Winter Wheat Breeding and Genetics

Principal Investigators:

Steve Kalsbech, Research Associate, Winter Wheat Breeding, SDSU, Brookings

Sue Blodgett, Head, Plant Science Department, SDSU, Brookings

Principal Cooperators:

Marie Langham, Professor Virology, SDSU, Brookings

Jeff Stein, Associate Professor, Small Grains Pathology, SDSU, Brookings

Project Objectives:

The primary objective of the winter wheat breeding effort at SDSU is varietal development and release. The specific breeding objectives include high yield and stability, superior milling and baking quality, desirable agronomic characteristics (optimum maturity and plant height, long coleoptile, standability), disease and insect resistance (various fungal and viral pathogens and cereal aphids), and environmental stress tolerance (freezing and drought). While it is virtually impossible to combine all of these characteristics into a single "perfect" variety, continuous work toward these objectives will ensure that new varieties possess as many desirable characteristics as possible.

Progress:

The ultimate measure of productivity of the breeding project is varietal release and adoption by producers. While this remains our top priority, we are also involved in several other areas that may not have an immediate impact on varietal development but are deemed important for longterm productivity. Three red lines (SD 01058, SD 01273, and SD 0111-9) are on Foundation Seed increase with intention to release in 2008. Two red lines (SD 05210 and SD 05118) and two white lines (SD 05W012 and SD 98W175-1) are being increased at the winter nursery in Arizona for possible release in 2009 or 2010.

Eight promising experimental lines are being tested in the 2008 Crop Performance Variety Trials (CPT) at 13 locations and another 29 experimental lines are being tested in the 2008 Advanced Yield Trail (AYT) at 10 locations. Fifty-four experimental lines are being tested in the 2008 Preliminary Yield Trial (PYT) planted in five locations, while 389 lines are in the 2008 Early Yield Trial (EYT) planted in three locations. The 2008 head-row nursery consisted of 16,920 lines. The F3 and F2 nurseries both tested in two locations consisted of 585 and 732 populations, respectively.

During 2007, 1005 successful crosses were made during two greenhouse cycles. We included 15 experimental lines and checks in the 2006 Tri-state Fusarium head blight (FHB) Nursery (South Dakota, Nebraska, and Kansas). Based on preliminary FHB disease index% average from the Kansas and Nebraska sites, our lines SD97059-2, SD00111-9, “Harding”, SD03018, SD02480, Darrell, SD97380-2, SD01058, “Expedition”, SD03178, SD01122, SD03184, SD03144, Alice, and “Wendy” ranked as numbers 1, 2, 3, 4, 6, 7 ,11 ,16 ,18 ,19 ,20 ,24 ,29 ,36 , and 38, respectively. We have been relying in the past on indigenous FHB resistance. The 2008 EYT and PYT nurseries included entries with tagged FHB QTL and will mark a new milestone in the project. Best lines out of the 2008 head-row nursery will be included in the EYT in 2009. Resistant lines will be entered into regional nurseries to facilitate development of varieties with broad adaptation to the northern Great Plains Crossing and germplasm enhancement efforts continue to address yield, end-use quality, and important constraints facing producers in the northern Great Plains (FHB, leaf and stem rust, leaf spotting diseases, and winter survival ability).

Ongoing research support projects include screening for resistance to FHB, genetic studies of stem rust resistance with SDSU Plant Molecular Biologist, Dr. Yang Yen, and hard white winter wheat end-use quality.

Foundation Seed Increases:
Foundation Seed of three lines (SD01058, SD01273, and SD0111-9) is being increased for potential release in 2008. SD 0111-9 hard red winter wheat was developed from the cross KS93U134/Arapahoe. It ranked first statewide in 2007 CPT Variety Trial. It has average baking and noodle quality based on preliminary testing. It has good resistance to stem, leaf, and stripe rusts. It has been shown to possess the Lr34 gene that contributes to durable resistance to leaf rust. It also has Lr16 and Lr24 which when combined hold up very good resistance to leaf rust, similar to Arapahoe. It has good resistance to scab. It is high in protein and test weight.

