The Southeastern U.S. Fusarium Head Blight Epidemic of 2003

Christina Cowger, Assistant Professor, and **Abbey L. Sutton,** Research Assistant, USDA-ARS, Department of Plant Pathology, North Carolina State University, Raleigh, NC 27695

Corresponding author: Christina Cowger. christina_cowger@ncsu.edu

Abstract

Fusarium head blight (FHB) caused unprecedented losses to southeastern U.S. wheat producers and millers in 2003. The epidemic was documented afterward through interviews with 120 researchers, extension agents, millers, and growers. Sixty-two counties in five states were assigned an FHB impact score of 1 to 4, and 2003 yield and weather data were obtained for those counties. The relationships of yield and pre- and post-flowering weather variables to impact score were evaluated using regression and correlation analyses. Yield as a percentage of the 10-year average was negatively correlated with FHB impact (r = -0.588, P < 0.0001). FHB impact was positively correlated with hours of post-flowering rainfall (r = 0.465, 0.590, and 0.619 for 10, 20, and 30 days post-flowering, respectively; $P \leq 0.0001$), but not correlated with hours of pre-flowering rainfall (P = 0.99). While this was not a controlled study, the results suggest that pre-flowering weather may have played a less significant role than post-flowering weather, and was unlikely to have been a good predictor of FHB severity in the southeast in 2003. Using 10-year average production data, pre-milling economic losses were estimated for 40 counties in Maryland, Virginia, and North Carolina at over $13.6 million. Wheat production in those counties comprised just 71.7%, 45.8%, and 48.0% of the statewide totals, respectively; thus, actual 2003 FHB-related losses to growers in those states were probably much higher. Additionally, mills in the region suffered losses of several million dollars in 2003 due to increased shipping, testing, and handling costs brought on by FHB.

Introduction

Fusarium head blight (FHB), or scab, has increased recently worldwide. In the U.S., FHB is mainly caused by *Fusarium graminearum* Schwabe (teleomorph = *Gibberella zeae*), a fungus that produces toxins including deoxynivalenol (DON) (7). Between 1990 and 2002, U.S. wheat and barley farmers lost over $3 billion due to FHB epidemics (5). The hardship caused by severe FHB epidemics in wheat and barley crops in the upper midwestern U.S. during six successive years of the 1990s has been documented (9).

In the southeastern U.S., losses to FHB historically have been geographically isolated and relatively minor, although researchers noted the potential for more severe epidemics based on pathogen population characteristics and environmental conditions (8). The year 2003 saw the most severe FHB outbreak in memory, with extensive losses throughout the mid-Atlantic states. The U.S. Wheat and Barley Scab Initiative (USWBSI) reported that FHB damage to the mid-Atlantic soft wheat-producing region was unprecedented, seriously disrupting the flow and trade of grain (1).

Moisture is the controlling factor for development of FHB. If sufficient moisture is available, infection may occur even at sub-optimal temperatures (7). Infection is favored by extended periods of high moisture and relative humidity (RH) >90%, and by moderate temperatures (59 to 86°F) (5).

Based on analyses of weather variables for the periods prior to and immediately following wheat flowering, FHB models were developed to forecast the probability of an epidemic of ≥ 10% severity (3). A model that uses pre-flowering weather to make FHB risk forecasts is now available for 23 states via a

web site maintained by Pennsylvania State University researchers (the Fusarium Head Blight Prediction Center, www.wheatscab.psu.edu).

Detailed surveys on disease incidence and severity were not conducted on the 2003 FHB epidemic in the southeast. Therefore, the first goal of this study was to develop a picture of the distribution and impact of the southeastern epidemic, while recognizing the risks of retrospective reporting. The second goal was to investigate the relationship of 2003 FHB incidence to weather influences in the pre- and post-flowering periods, in order to gather clues on why the epidemic was severe in that year and region. The limitations of the methodology are noted throughout this report.

