>2</sup>
Cossack	2.4±0.2	1.8±0.2	6.4±0.9	3.6±0.8	2.4±0.3	20.0±1.3
Chisholm	2.37±0.06	2.4±0.4	6.4±1.3	4.8±1.2	1.9±0.2	21.9±1.9
AP502CL	2.1±0.4	3.1±0.3	7.4±0.9	5.6±0.2	2.7±0.4	26.7±1.1
2145	1.66±0.01	3.12±0.09	6.9±0.4	4.3±0.1	3.0±0.3	22.8±0.5
Cutter	1.90±0.06	1.73±0.03	6.2±0.1	4.1±0.1	4.0±0.6	19.9±0.6
Enhancer	2.4±0.3	1.5±0.2	7.0±0.4	4.7±0.4	2.4±0.2	20.5±0.7
Intrada	3.3±0.1	3.0±0.1	5.3±0.2	7.2±0.3	7.7±0.2	37.0±0.5
G1878	3.3±0.1	3.0±0.1	3.5±0.1	5.34±0.07	5.0±0.14	22.9±0.3
OK 101	3.5±0.2	2.34±0.07	4.9±0.2	4.2±0.1	3.42±0.09	21.7±0.4
Trego	4.9±0.2	6.8±0.2	13.8±0.4	13.1±0.4	8.9±0.3	56.1±1.1

<sup>1</sup> Eicosanols (C20), docosanols (C22), tetracosanols (C24), hexacosanols (C26), octacosanols (C28), and policosanols (PC).

<sup>2</sup> Total of 9 PC (C20, C21, C22, C23, C24, C26, C27, C28, and C30).

# Analysis of Farmer-saved Wheat Seed in Oklahoma

Jeff Edwards and Neal Foster  
Plant and Soil Sciences

## *2003-2004 progress made possible through OWRF/OWC support*

- Bin-run wheat seed evaluated in this experiment had poor germination, produced less fall forage, and had lower grain yield than certified wheat seed.
- Contamination with weed seed was a common problem among farmer-saved wheat seed samples.
- Farmers wishing to save wheat seed would benefit from planting areas of certified seed from which to save each year.

The 2003-2004 production year was the second year for the farmer-saved wheat seed experiment and results clearly demonstrated the benefits of planting high-quality wheat seed. Farmer-saved wheat seed has been cleaned to some extent prior to planting compared to bin-run wheat, which is seed that has not been cleaned before being planted. Bin-run wheat has typically been thought of as a “cheap” alternative to buying certified wheat seed, however, results from 2003-2004 clearly demonstrate that bin-run wheat seed is no bargain. Based on the bin-run samples we received, added weed control costs would offset any savings in seed cost associated with using bin-run wheat seed. Cheat was the most common contaminant and contamination ranged from 1 to 2,400 cheat seed per pound of wheat seed. Other contaminants found were jointed goatgrass (3 samples), wild oat (2 samples), rye (2 samples), and rescuegrass (7 samples).

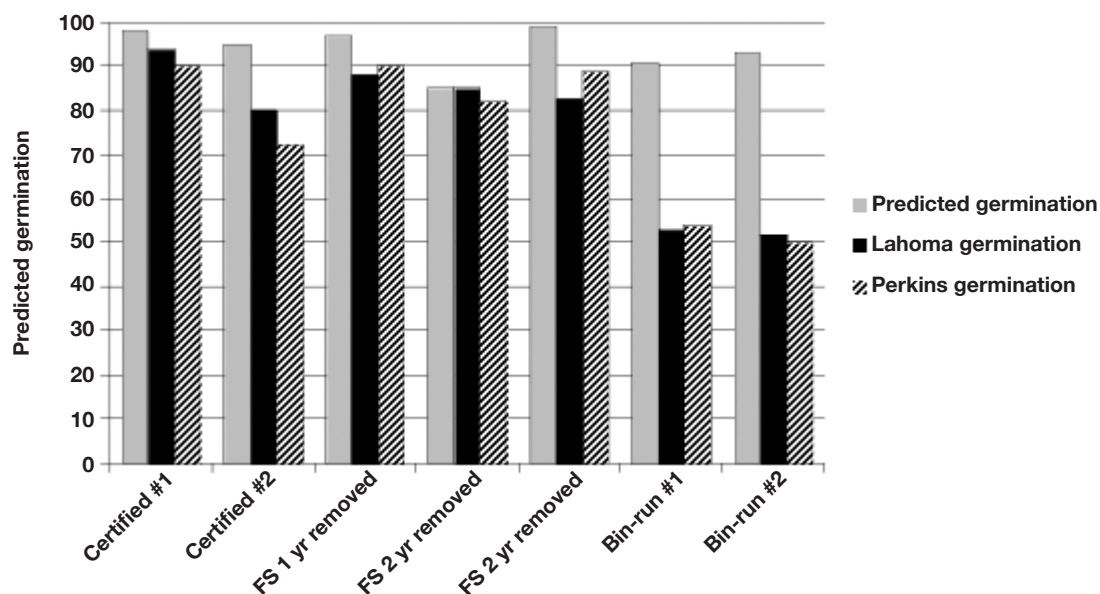
Numerous farmer-saved samples that were believed to be Jagger contained approximately 5 percent of other varieties. In addition, one sample was completely misidentified and another was a 50/50 mix. The problem of seed contamination appeared to increase as the number of generations away from certified seed increased, indicating that variety/purity problems could be reduced by never being more than 1 generation away from certified seed.