SD 01273 was developed from the cross KS95U589/ NE94517 and is in its second year of testing in the CPT. It has good resistance to stem and stripe rusts. It ranked 3rd in the National Baking evaluation in 2008 and has very high grain yield.

SD 01058 hard red winter wheat was developed from the cross XH1877/NE967430 and is in its second year of testing in the CPT. It has good resistance to stem rust and stripe rusts. It has high yield potential with good baking qualities.

Breeding Program:
South Dakota Crop Performance Testing (CPT) Variety Trial: The CPT trial included 30 entries, consisting of 20 released varieties (including new releases from other states), 8 advanced experimental lines from our program, and one experimental line each from Nebraska and Colorado public breeding programs. This trial was also grown at 13 other sites in South Dakota. Prior to cultivar release, promising elite lines must be grown in the CPT Variety Trial for three years to accurately measure the potential performance across a range of environmental conditions. Four of the 10 experimental lines from the breeding program evaluated in the 2007 CPT were retained for further testing in 2008: SD01058 (XH1877/NE967430), SD98W175-1 (KS84273BB-10/KSSB110-9//KS831374-141B/YE1110/3/KS82W418/SPN), SD01273 (KS95U589/NE967430), and SD0111-9(KS93U134/Arapahoe).

South Dakota Advanced Yield Trial (AYT): The 2007 Advanced Yield Trial (AYT) was grown at seven sites in South Dakota. The AYT included 45 entries, consisting of 31 advanced experimental lines from our program and two lines from Nebraska and twelve checks. Ten of the 33 experimental lines were white.

The screening tests performed on entries in the AYT included Wheat Streak Mosaic Virus (WSMV) field adult plant screening (Dr. Marie Langham), multiple-race seedling stem rust screening, field FHB screening, and field leaf rust screening. The SDSU program also evaluated pre-harvest sprouting tolerance, PPO enzyme activity, coleoptile length, protein levels, and mixograph performance. Based on field performance data and screening results, four lines were advanced to statewide yield trials (CPT) in 2008: SD05118 (Wesley/NE93613), SD05210

(SD98444/SD96060), SD05W012 (NW96S016/SD98W327), and SD05W018 (SD98W302/SD98W175).

Preliminary Yield Trial (PYT): Separate Preliminary Yield Trial (PYT) nurseries were planted for hard red and hard white winter wheat in 2007. The nurseries were planted on dry land pea stubble at Dakota Lakes, on spring wheat stubble at Selby, on spring wheat stubble at Winner, on fallow at Wall, and on millet stubble at Brookings.

Selections for advancement to the 2008 AYT were based on grain yield, test weight, optimum plant height and maturity, straw strength, height reduction under dry conditions, agronomic performance, coleoptile length, disease leaf area duration, resistance to leaf and stem rusts, as well as predictive baking and milling quality. Pre-harvest sprouting tolerance and PPO activity were also weighted during the selections of lines from the PYT white nursery. No lines with leaf or stem rust susceptibility or poor leaf area duration were advanced.

Early Yield Trial (EYT): Separate Early Yield Trial (EYT) nurseries were planted for hard red (EYTR) and hard white (EYTW) winter wheat in 2008 at three locations. The EYT nurseries consist of 230 experimental hard red lines and 82 experimental white lines.

Selection was weighted on grain yield, drought tolerance, volume weight, optimum height and maturity, height reduction under drought, straw strength, agronomic performance, disease leaf area duration, leaf and stem rust resistance, as well as predictive milling and baking quality. In addition to these traits, PPO levels and pre-harvest sprouting tolerance were also weighted heavily for advancing EYTW lines to the 2008 PYTW.

Only lines with resistance or moderate resistance to stem and leaf rusts were selected for advancement. Most lines with poor green leaf duration due to disease severity were also discarded.

Head -row Nursery: The 2008 head-row nursery consists of 17,200 rows, including periodic checks, originating from 213 different cross combinations. Of the 213, 40 were white and 173 were red populations. Ten white entries and 28 red entries were re-selections from the 2007 EYT nursery. Two hundred heads were picked from each EYT plot for each entry. The other entries were obtained by picking 100 heads from each selected F3 plot. Three of the head-row populations contained QTL-tagged FHB parents.

