Special Report

The Fusarium Head Blight Epidemic of 2003 in the Southeastern United States

U.S. Wheat & Barley
Scab Initiative

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Executive Summary

The year 2003 was generally considered to have seen one of the most severe Fusarium head blight (FHB) epidemics ever in the southeastern U.S. FHB causes losses in yield, test weight, and seed quality of wheat, barley, and oats. This report addresses losses to wheat. The mycotoxin deoxynivalenol (DON) is produced in infected spikes and kernels. The objective of this study was to document the severity of the Southeastern U.S. epidemic, estimate resulting losses, and examine environmental factors related to the epidemic.

Data on disease incidence, severity and losses were obtained from researchers, extension specialists, extension agents, millers and growers in Maryland, Virginia, North Carolina, South Carolina and Georgia. Data were obtained for the top 10 wheat-producing counties in each state; other counties were included as disease severities warranted. A total of 10 counties in Maryland, 12 in Virginia, 21 in North Carolina, 11 in South Carolina and 13 in Georgia were examined. Additional data were obtained for the following surrounding states: Indiana, Ohio, Pennsylvania, Delaware, Tennessee, Kentucky, Arkansas, Louisiana, Alabama and Florida. During the course of the study, 27 researchers and extension specialists, 57 extension agents, 16 millers and 20 growers were surveyed by phone and personal interview (see Appendix I).

Throughout the Southeast, no detailed notes were taken in 2003 on FHB incidence or severity in the conventional senses of those terms, i.e., proportion of affected plants and affected plant tissue, respectively. Therefore, in estimating relative severity of the epidemic by county and state, this study relies on general observations by growers and extension personnel. Unless otherwise indicated, "disease occurrence" refers to the proportion of growers affected in each county, and "severity" refers to the proportion of the crop in a county or state with observable FHB symptoms.

Summary of the 2003 Epidemic

- Disease occurrence and severity increased from Georgia to Maryland and from east to west in North Carolina and Georgia.
- **Maryland** – 70% - 100% of growers on the Eastern Shore were affected. Yields were reduced by nearly 60% compared to 2002. In research plots, DON levels ranged from 2 –12 ppm.
- **Virginia** – Disease occurrence in most counties ranged from 50% to 100%. Disease levels were moderate in the majority of the wheat-growing area, but some areas and growers were severely affected. Statewide, yields were cut by 40%. DON levels ranged from 0.0 to 3.4 ppm in state variety trials.
- **North Carolina** – Occurrence and severity varied widely among counties. In the Coastal Plain, occurrence ranged from 33% to 80%, with low to moderate severities. Counties in the western Piedmont had occurrence of 35% to 80%, with severities ranging from 60% to 80%. Yields in this area were decreased by 30% to 100%. DON levels reached as high as 10 ppm.
- **South Carolina** – Disease occurrence was greater than in previous years, but was still not greater than 10%. Disease severities were negligible. County agents recalled no difficulties with elevated DON levels; however, millers reported having rejected more loads than usual due to DON levels.
- **Georgia** – FHB was a widely scattered problem affecting less than 10% of the crop. Observed severities were generally minimal; however, millers in the northeastern portion of the state had severe difficulties

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Millers throughout the affected region reported losses due to DON ranging from $40,000 to $500,000 per mill, with total FHB-related costs to the region's milling industry estimated at several million dollars.

with DON, with levels averaging 8 ppm +/- 2 ppm.

- **Surrounding states** – FHB caused serious problems in Kentucky and parts of southern Indiana, Ohio, and Pennsylvania. Severity was similar to or less than in previous years in Delaware, Tennessee, Arkansas, Louisiana, Alabama, Florida and the Northern Plains region.

WEATHER CONDITIONS

Comparison of 2002 and 2003 -- During the period 7 days prior to and 30 days following anthesis:

- Average hours of FHB-conducive temperatures (59-86° F) were similar for 2002 and 2003 within states, although they increased progressively from Maryland south to Georgia.
- The average hours of rainfall were higher for all states in 2003 than in 2002, with the most significant increase in the three states where FHB was most severe: Maryland, Virginia and North Carolina.
- Hours of favorable relative humidity (RH >90%) were higher in Maryland and Virginia than in North Carolina, South Carolina, or Georgia.
- Georgia and South Carolina had the highest mean temperatures and the lowest mean hours of precipitation, such that both factors probably explained the relatively lower FHB levels in those states.

Correlation of severity and weather variables -- Across the 67 surveyed counties:

- No significant relationship was found between 2003 FHB severity and pre-anthesis temperature or precipitation, separately or when both variables were simultaneously conducive. FHB severity was significantly negatively correlated with conducive temperature in the 10 days post-anthesis, and positively correlated with relative humidity in that same period, although the correlation coefficients were low (-0.323 and 0.397, respectively). Relative humidity was strongly correlated with precipitation.
- A significant correlation ($P < 0.0001$) was found between FHB severity and hours of precipitation in the 10-day, 20-day, and 30-day post-anthesis periods. The correlation strengthened as hours of precipitation were tallied for successively longer time periods ($R = 0.477$, 0.603, and 0.622, respectively). These results suggest that cumulative post-anthesis rainfall was the most important weather variable driving the 2003 epidemic.

Weather conditions in the 7 days prior to anthesis do not appear to have played as significant a role in epidemic development as weather conditions following anthesis, and were not a good predictor of FHB severity in the Southeast in 2003. It is likely that in years of normal rainfall, temperatures limit FHB severity across the Southeast, the more so the farther south one goes. Since extended periods of rain appear to compensate for temperatures outside the conducive range, prolonged rainfall in May-June may be key to the development of a severe FHB epidemic in the southeastern U.S. wheat-growing region.

ECONOMIC IMPACT

- Minimum pre-milling losses in 40 surveyed counties in Maryland, Virginia and North Carolina were estimated at over $17 million. That figure does not include FHB damage to growers in unsurveyed counties, which accounted for 28% to 58% of total production in those states. Economic effects of FHB were minimal in South Carolina and Georgia.
- DON also severely reduces grain quality and marketability. Grain that tests above acceptable limits for DON concentration may be downgraded from food grade to feed wheat, at a considerable loss to the farmer. Costs to millers include increased testing for DON, additional cleaning, higher purchase prices, and additional freight and handling fees required to fill grain contracts when local grain is contaminated by DON. Millers throughout the affected region reported losses due to DON ranging from $40,000 to $500,000 per mill, with total FHB-related costs to the region's milling industry estimated at several million dollars.

Introduction

Fusarium head blight (FHB), or scab, was initially recognized approximately a century ago, and was considered a major threat to wheat at that time (4). More recently, FHB has increased in incidence and severity throughout the world, and is considered a major factor limiting wheat production in some areas (5). FHB epidemics occur sporadically in both space and time.

In the southeastern U.S., FHB has not caused major loss or hardship to growers or millers until recently. In 2003, the disease was more prevalent and severe than previously experienced, causing extensive losses and financial distress. The U. S. Wheat and Barley Scab Initiative reported FHB damage to the mid-Atlantic soft wheat-producing region to be unprecedented, seriously disrupting the flow and trade of grain (1). This case study documents the FHB epidemic in the mid-Atlantic region of the southeastern United States in 2003, and also touches on surrounding wheat-producing states. The relationship between disease severity levels and weather in the Southeast was analyzed in order to evaluate any possible trends. An effort was made to determine and quantify the costs of the epidemic to wheat producers and millers in affected states. Implications for research and control are discussed.

Disease Biology and Effects

Although several species of *Fusarium* have been implicated as causal agents of FHB, *Fusarium graminearum* has been responsible for most of the recent epidemics in North and South America, China, Japan, and Southern and Central Europe (10). The teleomorph (sexual stage) of *F. graminearum* is *Gibberella zeae*. The pathogen has a wide host range, encompassing small grains and numerous grasses, where it parasitizes the roots, stems, leaves, and flowering tissues. Its primary hosts are common wheat (*Triticum aestivum*), durum wheat (*T. durum*), barley (*Hordeum vulgare*), and corn (*Zea mays L.*). *F. graminearum* also colonizes senescent tissue, especially that of corn, where it survives in the stubble, providing inoculum for the following season.

F. graminearum produces several mycotoxins, including deoxynivalenol (DON). DON is also known as vomitoxin due to its nauseating effects on monogastric animals, including humans. Other symptoms of toxin ingestion can include dizziness, diarrhea, and muscle spasms. DON levels can reach as high as 20 ppm in infected wheat. The FDA has set an advisory level of no more than 1 ppm DON in finished human foods. In accordance, mills generally set a ceiling of 2 ppm in grain destined for human food, as DON levels generally decline by approximately 50% during the cleaning and milling process. Levels up to 10 ppm in poultry and ruminant feed are acceptable. All other animals have recommended limits of 5 ppm. DON is a stable toxin and may remain in stored grain indefinitely.

FHB is spread by both ascospores (sexual spores) and conidia (asexual spores). The forcible discharge of the ascospores from perithecia in colonized corn residue provides a mechanism for airborne dispersal to the susceptible small grain host. Infection of the wheat plant occurs primarily during heading and flowering, but the wheat heads are also susceptible at later stages (11). Given appropriate temperature and moisture conditions, visible masses of light pink conidia (asexual spores) may be produced on the rachis and glumes of affected spikelets within 7-10 days of infection. Infected tissues may also form bluish-black spherical perithecia, the sexual stage of the fungus, later in the season. Due to the short period of maximum susceptibility, there is generally only one infection cycle per season.

The relationships among timing of infection, symptom expression, and DON levels are complex and not well understood. Symptoms can become visible in as little as

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3 days following infection when weather conditions are favorable. In 2003, however, many in the wheat industry were surprised by high levels of DON in visually asymptomatic crops.

It is thought that infection timing plays a role in the degree of symptom expression (11):

Early infection, occurring just after emergence of the anthers, causes premature bleaching of the spikelets, and results in death of the floret; no kernel is formed.

