PROGRESS REPORT
TO
NORTH CAROLINA SMALL GRAIN GROWERS ASSOCIATION, INC.

TITLE: **Small Grain Variety and Germplasm Development**

LEADER(S): **J. Paul Murphy**

DEPARTMENT(S): **Crop and Soil Sciences**

REPORT:

Season and Impact on the Small Grains Breeding Program.

Favorable planting conditions during fall 2019 saw experiments at Salisbury, Lake Wheeler, Clayton, Goldsboro, Kinston, Plymouth and Belhaven planted in a timely manner with subsequent strong establishment. Temperatures were cool in December, but the remainder of the winter was warm and crop development was ahead of normal. In fact, many lines from Gulf States headed by the third week of March at Kinston. The more adapted lines from the Mid-Atlantic States started heading at the end of March, but we were spared damage from low temperatures. The April and May grain filling periods had mild temperatures with sufficient moisture and we harvested very high yields at all test locations. Some individual plots yielded the highest I have seen in my career at NC State. Excellent yield data were obtained from all locations except Belhaven, where plots were damaged by root and crown rot. We obtained excellent Hessian fly data at Kinston, and excellent scab data from misted and inoculated nurseries in Kinston and Lake Wheeler, NC and Warsaw, VA. Leaf rust was heavy at Kinston and Plymouth which greatly aided selection. Very little powdery mildew developed in the state except on very susceptible lines. Most of the harvest period was dry and yields were high with average test weights. Test weights likely suffered during two weeks of rain and showers as the crop was reaching full dry-down. Cash price for wheat, once again, is very disappointing with most elevators offering less than $4.00 and feed mills $4.00 to $4.40.

Despite the stressful / modified working conditions imposed by Covid-19 rules, we had one of the most productive field seasons, from a research perspective, in quite a number of years. The dedication of my co-workers Justin Page, George Van Esbroeck and graduate student, Zachary Winn, was key. They understood, without any need of explanation from me, the long-term damage that discontinuity does to a breeding program.

OBJECTIVE 1. Variety Development in Wheat, Oats and Triticale.

Seven NC State experimental wheat lines fell in the top performing group evaluated over five locations in the NC Official Variety Test in 2019-20 (Table 1). All of these lines have good Scab, Hessian fly, powdery mildew and leaf rust resistances. All have excellent test weights. NC11546-14 and NC11363-25 have undergone purification and are ready for release. NC11546-11 has the lowest scabby kernels score of any advanced line in my program.

Table 1. Statewide Experimental Wheat OVT results from evaluations at five locations 2019-20.

Statewide Experimental - 2020

Company/Brand	Variety	Yield (bu/A)	Test Weight (lb/bu)
Dyna-Gro Seed	WX20737	88.5	57.6
PROGENY	PROGENY PGX19-15	87.9	57.0
PROGENY	PROGENY PGX19-17	87.8	57.7
NCSU	NC11546-14	87.5	58.7
University of Georgia	GA11656-17E11	86.6	58.4
PROGENY	PROGENY PGX19-11	86.5	55.7
KWS Cereals	KWS263	86.4	57.3
PROGENY	PROGENY PGX18-7	85.8	57.9
VCIA	VA16W-202	85.2	55.6
Dyna-Gro Seed	WX20731	84.9	55.1
Limagrain	L11919	84.4	56.4
University of Georgia	GA10407-17E8	84.4	58.5
AgriMAXX	AgriMAXX EXP 2002	84.1	57.4
PROGENY	PROGENY PGX18-8	84.1	56.8
NCSU	NC12164-22T	83.7	58.5
University of Arkansas	AR09137UC-17-2	83.7	57.1
NCSU	NC16-21185	83.7	58.1
PROGENY	PROGENY PGX18-11	83.6	56.0
Harvey's	AP 1987	83.6	55.5
NCSU	NC12093-146	82.5	57.4
University of Arkansas	AR06146E-1-4	81.9	57.6
PROGENY	PROGENY PGX19-10	81.6	54.9
University of Georgia	GA10268-17LE16	81.6	57.3
NCSU	NC12753-139	80.3	58.5
VCIA	13VTK429-3	80.3	56.9
NCSU	NC11331-38	80.0	58.0
NCSU	NC11363-25	79.9	58.0
PROGENY	PROGENY PGX19-3	79.7	56.9
Local Seed	LWX20B	79.3	57.0
Texas A&M	TX15D9253	79.1	55.0
NCSU	NC15-21970	79.0	58.0