Selections were based on relative date to maturity, pedigree and visual observation of plants prior to and at maturity. Conditions in the head-row nursery were suitable for selecting against FHB and leaf rust susceptibility. Heads of progeny of red/white crosses were threshed individually and evaluated for seed color before placing in the appropriate EYT nursery. White lines were screened for PPO before advancing to the EYT White nursery.

Early Generation Bulk Populations:

F3 Bulk Generation: The 2008 F3 nursery of bulk populations was planted at Brookings and Dakota Lakes from seed of 585 F2 bulk populations. The F3 plots consist of 243 red, 85 white, 137 red/white bulks populations from crosses made in 2005. Of the white populations, 59 were from single crosses and 23 were from 3-way crosses. Of the red populations, 167 were from single crosses and 76 were from three-way crosses. Of the red/white populations, 94 were from single crosses and 43 were from 3-way crosses. Notes on overall appearance, disease leaf area duration, and relative maturation date were used, along with pedigree information, for selecting 213 of the 535 F3 plots from which heads were picked for the 2008 Head-row nursery. For most plots, 100 heads were picked, with an attempt to obtain a diversity of plant types.

F2 bulk Generation: The 2008 F2 nurseries of bulk populations consists of 732 entries from spring and fall 2006 greenhouse crossing cycles. Entries with adequate amount of seed (601 populations) were planted into 7-row plots in Brookings and Bison, SD. Entries with insufficient seed to plant two locations (131 populations) were planted into 4-row plots at Brookings only. The F2 plots consisted of 336 red, 61 white, and 303 red/white bulk populations. Eight of the populations included FHB QTL-tagged parents. Of the 700 F2 plots in 2007, 585 were advanced to the 2008 F3 plots planted in Brookings and Dakota Lakes.

Greenhouse Crossing and Increase Program: The basic strategy of the greenhouse crossing program is to make adapted/adapted and adapted/un-adapted//adapted crosses (three-way crosses) with adapted winter wheat from our program and neighboring programs and un-adapted (e.g., spring wheat or other exotic germplasm) material with special desirable traits. Unique germplasm with resistance to FHB, WSMV, tan spot, Septoria, stem and leaf rusts, and hard white grain characteristics continue to be used in the crossing program. During 2007, 1005 successful crosses were made during two greenhouse cycles (654 in the spring and 351 in the fall).

Research Support Projects:

Basic research support projects included inheritance studies on various biotic and abiotic stresses limiting yield and quality in South Dakota winter wheat.

Fusarium Head Blight: "Darrell" hard red winter wheat (HRWW) was released in 2006. It has the lowest FHB severity rating among all cultivars tested in South Dakota during the last six years. It ranked top for yield in South Dakota Crop Performance Testing (CPT) Variety Trial in 2006 and had an exceptional three-year yield average. It had exceptional performance in the state of Nebraska in the Northern Regional Performance Nursery (NRPN) in 2003 and 2004. It has acceptable milling, good baking quality, and a good diseases package. Lines (1,055) were dormant seeded in November 2005 in the mist-irrigated nursery in Brookings, SD. Due to excessive early spring rain, the seed failed to germinate and the nursery was lost for the first time in the last six years.

A backup nursery consisting of 257 lines, including the NRPN, CPT, Advanced Yield Trial (AYT), and Preliminary Yield Trials (PYT) was transplanted in May 2006 and evaluated in July 2006. Four lines with promising FHB resistance were included in the 2007 CPT and 10 in the 2007 AYT. We included 15 experimental lines and checks in the 2006 Tri-state FHB Nursery (South Dakota, Nebraska, and Kansas). About 3,800 head-rows and 51 EYT entries with tagged FHB QTL sources were planted in the 2006 – 2007 season. Best lines out of the head-row nursery will be included in the EYT in 2008. Resistant lines will be entered into regional nurseries to facilitate development of varieties with broad adaptation to the northern Great Plains. The 2008 EYT and PYT included lines with tagged QTL resistance. This marks a new milestone in our breeding program. Several of these lines were included in the regional FHB nursery planted in South Dakota, North Dakota, Nebraska, and Kansas.