Florets that are infected later produce kernels that do not develop properly; a 'scabby' kernel or 'tombstone' results. These kernels appear rough and shrunken or wilted. They range in color from pink to gray to light-brown, and can contain mycotoxin.

Infection occurring after the kernel has filled may result in a normal-appearing kernel that nevertheless harbors the pathogen and may contain high levels of mycotoxin. These kernels, which are of normal appearance and weight, are more likely to reach the milling stream and increase the threat of DON-contaminated flour.

SUMMARY OF THE 2003 FHB EPIDEMIC IN THE SOUTHEASTERN U.S.

Methodology and general trends: Researchers, agricultural extension agents, millers, and growers in the southeastern United States (Maryland, Virginia, North Carolina, South Carolina and Georgia) were interviewed to gain a better understanding of the severity of the epidemic in 2003. The top 10 wheat-producing counties were surveyed in each state. Additional counties were surveyed if disease levels warranted it.

Throughout the Southeast, no detailed notes were taken during the 2003 epidemic on FHB incidence or severity in the conventional senses of those terms, i.e., proportion

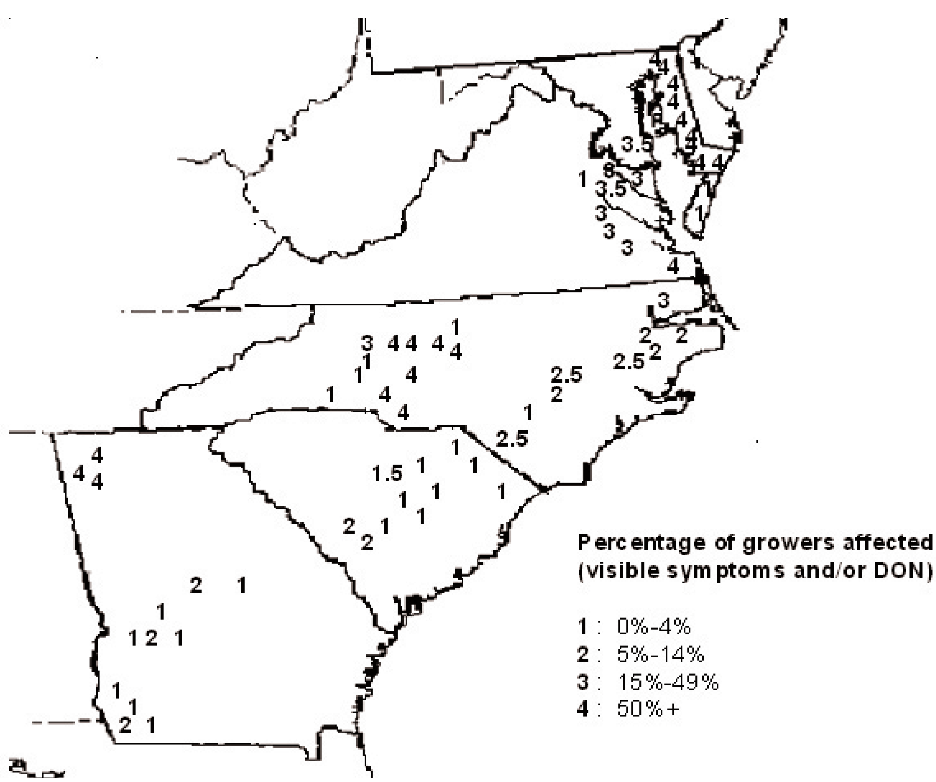

Fig. 1: FHB distribution and severity in the mid- and south-Atlantic U.S. in 2003

of affected plants and affected plant tissue, respectively. Therefore, in retrospectively estimating relative severity of the epidemic by county and state, this study relies on general observations by growers and extension personnel. Unless otherwise indicated, "disease occurrence" refers to the proportion of growers affected in each tion of the crop in a county or state with observable FHB symptoms.

As a general trend, disease occurrence and severity increased from south to north across the region, with Georgia and South Carolina being essentially similar (Fig. 1). Within North Carolina and Georgia, severity increased from east to west. According to Joe Bruton, wheat merchandiser for Perdue Farms chicken feed, the crop in North Carolina, while of reduced quality, was better than those in the states to the north: Virginia, Maryland, Delaware and Pennsylvania. In 2003, Mr. Bruton found that yields were decreased significantly in states from North Carolina northward, and increased DON levels were observed in these states.

FHB was responsible for some, but not all, of the dramatic losses in yield and test weight experienced across the region in 2003. Other diseases, such as Stagonospora nodorum blotch (SNB), and weather-related problems played roles that were more or less significant depending on locale.

Maryland: Fusarium head blight has been a recurrent problem in Maryland. In a normal year, up to 20% of growers might be adversely affected by FHB. The impact of FHB on Maryland's wheat production in 2003 was devastating, according to Scott Rowe, extension agent for Cecil County, MD. Eastern Shore counties were severely affected (Fig. 1), with 70%-100% of growers affected. On the Western Shore, FHB levels werelower -- for example, about 50% of growers were affected in St. Mary's County (Fig. 2) -- and yields were decreased by 20%-70%.

The average yield on the Eastern Shore was reduced by nearly 60% below that of 2002. Test weights were lowered to the 30's and 40's in lb/bu, a decline of 5%-50% over 2002 levels. Values were so low that most of the grain was never assessed for DON. In wheat variety trial research plots operated by Dr. Jose Costa, small grains breeder at the University of Maryland, incidences of infected plants ranged from 10% to 35%. DON levels ranged from 2 to 12 ppm (mean 6.4 ppm).

Seed from the 2003 crop had poor vigor throughout the counties surveyed, with germination rates as low as 20%, making the wheat unacceptable for use as seed. Some growers were unable to fulfill their mill contracts due to the poor quality of the harvest. "The loss of their wheat crop was pretty devastating, with effects extending out to the banking establishment, as lots of people rely on their wheat payment to meet their production loan or pay their out-of-pocket production expenses," according to Paul Gunter, extension agent for Queen Anne's Co.

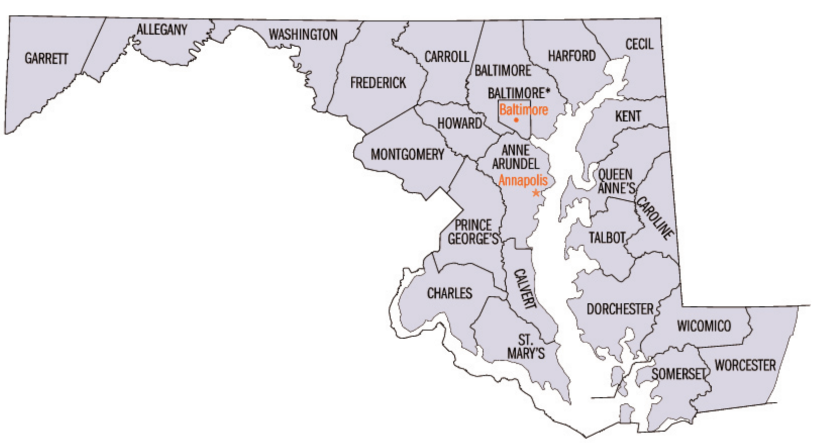

Fig. 2. Maryland county map

Virginia: FHB in wheat has also been a recurrent problem in Virginia. FHB was widespread in the state in 2003, es-

■ ***One grower, who called his contracted mill to inquire why his wheat field appeared pink, was told the FHB level "was so high he might as well get down off his combine and call it a day."***

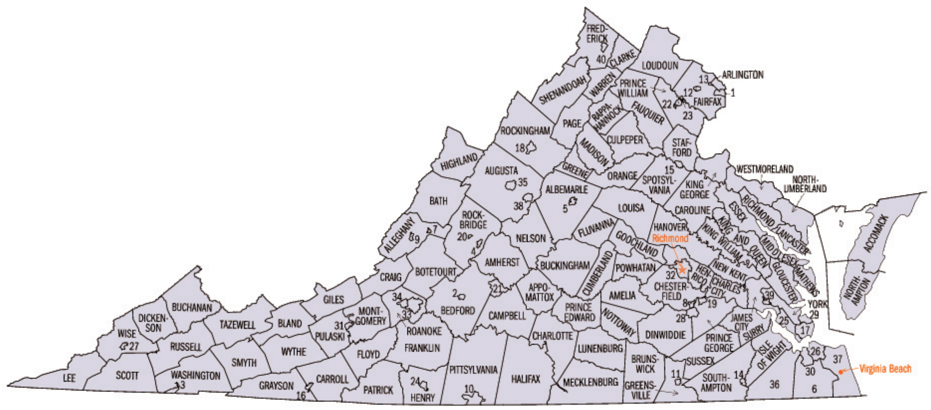

Fig. 3. Virginia county map

pecially in the eastern counties, where the majority of wheat is grown. Disease levels were moderate throughout the majority of the wheat-growing area, although some areas and individual growers were severely affected (Fig. 1). The Northern Neck region of Virginia, represented by Northumberland, Richmond and Westmoreland counties (Fig. 3), has historically had the highest levels of FHB in the state, with southern areas much less severely affected. In 2003, this situation was reversed. Growers from the northeastern portion of the state found FHB to be milder than in previous years, while the crop in southeastern Virginia was much more severely affected. Watson Lawrence, extension agent for Chesapeake City County (Fig. 3), said, "Scab has become a serious threat to small grain production in southeastern Virginia."

Disease occurrence in surveyed counties ranged from 0% to 100%, with the majority of counties falling into the 50% to 100% range. In counties where all growers were affected, approximately half had moderate severities. The remainder were affected only slightly. Yields fell from the usual 50-70 bu/acre to 30-40 bu/acre in some areas. While other problems affected yield in 2003, Keith Balderson, extension agent for Essex County (Fig. 3), felt FHB played a significant role in the decline. Lowered test weights were also a concern. Test weights, usually 58-60 lb, fell to as low as 48-50 lb, causing growers to have difficulty selling their wheat.