Predicted germination (germination in a controlled environment) of bin-run wheat samples was comparable to that of certified seed (approximately 80 percent), but when samples were actually sown in field situations, only 50 percent of bin-run seed germinated (Figure 1). This, along with small seed size, resulted in a 400 to 500 pound decrease in forage production and a 3 to 5 bushel decrease in grain yield for bin-run samples as compared to certified seed (data not shown).

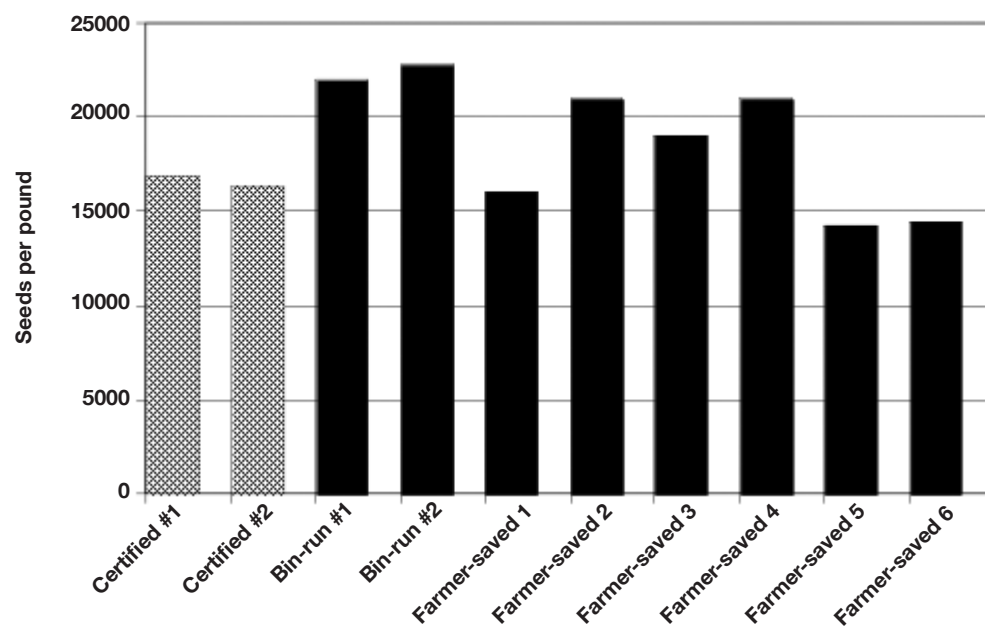
The 2 certified samples had a much larger seed size (approximately 15,000 seeds per pound) than the bin-run samples (greater than 21,000 seeds per pound) and most of the farmer-saved samples (Figure 2). Since these experiments were sown by weight and not seed number, a greater number of seed were planted for the bin-run samples, and, therefore, even at low germination percentages, a sufficient number of plants emerged to ensure adequate forage production and grain yield. Previous research has indicated, however, that larger seed produce more vigorous seedlings and more fall forage.

While this research does not indicate that certified seed always is better than

farmer-saved seed, it does clearly indicate that certified seed is superior to bin-run wheat seed. Growers who previously have chosen to plant bin-run wheat seed could plant a lower seeding rate of certified seed, achieve the same number of emerged plants, and, therefore, the same yield with less hassle and without the introduction of additional weed seed. Trends in the data also indicate that growers wishing to save their own seed would benefit from planting an area of certified seed from which to save each year. This would reduce the amount of comingling of varieties and ensure purity. However, the need is still there for cleaning to ensure that every seed planted is of high quality.