A study was conducted to determine combining ability and gene effects in populations derived from mating among spring, winter and facultative wheat genotypes. Six genotypes consisting of susceptible winter wheat "Nekota" and "2137", moderately susceptible winter wheat "Harding", moderately resistant spring wheat "ND2710" and "BacUp" and resistant facultative wheat "Ning7840" were crossed in a partial diallel mating design. F4:5 lines were hand transplanted in May 2006, and 2007, and screened under mist-irrigated field conditions. Artificial inoculation consisted of corn spawn spread at jointing and inoculum suspension spray at flowering stages.

Disease index (DI) percentage (incidence percentage * severity percentage/100) of the crosses was analyzed using Griffing's method 4 and model 1. General and specific combining abilities were highly significant ($P < 0.01$) for both years. The result showed that both additive and non-additive gene effects were involved in the of FHB resistance. The ratio of combining ability variation components [$2\sigma 2GCA/(2\sigma 2GCA+ \sigma 2SCA)$] was 0.85 and 0.81 in 2006 and 2007, respectively. The homogeneity of the data over two years was tested. The calculated F-value for the ratio of error variances (F = larger error MS/smaller error MS) for two years was 1.09 ($P = 0.10$, Dfnum = 846, Dfden = 867). The test of homogeneity indicated that the two years data could be pooled. The pooled analysis showed that general combining ability was significant ($P < 0.01$) but not the specific combining ability ($P = 0.17$). GGE biplot software was also used in the pooled diallel data set to graphically display the GCA and SCA effects of the parents and performance of the crosses. Both the individual and pooled analysis showed that additive gene effects were more important than non-additive gene effects. Thus, progress in developing resistance in wheat can be made by selection.

Stem rust: We have transferred several novel/under-utilized broad-spectrum stem rust resistance genes into selected adapted lines. Line derivation from these populations began in 2006. Research studies in coming years will focus on assessment of positive or negative effects of these genes with regard to yield, quality, or other agronomic traits. We are also building several populations for mapping markers associated with resistance of these sources in collaboration with Dr. Yang Yen, SDSU Molecular Biologist and Dr. Jeff Stein, SDSU Small Grains Pathologist. Our objectives are to: 1) to conduct a preliminary screen for the few existing markers linked with stem rust resistance genes, to assess the potential for using these markers in selection for the respective resistance genes, and 2) to search for molecular markers linked to the novel and under-utilized genes mentioned above. Resistance in most of these unique sources is believed to be conferred by a single major gene.

A segregating population from a cross between "2137" and CRL-Sr35 was made to develop a molecular marker for the stem rust resistant gene Sr35. Sr35 provide resistance to the new African stem rust race Ug99 which jumped the Red Sea in Yemen in 2006 and was recently detected in Iran. About 80 percent of spring wheat and 60 percent of winter wheat in the US is susceptible to this devastating race. Ninety-eight F2 plants were inoculated with a stem rust isolate of race QTH. Infection type and severity were evaluated 10 days after inoculation. Twenty-one microsatellite primer pairs developed previously from chromosome 3AL were used to determine polymorphism among parental lines and the F2 population. Chi square analysis indicated that resistance to stem rust was conferred by a dominant gene ($\chi 2=1.01$, $P=0.48$). Only four primers (Xgwm155, Xgwm391, Xgwm497 and Xfca2076) revealed polymorphism and they were used for linkage analysis. Xgwm391 revealed a polymorphic fragment of 200 bp found only in the susceptible bulk and 2137. In contrast, Xcfa2076 amplified polymorphic fragments of

210 bp in the resistant bulk and CRL-Sr35. Chi square analysis revealed that the Xcfa2076 marker was associated with the Sr35 resistance gene and no significant deviation from the expected ratio was observed ($\chi 2=0.78$; P=0.4).

Clearfield Wheat: South Dakota Agricultural Experiment Station has signed a Material Transfer Agreement (MTA) with BASF Corporation to develop hard winter wheat with tolerance to the Beyond® herbicide. To accelerate progress in this area we will select among advanced germplasm at the University of Nebraska. We also obtained 50 F3 bulks with tolerance to the Beyond® herbicide from the University of Nebraska. Fall spraying of these populations did not prove effective. The populations will be planted again this year and will be sprayed with the Beyond® herbicide in both the fall and early spring and selection of herbicide tolerance plants will be done. Heads will be picked from tolerant plants and planted as head-rows in Brookings in 2009. Promising head-rows will be entered into the EYT planted in 2010.