Dr. Erik Stromberg, plant pathologist at Virginia Polytechnic Institute, said DON levels in affected areas were fairly high. Across test sites, the mean DON level for entries in VPI's 2003 State Wheat Test was 1.18 ppm, with a range from 0.0-3.4 ppm. C. J. Lin of Mennel Milling found FHB to be his most serious problem in 2003. All of the wheat sourced from Virginia by Mr. Lin was contaminated to some extent. DON levels were a major concern. Normally, Mennel Milling rejects trucks testing higher than 1 ppm DON. In 2003, average DON levels were so high that the mill found it necessary to modify its rejection threshold. Even so, Mr. Lin was compelled to reject approximately 5% of incoming trucks.

North Carolina: As was typical for the other states surveyed, disease occurrence and severity in North Carolina varied widely among counties throughout the state (Fig. 1). There was an occasional severely affected field in the midst of a county where most growers were primarily unaffected. Head blight incidence was in general higher throughout North Carolina than in previous years. Dr. Paul Murphy, small grains breeder at North Carolina State University, found a large number of fields with up to 30% of the heads infected.

Disease severity varied by longitude. Severity was greater on average in the Piedmont than in the Coastal Plain. Seven of the 21 counties surveyed had no FHB to report, and five counties reported low to moderate occurrence and low severity. All of these counties are located in the Coastal Plain of North Carolina. One coastal county, Perquimans, had moderate FHB severity. Growers in the eastern part of the state found FHB to be patchy and not at major epidemic levels in most areas. Incidences of infected fields ranged from 33% to 80% with very low to moderate severities. Data were not obtained from one county, Pasquotank (Fig. 4), because little wheat was planted due to wet weather at planting.

Although some Coastal Plain counties reported decreased test weights, the primary impact was on yield, with yields being decreased by 10%-30%. Georgia Love, extension agent for Robeson County, could not say how much of the yield decrease was attributable to FHB, as yields were also driven down by the wet weather and other problems.

FHB was more severe in the western Piedmont than in the Coastal Plain (Fig. 1). Eight counties, all in the Piedmont, had incidences of affected fields that were moderate to high, ranging from 35% to 80%, and high severities, ranging from 60% to 80%. Yields from this area were decreased by 30%-100%. Test weights were poor in all areas of the Piedmont, according to Dr. Randy Weisz, small grains extension specialist at NCSU. According to Mike Pate, Mid-State Mills, the normal mean test weight for this region is 58.2 lb. In 2003, growers reported test weights in the 40- to 56-lb range. Although the mills lowered their test weight standards, many Piedmont growers had difficulty selling their wheat. The majority of growers with affected crops were still able to sell their wheat for use in flour, although many had to blend their wheat prior to sale to decrease DON levels. Some growers passed their wheat through their combines multiple times to decrease tombstone concentrations before they were able to sell their harvest for flour milling. At the same time, wheat in some counties in the western Piedmont appeared to be unaffected. The extension agents in Cleveland, Lincoln, and Catawba counties felt that they had a greater problem with Septoria disease than with FHB in 2003.

E. H. Cook, a grower in Mecklenburg County, had to sell all of his wheat for feed rather than flour, due to poor test weights (Fig. 5). "It was the worst wheat year I ever had, but these things happen and you just have to learn to deal with them." Some growers were unable to harvest their crops at all due to the high levels of FHB in their fields. One grower, who called his contracted mill to inquire why his wheat field

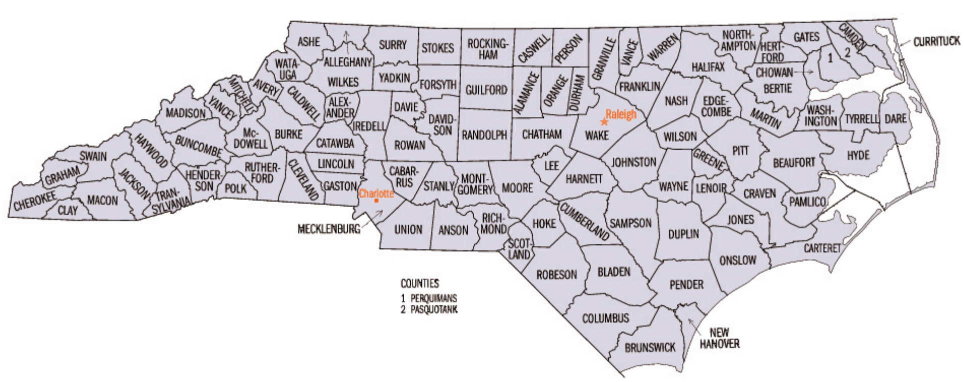

Fig. 4. North Carolina county map

Millers initially estimated that 50% of the wheat from North Carolina would not be suitable for human consumption in 2003.

appeared pink, was told the FHB level "was so high he might as well get down off his combine and call it a day." In Rowan County, some of the newer growers are growing wheat for seed production, and they had difficulty selling the wheat in 2003 due to low germination rates.

One of the biggest concerns with the 2003 harvest in North Carolina was the DON level, which was markedly higher than in previous years. Increased DON levels may have been related to the extended harvest, which was delayed due to rain. Millers initially estimated that 50% of the wheat from North Carolina would not be suitable for human consumption in 2003. Joe Mitchell of Bartlett Mills was forced to reject approximately 20% of submitted wheat loads due to elevated DON levels. According to Mr. Mitchell, 2003 was the worst year Bartlett Mills has experienced in terms of load rejection. Other area mills reported similar levels of rejection. More growers than ever before were forced to cancel their contracts due to high DON levels, resulting in a financial hardship for both the growers and the mills.

Although DON ceilings vary, most mills accept loads at 2 ppm DON and below, as a 50% reduction in DON levels is usually seen following milling. This reduction did not occur in 2003, and it is unclear why not. One reason may be that a higher proportion of "late" infections, i.e., those in mature wheat kernels, occurred. Infections of less mature kernels can generate tombstones, many of which are lost during cleaning. Infection of mature kernels may be asymptomatic and yet cause DON contamination. This may indicate that DON is not actually decreased following milling, but is decreased when the smaller lightweight infected kernels are removed prior to milling.

Lenuel Chamberlain of Deep Creek Grain found 2003 grain to have good test weight, but high DON levels. Deep Creek Grain, which buys grain and resells it for flour, feed, or seed depending on quality factors, does not test for DON and consequently did not reject any wheat. Mr. Chamberlain said pre-purchase DON testing was not conducted due to the high purchase cost of testing equipment. If the grain is subsequently rejected by flour mills, it is returned to the grain elevator and blended with wheat that has lower levels of mycotoxin in

Fig. 5. E. H and Will Cook, two small-grain growers in Mecklenburg Co., NC, who were severely affected by the 2003 FHB epidemic.

order to reduce the overall DON concentration to an acceptable level.

Mike Pate of Mid-State Mills reported seeing DON levels as high as 10 ppm in grain and 7 ppm in flour. According to Mr. Pate, many millers were not used to managing DON levels and were not able to meet the minimum requirements for 1 ppm in flour. Most mills do not blend their wheat post-milling, as DON distribution may not be uniform. Mr. Pate reported that major end-users of flour were concerned that the industry could be negatively affected by high mycotoxin levels.

The middlings obtained from the flour milling process are subsequently used in animal feed. Mixed reports were received on mycotoxin problems in middlings from North Carolina. Although DON ceilings are considerably higher in animal feeds than in flour for human use, Mr. Pate states that many of the middlings did not meet the standards for safety. However, DON had little impact last year on Murphy-Brown Corporation, which produces feed for hogs and chickens, according to Dr. Jeff Henson, swine nutritionist. Murphy-Brown has a goal of 5 ppm DON in finished feed for swine and will accept raw grain up to 10 ppm. In 2003, they found no decrease in their middlings supply, and no modifications of their program were required.

Troy Coggins, extension agent for Randolph and Davidson counties, found the elevated mycotoxin levels to be especially troubling because “many growers feed their wheat to their own livestock, and they don’t realize there is a problem with it before they feed it.”

South Carolina: In South Carolina, FHB was more prevalent than ever before, but still not more than 10% (Fig. 1). This level is considered “none to low” in the other areas of the Southeast surveyed. Dr. Benjamin Edge, small grain breeder at Clemson University, believes South Carolina’s historically low FHB level is due to the fact that the state warms up earlier that states to the north. Some growers were particularly affected by FHB in 2003, but distribution of FHB among growers was extremely patchy. Eight of 11 counties surveyed reported no FHB at all. Disease occurrence of less than 5% was found in 10% of the counties. The remainder had 5%-10% occurrence. The highest levels of FHB were found in Barnwell and Bamberg counties in the southern section of the state and in Lee County, which is centrally located (Fig. 6). Although most agents felt there was little disease of any sort in 2003, they considered Stagonospora nodorum blotch (SNB), powdery mildew and leaf rust to be the most important diseases. According to Dr. Jay Chapin, extension specialist at Clemson University, in rating wheat diseases it is difficult to distinguish FHB symptoms from those caused by *S. nodorum* and *Xanthomonas campestris* (cause of black chaff disease). South Carolina had a decreased wheat yield in 2003, primarily because of poor harvest weather. The wheat sat

Fig. 6. South Carolina county map

■ *High DON levels were detected in early truckloads of wheat obtained from an area within a 75-mile radius of Rome, GA, forcing mills to cease sourcing wheat from this area. Northern wheat was utilized to fill contractual obligations. Millers had difficulty explaining to growers that their wheat could not be sold due to something that they could not see, feel, taste or smell.*

in the fields 10-14 days post-maturity. Any effects from FHB were obscured by *S. nodorum* infection and harvest conditions.