Table 2. Performance of NC12-3578 oat line in NC over the 2018, 2019 and 2020 seasons

Genotype	Grain Yield bu ac	Test weight lb bu	Plant Height in	Heading date April
NC12-3578	**117**	**36.6**	**66**	**13**
Gerard 224	**113**	**35.7**	**65**	**12**
NC12-3753	**111**	**36.0**	**71**	**12**
Horizon 201	**109**	**33.4**	**77**	**12**
NC12-3922	**103**	**36.1**	**63**	**10**
NC17-6550	**100**	**36.0**	**68**	**12**
SS76-50	**89**	**34.4**	**60**	**11**
Mean	**105**	**36.3**	**67**	**10**
LSD (0.05)	**15**	**1.3**	**4**	**1**
CV%	**17.7**	**4.6**	**6.9**	**1.1**

Variety development in oats.

The hulled oat NC12-3578 continues to perform very well (Table 2) and should be licensed to a private company by fall planting. NC12-3578 has performed well in NC, SC and KY during the past several seasons. A seed dealer in KY is particularly anxious to license this line because winter oats generally do not perform well in Kentucky. NC12-3578 seems to be an exception. Of course, this line will be made available to North Carolina seedsmen should they desire to license it, also.

Variety development in Triticale.

Our previously terminated triticale program was taken out of mothballs in 2013-14 and continued in the intervening seasons. We have whittled down a large number of potential releases to two experimental lines based on testing over four years (Table 3). NCT07-1031-1 is the highest yielder and heads 13 days later than Southern States 1414. This provides growers with a later heading alternative, which may have better adaptation to the organic cover crop market. NCT08-180-4 is a very early line and has the best Hessian fly resistance in the group. This line may suit a different market and may fit better into production niches in southern parts of the state and South Carolina. Both these lines are undergoing purification prior to release.

Table 3. Performance of Advanced generation triticale lines in North Carolina during the 2017 through 2020 seasons.

Line	Grain Yield bu / ac	Test Weight lb / bu	Plant Height in	Heading Date Julian	Hessian Fly (0 - 9)
NCT07-1031-1	61.2	51.1	47	103	3.0
SS1414	60.7	51.3	49	90	4.0
MF07-1031-B5	58.4	51.6	46	86	4.5
NCT08-180-4	57.2	50.0	48	86	2.0
NCT07-1093-1	56.3	51.6	44	99	4.0
Arcia	51.6	50.8	48	91	3.5
Mean	57.6	51.1	47	93	3.5
CV	12.3	1.5	.	1.8	.
LSD (0.05)	5	0.55	.	2	.

We continued to coordinate the **Uniform Southern Scab Nursery** for nine public and private breeding programs in the USA. We solicited entries from public and private breeding programs in August 2019, packaged, and shipped seed to cooperators in September 2019. We are receiving data from cooperators and will conduct statistical analyses and publish a nursery report in fall 2020, similar to those we have published annually (https://scabusa.org/pdfs_dbupload/suwwsn19_report.pdf). This nursery is important for the independent verification of scab resistance levels in advanced breeding lines and it serves as a way to readily distribute the best scab resistant lines so they can be used as parents by other breeding programs.

OBJECTIVE 2. Determining the genetic control of Scab Resistance in NC13-20076 (Winn PhD. research).

Much research was conducted nationwide on scab resistance and several different genes have been identified that confer partial resistance (e.g. *Fhb1, NC-Neuse4A, Jamestown 1B, Bess 2B*). NC13-20076 (pedigree *Jamestown / /GA951231-4E29 / NCAG11*) has displayed excellent resistance in numerous tests, but interestingly is does not contain any of the known resistance genes. Thus, it likely contains very effective, yet unidentified, resistance gene(s). We conducted field evaluations in the 2018-19 and 2019-20 seasons at two locations in North Carolina and one location in Virginia using 200 progenies from the cross between NC13-20076 and GA06493-13LE6 (susceptible). This enabled us to track the resistance genes and the associated DNA markers in random progenies of NC13-20076. We are still conducting statistical analyses on the results and we have not obtained all the DON data, but our initial results indicate that four genes are involved (Figure 1). They are located on chromosomes 2A, 5A, 6A and 7A. We are in the process of developing DNA markers at the locations of these genes to provide breeders the wherewithal to select for resistance in the absence of the disease.