**Figure 1. Germination percentages predicted by laboratory testing as compared to actual germination obtained under field conditions at Lahoma and Perkins, Oklahoma, 2003-2004 for two samples of certified wheat; three farmer-saved (FS) samples, 1 and 2 years removed from certification; and two bin-run wheat samples.**



**Figure 2. Average number of seeds per pound for certified, bin-run, and farmer-saved wheat seed samples in 2003-2004.**

# Phosphorus Requirement for Dual-purpose Wheat

Solomon Kariuki, Hailin Zhang, and Gene Krenzer\*  
Plant and Soil Sciences

*2003-2004 progress made possible through OWRF/OWC support*

- **Phosphorus requirements for broadcast fertilizer appear to be the same for dual-purpose wheat and grain only wheat.**

Current phosphorus calibration for dual-purpose wheat was based on a grain only production system. This study was conducted to investigate whether a unique soil test calibration was needed for dual-purpose wheat to maximize forage yields. First-year results found that in 1 of 3 locations, forage yields increased with increased phosphorus application, even in plots with 100 percent phosphorus sufficiency. However, this information was not reproducible the second year.

The experiment was established in 2003 at Perkins and Lahoma where the soil test phosphorus (STP) index varied from 15 to 80. Currently, phosphorus is not recommended when STP is 65 or above. Phosphorus applied ranged from 0 to 200 pounds per acre with 20 pound increments for dual-purpose wheat. Grain only plot application rates ranged between 0 to 100 pounds per acre. For the dual-purpose experiment, both grain and fall forage were the response

factors, while in grain only plots, grain harvest was analyzed for response to different phosphorus application rates.

In 2004 at both Perkins and Lahoma, no response to phosphorus was observed in either dual-purpose or grain only systems. At Perkins, poor soil drainage and root rot disease may have interfered with wheat response to phosphorus. In contrast, Lahoma had a near perfect stand and growing conditions. Based on these results, there is no apparent difference in broadcast phosphorus requirements for dual-purpose wheat and grain only wheat.

A similar experiment was initiated in 2004 to determine if furrow-applied phosphorus in dual-purpose wheat requires a different calibration curve than the one currently used for broadcast phosphorus in a grain only production system. In this study, all plots are dual-purpose wheat with some having phosphorus applied in the furrow and some broadcast.

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\* Retired

# Optimization of the Study of Protein Analysis from Wheat Prior to Harvest

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Department of Biochemistry and Molecular Biology

## *2003-2004 progress made possible through OWRF/OWC support*

- **Small but significant improvements were made on the reduction of drying time for whole wheat by using a microwave treatment of samples containing more than 15 percent moisture.**
- **Preliminary results suggest that optimization of the microwave treatment (combination of power and time) can yield a practical approach to improving the accuracy of determining protein content by near infrared spectroscopy for a field test.**

The long-term objective of this project is to develop a portable test for estimating the protein content of physiologically mature wheat in the 10 days prior to harvest. At this stage, synthesis of protein and starch are completed and the wheat kernels are drying in the plant. A test that can estimate the protein content of wheat in the field with an acceptable correlation with the dry wheat delivered to the elevator could potentially be used for value discovery of wheat a few days before harvest time.

Last year, it was reported that water content affected the protein determination; when moisture in the wheat kernel was higher than 15 percent, a decrease in the accuracy of the protein determination using a rapid method, near infrared spectroscopy, was observed. This year, a microwave and convection oven were used to dry the wheat kernels exceeding 15 percent moisture. Microwave treatment was

used to accelerate the drying process. An average of 10 percent improvement of the accuracy of protein content determination was observed in samples treated with microwave followed by air-drying using a convection oven. Two watt levels and a control were used in this study. Results were under evaluation at the time of the preparation of this report, but the overall trend is that the higher wattage used produced a shorter drying time in the convection oven. The optimum level of watts to be used needs to be determined for wheat samples at the moisture contents of 15 through 20 percent, representing the moisture levels observed during the last 10 days prior to harvest. After the preliminary results of the 2 watt levels used, collaborative research will be conducted with a private company in the Woodward, Oklahoma, area to determine the optimal drying process by selecting the microwave oven size, power, and drying time.