County agents made no reports of high DON levels or of growers having difficulty selling their wheat. However, Jack Edgerton of Adluh Flour (Allen Brothers Milling Co.) was forced to reject approximately 40,000 bushels of wheat due to elevated DON levels, totaling more than 10% of submitted loads. It appears likely that there was a low level of FHB distributed fairly evenly throughout the state, with slightly higher levels in the southern regions. Since FHB has historically been of minor importance in South Carolina, agricultural extension agents have had little exposure to the disease. Due to the even distribution of FHB throughout the state, the low occurrence, and the presence of other wheat diseases that were confounded with FHB, extension agents, who were inexperienced with the disease, would have been unlikely to detect it. The elevated DON levels at Adluh Flour Mill may have been the result of asymptomatic FHB infections such as were seen in some areas of the Piedmont region of North Carolina.

Georgia: Like South Carolina, Georgia has historically had little FHB. Although 2003 was one of the worst years seen for FHB, it affected less than 10% of the wheat crop (Fig. 1). Dr. Dewey Lee, Associate Professor of Crop and Soil Science at the University of Georgia, found FHB to be a widely scattered problem.

County agricultural extension agents reported minimal disease from Gordon, Floyd and Bartow counties in northwest Georgia, but Dr. Jerry Johnson, small grains breeder at the University of Georgia, found that the disease impact was primarily concentrated in this area (Fig. 7). Georgia's milling industry encountered severe DON problems in northwest Georgia, with levels averaging 8 ppm ± 2 ppm. High DON levels were detected in early truckloads of wheat obtained from an area within a 75-mile radius of Rome, GA, forcing mills to cease sourcing wheat from this area. Northern wheat was utilized to fill contractual obligations. Millers had difficulty explaining to growers that their wheat could not be sold due to something that they could not see, feel, taste or smell.

Dr. Lee observed some FHB in south-

Fig. 7. Georgia county map

western Georgia, as well. There was an occasional wheat shipment that had high DON levels; however, there was little FHB in the remainder of the state. Jimmy Giles of Conagra Mills, which obtains all of its wheat from southern and central Georgia, reported no DON problems. The mill tested extensively for DON, as it had been warned that there might be a problem. Giles said 2003 was the worst year he has seen for wheat, but the problems were primarily due to sprouting and rain-delayed harvest, rather than to FHB.

Of the 13 counties surveyed, agents in eight counties reported seeing no FHB. Two other counties had occurrence of less than 5%. Bruce Stripling, extension agent for Houston County, saw one field with significant FHB, but "for the most part we didn't look for it and (therefore) didn't see it." Rome Etheridge, extension agent for Seminole County, stated that 20% of the growers in his county had some FHB, but severity was slight and growers were minimally affected, and yields were little affected, averaging 60-70 bu/acre. No problems with test weights were reported.

The fact that agricultural extension agents did not report high levels of FHB from the upper northwest section of Georgia is most probably explained by unfamiliarity with FHB, and also possibly by asymptomatic infections. According to Dr. Dewey Lee, extension agents in Georgia are not very familiar with FHB, and most mistook it for Septoria. One extension agent acknowledged that he had never heard of FHB before and that he had not seen any in 2003, but he doubted he would have recognized it if he had. However, if FHB had been severe with visible symptoms, agents would have quickly become familiar with it. We conclude that, although there was some low level of disease throughout Georgia, and one area was severely affected, FHB impact in most of the state was low in 2003.

Surrounding States: The wheat-producing states surrounding those discussed above -- Indiana, Ohio, Pennsylvania, Delaware, Tennessee, Kentucky, Arkansas, Alabama, Louisiana, and Florida -- were not surveyed intensively by the authors of this case study. Instead, information regarding disease levels in 2003 was obtained primarily from researchers working there, as noted below. Here, "incidence" refers to the proportion of symptomatic heads, and "severity" refers to the mean proportion of diseased spikelets per head.

Indiana (Dr. Greg Shaner): In the southern part of the state, FHB was fairly severe, blending gradually to the north, where virtually no disease was evident. In affected areas, symptoms were not marked, but DON levels were nevertheless fairly high, ranging up to approximately 8 ppm. Temperatures during May were cool and precipitation persisted late in the season, causing a longer-than-normal grain-fill period. This increased the possibility of late infections. Disease indices, calculated as incidence x severity, were obtained from Dr. Shaner's Purdue University Variety Trials. Indices ranged from 2%-40%, with most being less than 20%. Dr. Shaner reported that DON levels showed a low correlation with disease index. DON levels of 6-8 ppm were found in infected wheat with disease indices ranging from 6%-40%.

Ohio (Dr. Pat Lipps): Fusarium head blight levels in Ohio were overall low to moderate, with some isolated outbreaks being higher. Surveys of 148 fields in 30 counties coordinated by Lipps in 2003 found FHB incidences ranging from 0% to 73%, with the average incidence per field being 8.9%. In most cases, severities were low; 8.1% of surveyed fields had moderate to high levels of FHB (7).

Pennsylvania (Dr. Erick De Wolf): Pennsylvania experienced moderate FHB infection overall, with areas of localized severe disease. Disease incidence in 30 wheat fields surveyed in 11 counties in 2003 ranged from 1% to 87%, with an average of 34.5%. The counties with the highest FHB incidence were in the southeastern corner of the state (2).

Delaware (Dr. Robert Mulrooney): FHB appeared to occur in all varieties in the state wheat variety trial, in spite of the wide range of flowering dates. However, overall severity levels were light to moderate, lower than in previous years. Approximately 30%

of wheat fields were affected, with varying severities. Disease severity was greatest in New Castle Co., in the north of the state. The lower two counties had high proportions of affected growers, but lower disease severities. Test weights were lowered and yields were decreased; however, it was difficult to determine how much of these decreases was due to FHB.

Tennessee (Dr. Melvin Newman): FHB was light and effects were relatively negligible compared to 1991, when Tennessee lost 50% of its wheat yield to FHB.

Kentucky (Dr. Don Hershman): FHB was severe in Kentucky in 2003, where about 25% of small-grain acreage is cultivated with minimum or no tillage. A cool grain-fill period limited symptom expression, but much of Kentucky's wheat exceeded the acceptable DON levels for human consumption, and was not readily marketable. Seed germination was also severely affected; 80% of samples received by the University of Kentucky Seed Testing Laboratory were significantly below the 85% germination standard, while in low-FHB years most samples exceed the 85% standard. FHB is chronic in Kentucky, where in-

Table 1. Site locations and descriptions of weather source data

STATE	COUNTY	STATION	DESCRIPTION
GA	DOUGHERTY	KABY	ALBANY MUNICIPAL
GA	FLOYD	KRMG	ROME/RUSSELL(RAMOS)
GA	BARTOW	KVPC	CARTERSVILLE_CARTERSVILLE ARPT
MD	ST. MARY'S	KNHK	PATUXENT RIVER NAS
MD	WORCESTER	KOXB	OCEAN CITY_OCEAN CITY MUNICIPAL ARPT
MD	WICOMICO	KSBY	SALISBURY REGIONAL
NC	MECKLENBURG	KCLT	CHARLOTTE/DOUGLAS
NC	DUPLIN	KDPL	KENANSVILLE_DUPLIN CO ARPT
NC	CHOWAN	KEDE	EDENTON_NORTHEASTERN REGIONAL ARPT
NC	UNION	KEQY	MONROE_MONROE ARPT
NC	DAVIDSON	KEXX	LEXINGTON_DAVIDSON CO ARPT
NC	WAYNE	KGSB	SEYMOUR-JOHNSON AFB
NC	GUILFORD	KGSO	GREENSBORO/PIEDMONT
NC	RANDOLPH	KHBI	ASHEBORO_ASHEBORO MUNICIPAL ARPT
NC	CATAWBA	KHKY	HICKORY REGIONAL
NC	LINCOLN	KIPJ	LINCOLNTON_LINCOLNTON-LINCOLN CO.REGIONAL ARPT
NC	ROBESON	KLBT	LUMBERTON_LUMBERTON MUNICIPAL ARPT
NC	BEAUFORT	KOCW	WASHINGTON_WARREN FIELD ARPT
NC	ROWAN	KRUQ	SALISBURY_ROWAN CO ARPT
NC	IREDELL	KSVH	STATESVILLE_STATESVILLE MUNICIPAL ARPT
SC	FLORENCE	KFLO	FLORENCE REGIONAL
SC	ORANGEBURG	KOGB	ORANGEBURG_ORANGEBURG MUNICIPAL ARPT
SC	SUMTER	KSSC	SHAW SFB/SUMTER
SC	DARLINGTON	KUDG	DARLINGTON_DARLINGTON CO JETPORT ARPT
VA	CHESAPEAKE CITY	KCPK	CHESAPEAKE_CHESAPEAKE MUNICIPAL ARPT
VA	ACCOMACK	KMFV	MELFA/ACCOMACK ARPT
VA	CHESTERFIELD	KRIC	RICHMOND/BYRD FIELD

dustry sources estimate that DON in small grains causes significant problems in about three of every five years.

Arkansas (Dr. Gene Milus): Arkansas did not have FHB-conducive weather during the wheat flowering period of 2003. April and the first half of May were dry; the latter half of May was very wet. This resulted in very late infection, with some head blight occurring in virtually every wheat field, but disease incidence and DON levels remained low.

Louisiana (Dr. Boyd Padgett): Although FHB was quite severe in the wheat in Louisiana's rice-growing region, it was patchily distributed in the rest of the state. The number of affected fields was small and the economic impact was fairly minimal. Growers that were affected by head blight were severely affected.

Alabama (Dr. Paul Mask): A small amount of FHB is present in Alabama in most years. However, Dr. Paul Mask, Assistant Director of Extension at Auburn University, did not observe FHB in the state in 2003. This may have been due to an absence of rain during anthesis.

Florida (Dr. Ron Barnett): Florida has little acreage devoted to wheat. While there is always a small amount of FHB present, it has never been a serious problem.

Northern Plains: Fusarium head blight was of minor concern in 2003 in the Northern Plains region of the U.S., which produced one of its best wheat and barley crops on record.