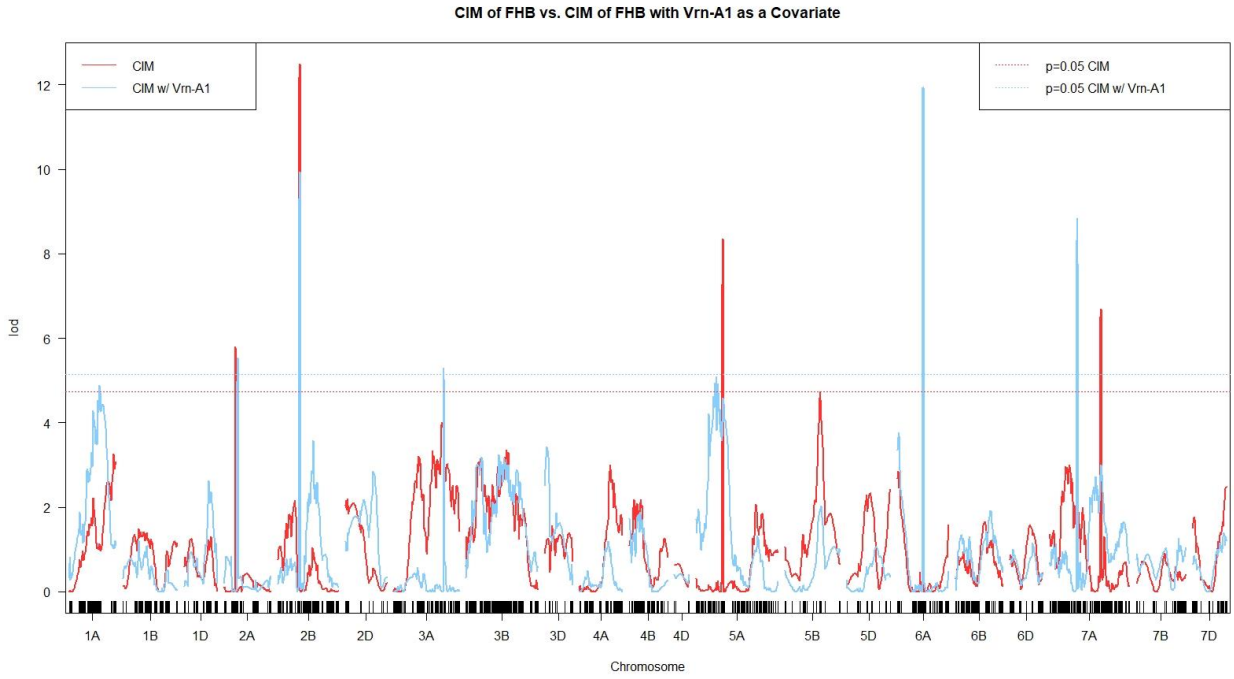

Figure 1. Locations of four genes associated with Scab resistance in the resistant line NC13-20076. The peaks associated with chromosomes 2B, 5A, 6A and 7A are strongly associate with scab resistance.

OBJECTIVE 3. Determining the genetic control of Hessian fly resistance in LA03136E71 (Winn PhD research).

The typical resistance utilized to combat Hessian fly is known as single gene, complete resistance. It is effective, but is generally overcome by the insect in short order due to heavy selection for more virulent fly biotypes. The resistance observed in LA03136E71 is known as partial resistance. The plant does not appear significantly damaged by insect feeding, but a small number of insects are found resting between healthy tillers. The resistance is valuable because the current Hessian fly biotype survives at a low frequency, so there is no pressure exerted by Mother Nature to select a more virulent biotype. Thus, the resistance should be long-lived. We developed a research population of 200 progenies from the cross of LA03136E71 X Shirley (susceptible) and traced the gene controlling the resistance in 200 progenies in field tests in 2018-19 and 2019-20. The occurrence of Hessian fly is sporadic and we obtained one replication of data on the population in Wilson County in 2018-19, and two replications of data at two locations near Kinston, NC in the 2019-20 season.