# A Descriptive Study of Proteins from Wheat Endosperm during Grain Fill

Patricia Rayas Duarte

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Department of Biochemistry and Molecular Biology

*2003-2004 progress made possible through OWRF/OWC support*

- **Methodology for the enrichment of 2 wheat endosperm organelles was developed and optimized.**
- **Two organelles, endoplasmic reticulum and Golgi complex, were obtained through enriched fractionation using a sucrose gradient.**

The long-term objective of this project is to describe all the proteins and their functions that are present in wheat endosperm during the grain fill stage under normal and water stress conditions. Among the specific aims of this project are to perform a descriptive analysis of the proteins present in the wheat endosperm that will help us understand the relationship and possible identification of marker proteins during the active development of grain fill and the quality of wheat. The quality of wheat is associated with specific subunits of gluten proteins, but the presence of these proteins in certain wheat cultivars or breeder lines do not completely explain the performance of the flours obtained from the specific wheat. In an attempt to better understand the basic biochemical processes taking place during the active synthesis and deposition of key proteins during the grain development, the present project was initiated to identify

the proteins found in specific organelles of the endosperm. Using a proteomics approach, endoplasmic reticulum and Golgi complex were identified as the first organelles to study. Proteomics is an area that uses analytical biochemical tools to identify all the proteins present in a system. It is expected that by identifying all the proteins present, some may be participating in complex forms that control a specific cascade of events that could be related to the synthesis of the proteins associated with wheat quality. Endoplasmic reticulum and Golgi complex are important organelles in the synthesis of proteins. It is in these organelles where proteins are synthesized, temporarily stored, and moved to protein bodies as reserves to be utilized when the seed is germinating.

The methodology employed in this project was adapted from studies on different tissues and optimized for the enrichment of wheat endosperm.

An important contribution of this project was the development of the methodology. The wheat plants were grown in the greenhouse and the grain was harvested at 7, 14, and 34 days after flowering (days after anthesis). The wheat grain was then stored at - 40°F until needed for analysis.

During the enrichment procedure, crude extracts of wheat endosperm were used for fractionation of the two organelles using the sucrose gradient and a cocktail of enzyme inhibitors to avoid protein degradation. One- and 2-dimensional electrophoresis are being used to obtain protein profiles that will be digested with trypsin. The peptide mass fingerprint is then compared to a database that contains previously identified proteins. The recovery of the

proteins from endoplasmic reticulum and Golgi complex averaged less than 1 percent total protein. Confirmation of the enrichment efficiency was done by the identification of marker enzymes associated with the 2 organelles using Western blots.

One of the activities to be completed in this project is the comparison of the optimum and water stressed plants. Two graduate Ph.D. students are conducting this research under my direction. It is expected the project will continue for several years in an effort to identify all the proteins from the organelles. One major challenge for the successful identification of all the proteins is the incomplete wheat genome and known proteins reported in public databases.

# Identification of Grass Weeds in Oklahoma Fields

**Case Medlin**  
**Extension Weed Specialist**

Accurate weed identification is essential to effective weed management in agronomic crop production systems. Herbicide recommendations are developed for the identified weed(s), therefore, inaccurate identification of the weed can lead to poor or lack of weed control. The purpose of this funding is to cover the production cost of an identification guide to help wheat producers identify the grassy weeds infesting their wheat fields. Weed species in the publication will include cheat, downy brome, feral rye, Italian ryegrass, jointed goatgrass, rescuegrass, and wild oats. Work on the plant and seed sketches has begun and the document is expected to be completed in the spring of 2005.

## Seed Counter and Walk-in Germination Chamber

**Neal Foster**  
**Plant and Soil Sciences**

### **Seed Counter**

The Oklahoma Crop Improvement Association (OCIA) purchased a seed counter in the fall of 2003 with the grant received from the Oklahoma Wheat Commission. The seed counter currently is being used on all small grain and peanut samples being tested for purity and germination. This information is placed on the seed analysis report in the form of seeds per pound and thousand kernel weight. With further development of the OCIA computing

system, the pure live seed and live seed per pound also will be given on these reports. This information will greatly benefit our customers in their ability to accurately set planting rates.

### **Walk-in Germination Chamber**

The walk-in germination chamber has been ordered and is scheduled to arrive in late April 2005. This chamber will be used to conduct germination tests on small grains and peanuts.