Table 2. Interpolated weather data sites

STATE	COUNTY	DESCRIPTION
GA	LAURENS	CADWELL
GA	HOUSTON	KATHLEEN
GA	SUMTER	PLAINS
GA	RANDOLPH	CARNEGIE
GA	SEMINOLE	IRON CITY
MD	CECIL	CHERRY HILL
MD	QUEEN ANNE'S	INGLESIDE
MD	CAROLINE	CONCORD
MD	DORCHESTER	AIREY
SC	BARNWELL	BARNWELL
VA	WESTMORE-LAND	TEMPLEMAN
VA	NORTHUM-BERLAND	HEATHSVILLE
VA	ESSEX	CARET
VA	HANOVER	ASHLAND
VA	SURRY	SPRING GROVE

WEATHER CONDITIONS AND THE SOUTH-ATLANTIC FHB EPIDEMIC

Moisture is the controlling factor for development of FHB (11). If sufficient moisture is available, infection may occur even at sub-optimal temperatures. Infection is favored by extended periods of high moisture and relative humidity >90%, and by moderate temperatures (15-30° C = 59-86° F) (9).

Disease forecasting models for FHB were jointly developed by university researchers in Pennsylvania, Ohio, and other states, with funding from the USWBSI. DeWolf et al. (3) analyzed the effects of various weather variables and their interactions prior to and during anthesis. They developed four models using logistic regression to predict the probability that an epidemic of ≥10% severity would occur.

Lipps and Mills (8) have subsequently utilized two of these models to forecast FHB in Ohio. Model I uses the hours of precipitation and the hours that air temperature is between 59 F and 86 F during the 7 days pre-anthesis. Model II utilizes the hours that temperature is between 59° F and 86° F during the 7 days pre-anthesis and the hours that relative humidity is >90% while temperature is 59-86° F during the 10 days post-anthesis. Model I was found to be more accurate at predicting when head blight would not develop (negative predictive value of 78%) than in predicting when FHB would develop (positive predictive value of 54%).

We examined environmental data for various time periods relative to anthesis in order to determine those that were most closely related to the FHB epidemic in 2003. Hourly temperatures, relative humidities,

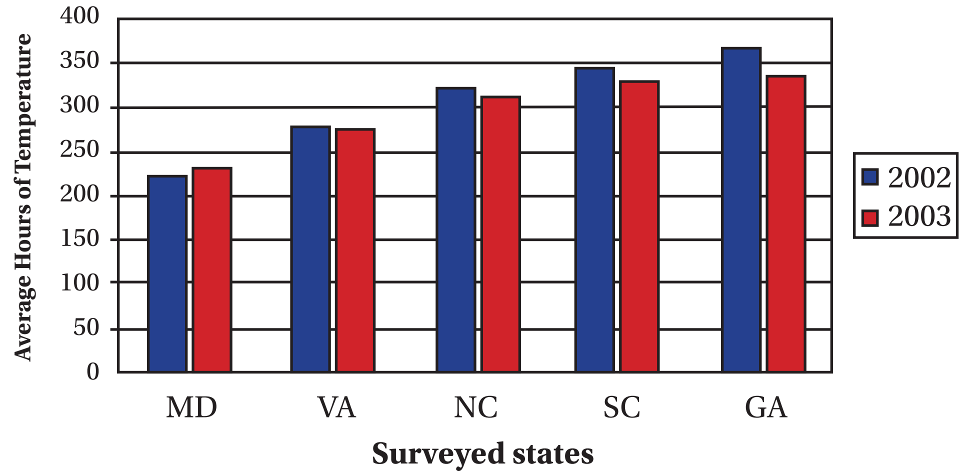

Fig. 8. Mean hours of conducive temperature (59-86°) for the period from 7 days pre-anthesis to 30 days post-anthesis.

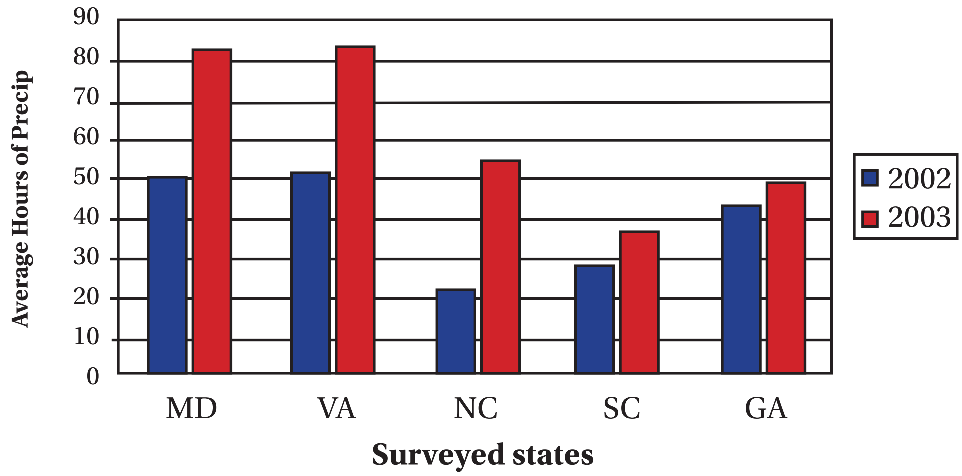

Fig. 9. Mean hours of rainfall for the period from 7 days pre-anthesis to 30 days post-anthesis

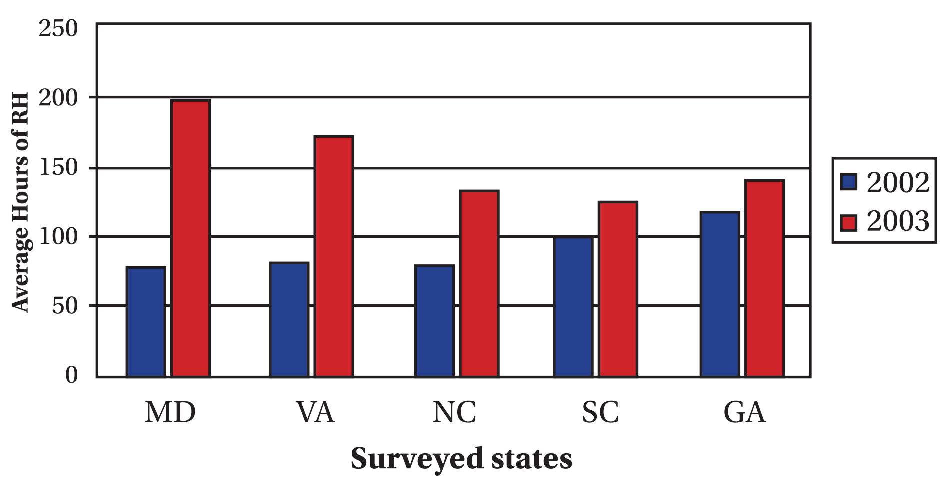

Fig. 10. Mean hours of conducive relative humidity for the period from 7 days pre-anthesis to 30 days post-anthesis

and hours of precipitation were obtained (ZedX Inc., Bellefonte, PA) for the period from 7 days prior to anthesis until 30 days following anthesis (Table 1). The data were obtained for 2002, a low-FHB year with drought conditions throughout the Southeast, and for 2003. If no weather data were available for a surveyed county, data from an adjacent county or interpolated values based on data from adjacent counties were used (Table 2).

Heading dates were obtained from state variety trials for all states and based on AGS 2000, a medium-maturity variety (Table 3). Where AGS 2000 was not available, the average heading date for all varieties in a trial was calculated. Five days were added to each heading date to estimate dates of anthesis. Approximate anthesis dates were generated for each surveyed county by inference from the anthesis dates at variety trial test sites.

Each of the 67 surveyed counties was assigned an FHB severity value of 1-4 as follows: 1 = "none to slight," 2 = "low," 3 = "moderate," and 4 = "severe."

Comparison of 2002 and 2003: For this comparison, severities in surveyed counties were averaged within states. Temperature variables were averaged by state for the period from 7 days prior to anthesis to 30 days post-anthesis. Hours of FHB-conducive temperatures were similar in 2002 and 2003 (Fig. 8). The mean hours of conducive temperature increased progressively from Maryland south to Georgia. The mean hours of rainfall were higher for all states in 2003 than in 2002, with the most significant increase in the three states where FHB was most severe: Maryland, Virginia and North Carolina (Fig. 9). Hours of favorable relative humidity were higher in Maryland and Virginia than in North Carolina, South Carolina, or Georgia (Fig. 10). Of the five states, the two with the highest mean temperatures, Georgia and South Carolina, also had the fewest mean hours of precipitation, such that both factors probably explained the relatively lower FHB levels in those states.

Table 3. Mean estimated heading dates for 2003

State	Site	Heading Date
MD	Beltsville	14-May
	Wye	19-Apr
	Quantico	9-May
VA	Orange	8-May
	Warsaw	6-May
NC	Rowan*	24-Apr
	Lenoir	19-Apr
SC	Simpson	28-Apr
	Blackville	12-Apr
GA	Griffin	5-Apr
	Plains**	10-Apr
	Tifton	30-Mar

* based on split boot dates
** approx. 2-wk delay in planting

Correlation of severity and weather variables: Hours of precipitation, hours of conducive temperatures, and hours of conducive relative humidity (>90%) were tallied for specific time intervals relative to anthesis. Data from all 67 counties surveyed were included in analyses to determine possible correlations between each variable and numerical severity on the 1-4 scale. Selected results are presented in Table 4.

No significant correlation was found between pre-anthesis temperature or precipitation, either separately or when both factors were conducive, and 2003 FHB severity (Table 4).

A significant negative relationship was found for conducive temperature and severity during the 10 days post-anthesis, although the correlation coefficient was low (r = Pearson's correlation coefficient = -0.323, P = 0.008).

Relative humidity (RH) in the 10 days post-anthesis was positively correlated with FHB severity, although with a low correlation coefficient (r = 0.397, P = 0.001), and was also strongly correlated with precipitation in the same period (r = 0.627, P < 0.0001, data not in Table 4).