In the meanwhile, the two events that control resistance to the Beyond® herbicide are being incorporated into selected white and red genotypes using adapted germplasm from Nebraska to produce segregating populations containing the herbicide-tolerant events. These populations will be tested for herbicide tolerance by treating with the Beyond® herbicide in the greenhouse and field until resistance is confirmed. Marker assisted selection using sequences provided by BASF Corporation will be utilized. Selection for yield, stability, quality, disease and abiotic stress tolerance will also be practiced prior to line increase and release. We expect the release of such genotypes to have an impact in certain production areas in Southwestern South Dakota where jointed goat grass, a close wheat relative, is problematic in wheat-fallow rotations.

Near Infrared Reflectance (NIR) analyzer: The winter and spring wheat breeding programs obtained a FOSS 6500 Near Infrared Reflectance (NIR) analyzer, along with a computer and software that are required to operate the machine. The FOSS 6500 is the most widely used system of its kind in the USA. Several universities as well as some USDA wheat quality labs currently use THE FOSS 6500 where it is appropriate. It has a very broad wavelength range spectrum which covers both the near-infrared (1100 to 2500 nm) and the visible ranges of light (400 to 1100 nm). This allows an extensive array of materials, such as flour or whole grain, to be subjected to analysis. FOSS NIR Systems has developed a software package (winISI III) that is used to calibrate and operate their machines. Calibration takes place by first using standard analysis methods (i.e., wet lab, physical or chemical analysis, etc.) to obtain a dataset used for training purposes. Then grain or flour, as examples, are analyzed and the calibration software is used to build a model that will approximate the dataset used for training purposes. After a satisfactory model has been developed for any particular characteristic, samples can be analyzed with the NIR machine and data that are produced will mimic, or be highly correlated with, results from standard analysis procedures.

The FOSS 6500 will hopefully improve selection strategies within our breeding programs through the rapid and non-destructive analysis of milling and baking quality in thousands of early generation breeding lines. Program efficiency will thereby be increased through discarding materials with little potential. We are entirely cognizant that before we may predict milling and baking quality, etc. calibration models must be formulated. Fortunately, the software allows for calibrations to be shared from one unit to another. This may allow us to use calibrations derived by other programs.

Mixolab For Rheological And Enzymatic Analysis: We recently acquired a mixolab in collaboration with the Spring Wheat Breeding project and the Department of Food Science and Hospitality at SDSU. It is a farinograph and a rapid visco analyzer combined in one instrument. It measures dough development time, protein weakening, starch gelatinization, enzymatic activity, and gel strength using one run of a sample. In addition, the mixolab obtains highly repeatable water absorption values. Dough properties evaluated by a mixograph or a farinograph are not always sufficient to predict bread-making properties. Some bread-making properties are not apparent until the dough is heated, when gluten proteins begin to denature. The mixolab has the capability of precisely controlling and ramping up the temperature after the kneading stage. In addition to the effect on proteins, the higher temperatures affect starch-pasting properties, which are important in assessing the suitability of flour for making noodles. Mixolab profiles will be used in studies of the effects of diverse glutenin and gliadin molecules on bread-making properties, and will be used for screening samples for both bread and noodle properties. Thirty-eight flour samples from the 2006 harvest were milled and evaluated in baking and mixograph tests at USDA-GMPRC in Kansas have been analyzed on the mixolab. Mixolab data will be compared to bread quality traits such as loaf volume to determine the reliability of the mixolab for predicting baking quality.

Project Proposal:

The winter wheat breeding project is necessarily an ongoing effort. The fruits of what we do today will most likely be realized at some point in the future. Our efforts are focused in several different areas to develop both the germplasm and knowledge base to support winter wheat cultivar development in South Dakota. We continue to critically examine not only what we do, but also how we do it so that hopefully, when necessary, timely changes may be made for the betterment of the overall breeding program.