We were surprised to find that a single gene on chromosome 7D controlled this resistance (Figure 2), because, typically, the tolerance types of resistance is controlled by multiple loci (as with our scab research above). We are in the process of developing DNA markers at the locations of the gene to provide breeders the wherewithal to select for resistance in the absence of the insect. This is the first identification of the genetic control of this field resistance and breeders have been awaiting this line of research for at least 20 years. Its existence has been known, but an understanding has been lacking. The fact that the resistance is controlled by a single gene will make it easier to work with in variety development.

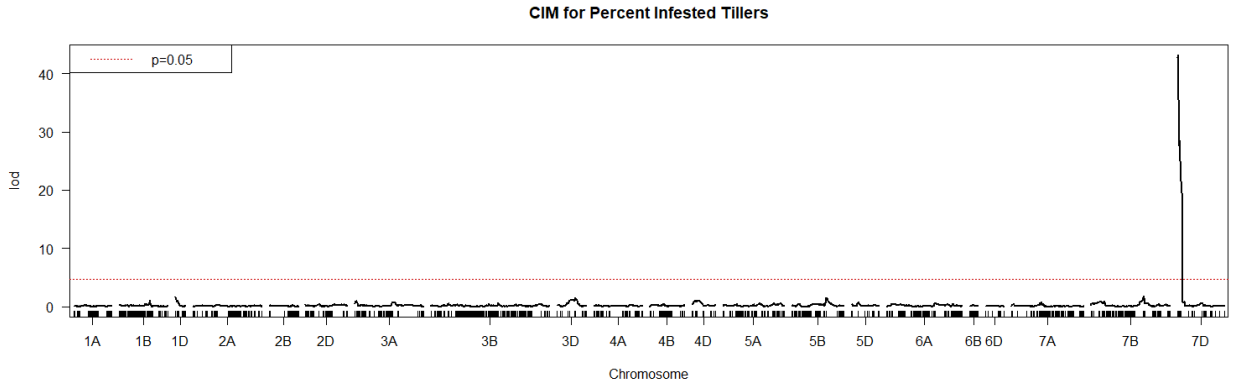

Figure 2. Locations of the gene associated with Hessian fly resistance in LA03136E71. The single peak associated with chromosomes 7D identifies the gene controlling the Hessian fly resistance.

OBJECTIVE 4. Coordinate Genome Wide Selection for the wheat breeding programs of David Marshall, Paul Murphy, Clemson, UGA, UF, LSU, UAR, TAM, UK and VA Tech.

Marker Assisted Selection (described in Objectives 2 and 3 above) has proved very effective at improving traits controlled by single, or a few major genes such as mildew, leaf rust, and Hessian fly resistance, but it is less effective at improving traits controlled by many genes such as grain yield. However, DNA marker technologies have improved dramatically and become much less expensive. This opened a new set of possibilities to use DNA marker technology to improve many-gene traits such as grain yield. This area of research, termed Genomic Selection, combines DNA sequence data with historic field data to increase the accuracy of the selections by predicting which lines will perform at superior levels before they are evaluated in expensive field trials,

By default, because the USDA-ARS Regional Genotyping Lab is located on campus under the direction of Dr. Gina Brown-Guedira, NC State has become the campus that coordinates the data curation, DNA sequencing, interpretation and prediction for the entire southern region. My Research Associate, Jeanette Lyerley, funded by the US Wheat and Barley Scab Initiative, does much of this day-to-day activity.

We are still learning how to utilize this new technology to speed up cultivar development – how accurate are predictions, what exactly are they telling us? During the past year, we determined that the computer generated yield predictions of lines provide information equivalent to two years of field testing at five locations. This is quite exciting.