A significant correlation was found between severity and hours of precipitation in the 10-day, 20-day, and 30-day post anthe-

Altogether, these data suggest that post-anthesis rainfall was the most important weather variable driving the 2003 epidemic in the Southeast.

sis periods. The longer the post-anthesis interval, the larger was the correlation coefficient. Conducive RH for the 30-day post-anthesis period correlated significantly with disease severity (r = 0.431, P = 0.0003), and was also correlated with hours of precipitation in that same period (r = 0.498, P < 0.0001, data not in Table 4).

Altogether, these data suggest that post-anthesis rainfall was the most important weather variable driving the 2003 epidemic in the Southeast. Weather conditions in the seven days prior to anthesis do not appear to have played as significant a role as post-anthesis weather, and were not a good predictor of FHB severity in the Southeast in 2003. Hours of precipitation within the first 10 days following anthesis correlated significantly with epidemic severity, and the

Table 4. Correlation between FHB severity and weather variables for 62 counties in Maryland, Virginia, North Carolina, South Carolina, and Georgia in 2003

Variable*	Correlation Coefficient (r)**	P-value**
Yield (bu/acre) as % of 10-year average	-0.588	< 0.0001
Conducive temperature during 7 d pre-anthesis	-0.139	0.2823
Hours of precipitation during 7 d pre-anthesis	0.002	0.9899
Conducive relative humidity during 10 d post-anthesis	0.383	0.0021
Conducive temperature during 10 d post-anthesis	-0.344	0.0061
Hours of precipitation during 10 d post-anthesis	0.465	0.0001
Hours of precipitation during 20 d post-anthesis	0.590	< 0.0001
Hours of precipitation during 30 d post-anthesis	0.619	< 0.0001
Conducive relative humidity during 30 d post-anthesis	0.408	0.0010
Conducive temperature during 30 d post-anthesis	-0.333	0.0081

*Conducive temperature = 15-30º C = 59-86º F.
Conducive relative humidity = greater than 90%.
**Null hypothesis: r = 0.

Table 5. Total 2003 winter wheat production in five southeastern U.S. states as compared to the 10-year average.

	Yield		Production	
State	2003 mean (bu/acre)	% of 10-yr average[a]	2003 total (1000 bu)	% of 10-yr average[a]
Maryland	37	62.2	5,365	44.3
Virginia	46	79.4	7,360	54.4
North Carolina	36	79.8	14,760	57.0
South Carolina	39	93.1	7,215	68.1
Georgia	46	101.3	10,580	83.9

[a]1993-2002.

correlation improved as hours of precipitation were tallied for successively longer time periods.

Of course, the relationships we found by correlation analysis cannot be extrapolated outside the region. It is likely that in years of normal rainfall, temperatures limit FHB severity across the Southeast, the more so the farther south one goes. Since extended periods of rain appear to compensate for temperatures outside the conducive range, it may be that prolonged rainfall in May-June is in general necessary for a severe FHB epidemic to develop in the southeastern U.S. wheat-growing region.

ECONOMIC IMPACT

Fusarium head blight has far-reaching economic effects. Its biggest effect in the United States in recent years has been felt in the spring grain region of the upper Midwest. Farmers have sustained large losses that have resulted in bankruptcy for many. Between 1990 and 2002, wheat and barley farmers lost over $3 billion due to FHB epidemics in the U.S (9). In general, the Southeast has been exempt from the ravages of FHB. This changed in 2003, when FHB reached epidemic proportions in this region

FHB primarily causes economic loss by diminishing yield, test weight and seed/grain quality. In order to estimate FHB damage, data on yield and wheat acreage planted and harvested were obtained for the period 1993-2003 from the USDA National Agricultural Statistics Service (NASS). Of the 67 surveyed counties, 2003 yield data were unavailable for five.

Production: The disease affects yield by decreasing the number of kernels produced, and by affecting the quality of kernels that are produced. Kernels may be small, light-weight and "scabby." This decreases the volume and mass of kernels obtained at harvest, as the smaller, light-weight kernels are frequently lost from the rear of the combine. Yields in all counties surveyed in 2003 were greatly decreased from the 10-year average, with the largest decrease occuring in Maryland (Table 5).

The percentage of wheat acreage that is harvested may be reduced by FHB if infection is so severe that the crop is a total loss. The percentages of harvested acreage in the counties surveyed dropped in all three states in 2003 as compared to the 10-year average (Fig. 11). This percentage can also be affected by many other factors, such as weather, other diseases and the original use for which the wheat was planted, i.e. grazing versus milling/seed. Yield and percentage of acreage harvested together determine the total wheat production for the state. Total wheat production for all surveyed states was much lower in 2003

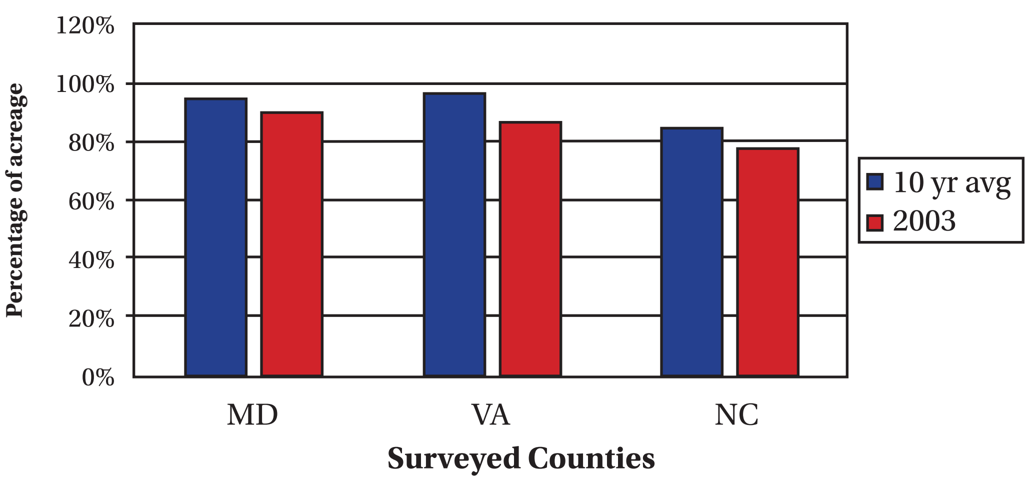

Fig. 11. Percentages of planted acres that were harvested in 2003 versus the 10-year average.

(Table 5).

For the surveyed counties, 2003 yields as a percentage of 10-year average yields were significantly correlated with estimated FHB severity ($r = -0.588$, $P < 0.0001$). In order to separate the FHB effect on yield from those of other factors, 2003 yield as a percentage of the 10-year county average yield was regressed on estimated severity. Yields in 2003 were 90% of the 10-year average when the FHB effect was removed, and yield declined an additional 7.9 percentage points for each one-point increase in estimated FHB severity.

In surveyed counties in Maryland, Virginia, and North Carolina, estimated FHB severity was significantly correlated with the 2003 harvested percentage of planted acres in relation to the 10-year average harvested percentage ($r = -0.343$, $P = 0.0301$), with a loss of 4.1 percentage points for each one-point increase in estimated FHB severity. In Georgia and South Carolina, FHB effects on acreage harvested were confounded by effects of other diseases, weather, and wheat usage (e.g., forage), and harvested acreage percentages were not significantly correlated with estimated disease severity.

Production losses due to FHB were calculated based on the estimated FHB effect on yield and acreage harvested. Economic losses due to FHB were calculated using mean statewide wheat prices reported by NASS ($3.15/bu in MD, $2.95/bu in VA, and $2.90/bu in NC).

Estimated pre-milling losses due to FHB in 40 surveyed counties in Maryland, Virginia, and North Carolina totaled over $17 million (Table 6). In 2003, these counties accounted for 71.7%, 45.8%, and 48.0% of wheat production in the three states, respectively. Thus, total production losses due to FHB in those states in 2003 were substantially higher. For example, FHB probably causes an average 2- to 5-bu/acre yield loss in eastern North Carolina wheat fields in most years, according to Brian Ashford of Beaufort County.

Regression analysis indicated that, with the exception of several counties in northwest Georgia, most South Carolina and Georgia wheat growers did not suffer significant economic losses due to FHB.

Test weights: As well as decreased yield, lowered test weight due to FHB has a tremendous impact on grower revenue. The smaller ‘scabby’ kernels or tombstones have

Table 6. Estimates of 2003 pre-milling economic losses in winter wheat due to FHB for 40 surveyed counties in Maryland, Virginia, and North Carolina.

MD – 10 counties	
Production*	$ 6,951,465
Test weight**	2,155,065
MD 10-county pre-milling total	$ 9,106,530
VA – 10 counties	
Production*	3,057,427
Test weight**	300,725
VA 10-county pre-milling total	$ 3,358,152
NC – 20 counties	
Production*	4,461,793
Test weight**	196,105
NC 20-county pre-milling total	$ 4,657,898
Pre-milling total for 40 surveyed counties	$17,122,580

*Losses due to FHB effects on yield and harvested acreage.
**Includes only losses in counties ranked 3-4 in FHB severity.

lower test weights. As test weight drops, the price per bushel that millers are able to pay the grower also drops (Table 7). When test weight falls below 56 lb/bu, the grain is suitable for sale only as feed wheat, which commands a much-reduced price.

No detailed data are available on the losses due to FHB-decreased test weights. In Maryland, the price paid for wheat for flour averaged around $3.00 per bushel in 2003, whereas growers received just $0.80 per bushel for wheat subsequently sold for use in chicken feed. Thus, if a grower harvested 100 acres of wheat with a yield of 37 bu/acre, the average yield for Maryland in 2003, s/he received approximately $8,100 less if the wheat was sold for feed than if it was sold it for flour. The food-feed differential in Virginia and North Carolina appears to have been $1-$2/bu.

Although many factors affect test weight, the following are estimates of the economic effect of lowered test weight due to FHB in 2003, based on authors' estimates of the percentage of harvested acres in which lowered test weights would have necessitated selling wheat for feed, not food:

Maryland: 50% of crop affected x 50% of that was due to FHB x 105,900 harvested wheat acres in Maryland's 10 severely- to moderately-scabbed counties x 37 bu/A x $2.20 less per bu = $2.2 million loss.

Virginia: 25% of crop affected x 50% of that was due to FHB x 52,300 harvest acres in eight moderately- to severely-scabbed counties x 46 bu/A statewide average yield for 2003 x $1 less per bu = $300,725 loss.

Test Weight	Price Discount/Bu.
57.9 lb - 57.5 lb	(-) $0.02
57.4 lb - 57.0 lb	(-) $0.04
56.9 lb - 56.5 lb	(-) $0.06
56.4 lb - 56.0 lb	(-) $0.08
55.9 lb - 54.0 lb	Feed wheat

Table 7. Discount schedule for soft red winter wheat crop. Midstate Mills, Newton, NC.

North Carolina: 25% of crop affected x 50% of that was due to FHB x 43,100 harvest acres in nine moderately- to severely-scabbed counties x 36.4 bu/A x $1 less per bu = $196,105.

Seed production: FHB takes a toll in several ways on wheat that is produced for seed. Severe FHB increases the "cleanout" rate, i.e., wheat rejected in the process of cleaning grain for seed. The rejected wheat fails to receive a premium of approximately $0.30-$0.60/bu, and must be sold for feed, not flour. Also, processors of certified seed incur increased costs for fungicidal seed treatment, and lowered germination rates may reduce yields or necessitate higher seeding rates in the next year. An increase due to FHB of approximately 6% in the cleanout rate occurred on a statewide basis in Maryland, Virginia, and North Carolina in 2003. Assuming an average of $1.50/bu loss on the rejected wheat, this resulted in approximately $172,500 in losses to growers. To that must be added higher handling and conditioning costs, and long-term effects on yield.

DON: DON, which may be present in both abnormal- and normal-appearing kernels, also severely reduces grain quality and marketability. Grain that tests above acceptable limits for DON concentration may be downgraded from food grade to feed wheat at a considerable loss to the farmer. DON levels may be high enough to make the grain unacceptable for any use, representing a complete loss to the grower.

DON has a severe impact on the milling establishment as well as the wheat producer. Millers incur higher costs through the need to test more wheat than usual for DON and the additional handling and cleaning procedures needed to improve grain quality. Rejection of large numbers of wheat loads can severely decrease the amount of grain available to mills to fulfill contracts. Although some mills make growers responsible for obtaining grain to fulfill their mill contracts, the majority of mills bear the financial burden of obtaining the additional wheat. This can mean higher purchase prices, additional freight and handling fees, or both.

"Vomitoxin is a big threat to our bottom line. Other wheat quality problems can be dealt with, but with vomitoxin there is nothing we can do." (C.J. Lin, Mennel Milling)

Mennel Milling in Virginia generally outsources wheat from Ohio to complete contractual needs. However, in 2003 FHB limited the wheat supply even in southern Ohio. The company was then forced to source wheat from Michigan at an increased freight cost of $200,000, a significant financial hardship. C. J. Lin of Mennel Milling stated that "vomitoxin is a big threat. It causes great loss of money and financial hardship for the flour mill. It was a big problem in 2003 as compared to previous years, approximately half a million dollars difference. Vomitoxin is a big threat to our bottom line. Other wheat quality problems can be dealt with, but with vomitoxin there is nothing we can do."

Mills in North Carolina were similarly affected. Deep Creek Grain usually buys from local sources, but in 2003 was forced to truck in wheat from Indiana to cover contracts at an additional cost of approximately 50 cents per bushel. Bartlett Mills generally starts outsourcing wheat from Ohio in January-February, after exhausting local supplies, in order to complete contracts. In 2003, Bartlett was forced to begin outsourcing in September-October. Mid-State Mills ceased sourcing wheat from North Carolina early in the season and began drawing grain from 100–300 miles away, even from as far away as Ontario. Bill Saunders of Murphy Brown Farms was forced to bring in 525 rail cars from outside North Carolina in 2003.

The early outsourcing and the large shipping distances substantially increased costs to grain mills. Although Deep Creek Grain was able to sell all of its wheat for some level of use last year, it sustained a $50,000 loss. "If I had another year like last year," said Lenuel Chamberlain of Deep Creek, "I would have to stop buying wheat."

Adluh Flour in South Carolina does not outsource wheat. In order to fill their contracts, growers outsource the wheat as needed on an individual basis. In 2003, four growers contracted to Adluh Flour were unable to fill their contracts. Due to the decreased supply, the mill was forced to offer price premiums in order to obtain quality wheat. The lost contracts and price increases resulted in a loss to the flour mill of approximately $40,000.

FHB has an ancillary impact on mills' customers, who are forced to utilize grain with different milling and baking properties than those to which they are accustomed. In fact, the disease can have far-reaching effects on people beyond those directly involved in milling and production. In Kent County, Maryland, a bakery is being developed as a new business venture. If wheat of sufficient quality for bakery use cannot be grown, it will have a significant impact on the economy of the county.

In sum, staff at 10 mills in the mid- and south-Atlantic region reported per-mill losses to FHB ranging from $40,000 to $500,000. If such loss rates prevailed among mills throughout the region, total losses of at least several million dollars can be estimated.

ISSUES RAISED

Tillage: The choice of crop rotation and tillage pattern can affect disease incidence. Rotations including corn provide for the overwintering of the pathogen and subsequent inoculum availability in the spring. No-tillage wheat/double-crop soybean rotations will have similar effects if wheat is planted into wheat straw left from the previous crop.

The majority of *F. graminearum* spores travel only short distances, but given appropriate wind, spores have been collected hundreds of feet in the air above fields, forests and lakes. If spores are able to remain viable over long distances, local rotation and tillage practices for disease control may be rendered less effective. Opinions concerning the ability of *F. graminearum* spores to cause diseases by traveling long distances vary considerably. Dr. Erik Stromberg feels that the spores can not withstand the UV radiation to which they are exposed, and that most inoculum sources are local, such that tillage is the principal determinant of disease.

Dr. Stromberg's view is supported by disease patterns in North Carolina in 2003. Although weather variables did not vary significantly across the state, severities varied considerably, roughly in accordance with tillage. In the Coastal Plain region, which was much less affected in 2003, conventional tillage prevails. Conservation tillage is the norm in the Piedmont region, where disease was severe. The majority of North Carolina's corn silage crop is also produced in this region, providing a significant inoculum source.

Stephen Gibson, extension agent for the North Carolina Piedmont counties of Cleveland and Lincoln, felt these counties were much less FHB-affected than the rest of the Piedmont, in spite of similar weather conditions, because little corn is grown in either county. The reverse may be true for Randolph and Iredell Counties, which had high severities, moderate weather conditions and large amounts of corn grown in their counties, as well as 100% no-till farming. Farmers in this area remain committed to conservation tillage due to water quality factors and other benefits of the practice. According to Michael Miller, agricultural extension agent for Iredell County, "No-till wheat is a breakeven or slight-loss crop, but growers make up for it with no-till corn and soybeans. The decrease in soil erosion and sedimentation is very important. Growers (in this area) are unlikely to change their tillage practices."

However, 2003 saw an unusual relationship between tillage and FHB severity in Virginia. The northern portion of the state is primarily no-till, and historically has had more FHB than southeastern Virginia, where conventional tillage is more common. In 2003, FHB was more severe in the southeast than in the north. This variation in the relationship between severity and tillage pattern indicates key information regarding the epidemiology of FHB is still missing.

Mycotoxin minimization: Drying harvested wheat to 13.5 % moisture as soon as possible following harvest has been found to reduce mycotoxin production (6). The strategy of minimizing DON levels through early harvest and mechanical drying of the crop has not been tested experimentally, to our knowledge, in North Carolina. At present, it appears that many mid-Atlantic growers with potential FHB problems are unaware of the importance of timely harvest. Considering the major impact DON has on the flour and feed industry, continued research and education in the areas of harvest and post-harvest DON management is essential.

Role of corn: According to Scott Walker, a plant pathologist with Monsanto Corporation in Haubstadt, Indiana, southern corn hybrids vary for susceptibility to both Gibberella ear rot and stalk rot (both caused by *F.* = *Gibberella zeae*). However, commercial corn pathologists consider *F. graminearum* a northern problem in corn, mostly as a stalk rot agent, and not a southern problem, according to Dr. Walker.

Forage tests conducted by the North Carolina Department of Agriculture indicate that North Carolina corn whole plant silage not infrequently contains DON, although rarely at levels above the acceptable limits for animal feed. Of 313 forage samples tested for DON in 2003, almost all from the North Carolina Piedmont region, 114 were positive for DON. Of those 114 samples, 16% were small-grain, and 84% were corn whole-plant samples. Of the 114, 11 were also positive for zearalenone, all under 0.7 ppm. Only four of the 114 were corn samples with >5 ppm DON, and none of those were above 10 ppm. The recommended ceilings are 5 ppm for swine feed, and 10 ppm for poultry and cow feed. The 313 samples represented about 20% of all forage samples submitted to the NCDA for testing in 2003; most cereal forage samples that are tested are not tested for DON.

It appears that Mid-Atlantic and Southeastern corn may be widely infected by *F. graminearum,* and that this fungus may not present a significant threat to human or animal health via corn consumption. However, the infected corn provides abundant and widespread inoculum for wheat crops. It is unclear whether *F. graminearum* is infecting corn at the seedling stage, at silking, or later. It would be beneficial to learn more about the *F. graminearum*/corn pathosystem in the Mid-Atlantic and Southeast, in order to better understand opportunities to manage the pathogen.