We looked at a cohort of wheat lines from the 2019 season upon which we obtained computer-generated yield predictions and actual field data (Figure 3). The observed yields, expressed as a percentage of Hilliard, were plotted against the predicted yields. The correlation was only 0.27, but the observed yields were only based on a single plot at one location in one year – not very robust data, but we were limited by seed availability at that point in the breeding pipeline. The following season 2020, we evaluated the materials at four locations across the state and, based on the data over the two years, we picked a set of 28 lines to advance for further testing in 2021 (lines in black in figure). Note that almost all the black lines were predicted to have above average yields back in 2019. Thus if we had only field tested lines with above average yield predictions (right hand side of the figure), we would have thrown away almost none of the superior lines identified by yield testing in 2019 and 2020.

Figure 3. Observed and predicted yields of lines in the NCSU Observations Test in 2019 grown at Kinston. Lines identified with black numerals were selected for advancement into 2021 trials based on data from field trials in the 2019 and 2020 seasons. Note that most of the identified lines were above the average for predicted yield in 2019.

OBJECTIVE 5. Finding novel photoperiod genes for Southeastern US wheat varieties.

Two genetic mechanisms control heading date in Southeastern US wheat varieties – vernalization and photoperiod. Vernalization refers to the prolonged exposure of the wheat plant to cold temperatures during winter. After a given exposure time, a trigger is switched that permits flowering. Vernalization is the most important control mechanism in Southeastern US wheats. Photoperiod refers to the number of hours of sunlight a plant is exposed to in a 24-hour period. This mechanism plays a secondary role in controlling flowering time, after the vernalization requirement has been met.

Temperatures during North Carolina winter have been consistently unreliable during the past several years. We initiated research to move photoperiod into the dominant role in controlling date of heading in our wheat crop. Day length is controlled by the angle of rotation of the earth around the sun. This event will likely be stable and predictable for the foreseeable future – unlike temperatures.

We want to develop wheats that will reliably flower between April 15 and April 30, each year, despite the temperatures encountered during the winter. To do this we need to find genes that exert strong photoperiod control, rather than strong vernalization control. By using spring wheats in this research, we avoided the confounding impact of vernalization genes that would occur if we used fall-sown wheats. This research is not designed to find spring wheats for North Carolina, rather to find and utilize their strong photoperiod genes in our adapted winter wheats.

Beginning in November 2017 we planted 3,000 spring wheats from around the world at Lake Wheeler in Raleigh. In 2018 and 2019 we selected lines that consistently headed between April 15 and April 30. There were 20 candidates left in 2020 representing Asia, Africa, Europe and the Americas. We planted them in Lake Wheeler and crossed each to NC-Neuse, and older variety. NC-Neuse was chosen because it has outstanding soft wheat milling and baking quality to help make up for those deficiencies in the spring wheats. This was the first step in bringing these strong photoperiod genes into NC breeding program. This work will continue.

OBJECTIVE 6: Developing rye varieties with enhanced allelopathic activity for use as cover-crop (assisting Chris Reberg-Horton)

I have noticed an increased interest in rye as a cover crop in North Carolina over the past several years. I conducted research with Chris Reberg-Horton on allelopathy in rye when he was a graduate student about 20 years ago. We developed a population by intercrossing rye varieties from around the world that exhibited allelopathic properties with Wrens Abruzzi, a variety adapted to North Carolina. Chris became a professor at the University of New Hampshire and the material was put in a freezer. We revived the materials three years ago and we have been conducting field evaluations of sub-lines from that population for allelopathic activity. During the past season we evaluated about 3,000 lines from that population for leafiness, heading date, disease resistance and allelopathy. We harvested 60 superior lines and these will be advanced for yield testing in the 2020-21 season. Chris's main stakeholders are organic growers, but an improved cover crop rye would have utility for the non-organic community also.

BUDGET / EXPENDITURE SUMMARY:

Undergraduate Wages and Benefits	$6,120
Program and Laboratory Supplies (including fuel)	6,464
Vendor Charges / Current Services (including motor vehicle repair and maintenance, and freight / shipping costs)	2,152
Other Costs (Vehicle operational costs)	704
Total	$15,440
Awarded by NCSGGA	$40,000
Funds remaining at July 13, 2020	$24,560

IMPACT STATEMENT:

The identification of QTL associated with resistance genes for two of our most important wheat pests Fusarium Head Blight and Hessian fly with enhance efforts by breeders across the Southeast to develop improved cultivars.