Weather : Controlled studies are needed to investigate the relative influence of pre- and post-anthesis weather conditions on FHB severity in the Southeast. The patterns observed in 2003, together with the widespread observation of asymptomatic grain with high DON levels, suggest that late infections – perhaps even those occurring 2-3 weeks post-anthesis – can make up a significant proportion of total infections. It is possible that some of these infections occurred in the glumes, rather than the grain itself, with DON being leached from the glumes into the grain by moisture. The timing and site of infection relative to ultimate DON level needs to be investigated.

Literature Cited

1. Bakingbusiness.com. 2004. Headline stories. http://www.bakingbusiness.com/headline_stories.asp?ArticleID=69530

2. De Wolf, E. 2003. Pennsylvania Survey for Fusarium Head Blight (Scab) of Wheat, 2003. Department of Plant Pathology, Penn State University.

3. De Wolf, E.D., Madden, L.V. and Lipps, P.E. 2002. Risk assessment models for wheat Fusarium head blight epidemics based on within-season weather data. Phytopathology 93:428-435.

4. Dickson, J.G., and Mains, E.B. 1929. Scab of wheat and barley and its control. USDA Farmer's Bulletin 1599. p. 1-18.

5. Dubin, H.J., Gilchrist, L., Reeves, J., and McNab, A., eds. 1997. Fusarium head scab: Global status and prospects. CIMMYT, Mexico, DF Mexico. 130p.

6. Lipps, P. 1996. Head blight or scab of small grains. The OSU Extension Fact Sheet AC-4-96.

7. Lipps, P. E., and Mills, D. 2003. Forecasting Fusarium head scab of wheat in Ohio, 2003. Dept. of Plant Pathology, The Ohio State University, OARDC, and OSUE, Wooster, OH.

8. Lipps, P.E. and Mills, D. 2003. Forecasting Fusarium head scab of wheat in Ohio, 2003. Ohio State University Extension Plant Pathology Department Series 119.

9. Schmale III, D.G. and Bergstrom, G.C. 2003. Fusarium head blight. The Plant Health Instructor. DOI:10.1094/PHI-I-2003-0612-01.

10. Stack, R.W. 1999. Plant health progress. APSnet Features. The American Phytopathological Society, St. Paul, MN, U.S.A. p. 1-6.

11. Stack, R.W. 2000. Plant health progress. Plt. Health Reviews. Accession DOI:10.1094/PHP-2000-0622-01-RV.

Appendix I - Study Participants

Maryland

Researchers and specialists:

Costa, Dr. Jose M.: Small grain breeder, Associate Professor of Breeding and Genetic Engineering, University of Maryland

Agricultural Extension Agents:

Beale, Ben: St. Mary's County
Gallagher, Betsy: Dorchester County
Gunther, Paul: Queen Anne's County
Hall, John: Kent County
Johnson, Eddie: Wicomico, Somerset, and Worcester Counties
Lewis, Jim: Caroline County
Potter, Shannon: Talbot County
Rowe, Scott: Cecil County

Virginia

Researchers and specialists:

Griffey, Dr. Carl A.: Small grain breeder, Professor of Crop and Soil Environmental Sciences, Virginia Polytechnic Institute
Stromberg, Dr. Erik: Professor of Plant pathology, Physiology and Weed Science, Virginia Polytechnic Institute

Agricultural Extension Agents:

Balderson, Keith: Essex, Hanover and Charles City Counties
Belote, Jim: Accomack County
Davis, Paul: New Kent County
Johnson, Samuel: Northumberland, Westmoreland and Richmond Counties
Lawrence, Watson: Chesapeake City County
Saphir, Mac: Caroline County
Shockley, William: Northhampton County
Slade, Glen: Surry County

Growers:

Beahm, Bruce: Manager VCIA Foundation Seed Farm, Westmoreland County
Hula, David: Charles City County
Sanford, Richard T.: Westmoreland County

Millers:

Lin, C. J.: The Mennel Milling Co., Roanoke, VA

North Carolina

Researchers and specialists:

Anderson, Dr. Kevin: Professor of Ruminant Medicine, North Carolina State University, College of Veterinary Medicine
Farrer, Dianne: Graduate research assistant, Department of Crop Science, North Carolina State University
Fountain, Dr. Myron O.: Director of NC Crop Improvement Assoc., Inc. and NC Foundation Seed Producers, Inc., North Carolina State University
Hagler, Dr. Winston: Professor and Mycotoxin Laboratory Director, North Carolina State University
Jordan, Sheila: Feed Administrator, Food and Drug Protection Division, North Carolina Department of Agriculture
Martin, Eddie: Seed Administrator, Plant Industry Division, North Carolina Department of Agriculture
Murphy, Dr. J. Paul: Small grain breeder, Professor of Crop Science, North Carolina State University
Piggott, Dr. Nick E.: Associate Professor, Agricultural and Resource Economics, North Carolina State University
Spears, Dr. Jan: Professor of Crop Science, North Carolina State University
Weisz, Dr. Randy: Associate Professor of Crop Science and Small Grains, North Carolina State University
Whitlow, Dr. Lon: Professor and Interim Departmental Extension Leader, Department of Animal Science, North Carolina State University

Agricultural Extension Agents:

Ambrose, Gaylon: Beaufort County
Beasley, George (Bert): Wayne County
Brown, Allison: Alexander County
Carpenter, Jeff: Lincoln and Catawba Counties
Coggins, Troy: Randolph and Davidson Counties
Cowden, Jim: Rowan County
Gibbs, Mac: Hyde County
Gibson, Stephen: Cleveland and Lincoln Counties
Gonzalez, Paul: Sampson County
Hoover, Gregory M.: Davie County
Love, Georgia: Robeson County

Miller, Michael: Iredell County
Monroe, James: Mecklenburg County
Pegram, Tom: Union County
Smith, Lewis: Perquimans County
Spivey, Bryant: Duplin County
Wickliffe, William B. II: Guilford County
Winslow, Frank: Washington and Tyrell Counties
Wood, Al: Pasquotank County

Growers:

Angell, Rusell: Davie County
Ashford, Brian: Agronomist, Beaufort County
Cook, E. H.: Mecklenburg County
Cook, Will: Mecklenburg County
Cox, Rusty: Union County
Foster, Spurgeon: Davie, Davidson, and Randolph Counties
Howey, Frank Jr.: Monroe and Union Counties
Hunter, Gene: Mecklenburg County
McClain, Phil: Iredell County
Smith, Jerry: Union County
Stone, Bo: Robeson County

Millers:

Chamberlain, Lenuel: Deep Creek Grain, Yadkinville, NC
Fryar, David: Bartlett Milling Co., Statesville, NC
Mitchell, Joe: Bartlett Milling Co., Statesville, NC
Pate, Mike: Midstate Mills, Inc., Newton, NC
Tucker, Dennis: ADM Milling Co., Charlotte, NC

South Carolina

Researchers and specialists:

Chapin, Dr. Jay W.: Small Grain Extension Specialist, Professor of Entomology, Clemson University
Edge, Dr. Benjamin E.: Small grain breeder, Department of Entomology, Soils and Plant Sciences, Clemson University
White, Dawn: Wheat consultant

Agricultural Extension Agents:

Bethea, Vic: Dillon and Marlboro Counties
Beckham Lewis R., Jr.: Orangeburg County
Cubbage, Randy: Lee County
Duncan, Charles R.: Clarendon County
Gunter, David: Darlington County
Harvey, Greg: Sumter County
Johnson, Bruce: Horry County
Martin, Jody: Florence County
Varn, Joe: Barnwell and Bamberg Counties

Millers:

Edgerton, Jack: Adluh Flour, Allen Brothers Milling Co., Columbia, SC

Georgia

Researchers and specialists:

Johnson, Dr. Jerry W.: Small grain breeder, Professor of Crop and Soil Sciences, University of Georgia
Lee, Dr. Dewey R.: Small grain agronomist, Associate Professor of Crop and Soil Sciences, University of Georgia

Agricultural Extension Agents:

Collins, Doug: Lee County
Crawford, Jim: Jefferson County
Creswell, Brian: Early County
Drinkard, Randy: Bartow and Floyd Counties
Duffie, Will: Terrell County
Etheridge, Rome: Seminole County
Hudgins, Joel: Decatur County
Joyce, Raymond: Laurens County
Komer, Steven: Randolph County
Latimore, Frank: Sumter County
Moraitakis, Steve: Gordon County
Moore, Tim: Miller County
Peavey, Krispin: Randolph County
Stripling, Bruce: Houston County

Millers:

Giles, Jimmy: Conagra Grain Processing, Macon, GA

Surrounding States and Region

Researchers and specialists:

Barnett, Dr. Ronald D.: Small grain breeder, Professor of Agronomy, University of Florida
De Wolf, Erick D., Assistant Professor of Plant Pathology, Pennsylvania State University
Harrison, Dr. Stephen A.: Small grain breeder, Professor of Agronomy, Louisiana State University
Hershman, Dr. Donald E.: Extension plant pathologist, University of Kentucky
Lipps, Dr. Patrick E.: Professor of Plant Pathology, The Ohio State University
Milus, Dr. Gene: Associate Professor, Cooperative Extension Service, Department of

Plant Pathology, University of Arkansas

Mask, Dr. Paul: Assistant Director, Cooperative Extension Service, Auburn University

Mulrooney, Dr. Bob: Extension Specialist, Department of Plant and Soil Science, Delaware State University

Newman, Dr. Melvin A.: Professor of Entomology and Plant Pathology, The University of Tennessee

Padgett, Dr. Boyd: Associate Professor of Plant Pathology, Louisiana State University

Shaner, Dr. Gregory E.: Professor of Botany and Plant Pathology, Purdue University

Millers:

Bruton, Joe: grain merchandiser for chicken feed, Perdue Farms

Henson, Dr. Jeff: swine nutritionist, Murphy-Brown Farms

Keller, Jerry: Southern States Feeds

Pate, Tim: Southern States Feeds

Saunders, William: Murphy-Brown Farms

Upton, Fred: grain merchandiser for chicken feed, Perdue Farms