Disease Impact Assessment

In spring 2004, interviews were conducted with 27 researchers and extension specialists; 58 extension agents, each responsible for one or two counties; 16 millers; and 20 growers in the southeastern U.S. (Maryland, Virginia, North Carolina, South Carolina, and Georgia). The purpose of the interviews was to assess the incidence and impact of the 2003 FHB epidemic. In each state, FHB information was collected for growers in the top 10 wheat-producing counties, as well as for growers in additional counties in areas with high disease levels, for a total of 62 counties regionwide.

Each county was assigned an FHB impact score of 1 to 4 as follows: 1 = none to slight with 0 to 4% of growers affected; 2 = low with 5 to 14% of growers affected; 3 = moderate with 15 to 49% of growers affected; and 4 = severe with 50%+ of growers affected. These impact values were not disease severities, but rather were based on the estimated percentage of growers who observed FHB symptoms (Figs. 1 and 2) and/or experienced problems with DON. A non-integer value, such as 2.5, indicated there was approximately equal evidence placing the county in the higher and lower categories.

Fig. 1. Soft red winter wheat heads bleached by Fusarium head blight (S. Harrison, Lousiana State University).
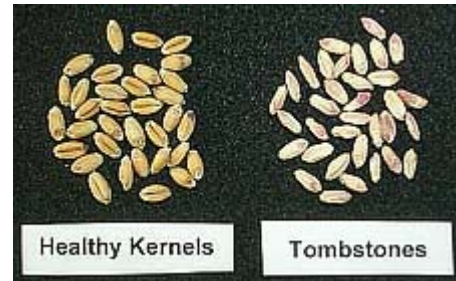

Fig. 2. Healthy soft red winter wheat kernels compared to kernels shriveled by *F. graminearum* infection ("tombstones") (J. P. Murphy, North Carolina State University).

As a general trend, FHB appeared to be most common in a belt stretching from the Maryland Eastern Shore to the northwest corner of Georgia (Fig. 3). However, within sub-regions such as the west-central North Carolina Piedmont, there were severely affected counties as well as counties that escaped significant FHB damage. Most wheat is planted no-till throughout the Piedmont, but the frequency of corn planted varies from county to county, and may explain some local differences, as FHB incidence and severity generally increase when wheat follows corn under reduced tillage (4).
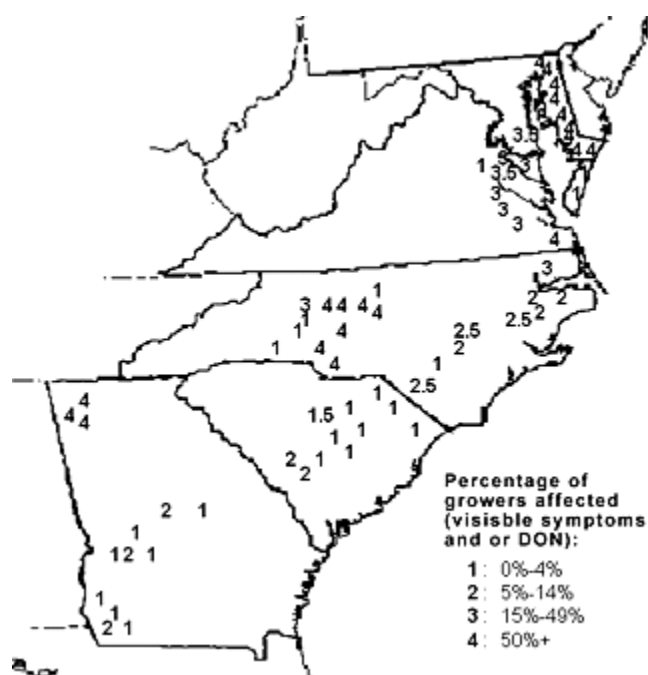
Fig. 3. FHB distribution and estimated impact in the mid- and south-Atlantic U.S. in 2003.

Flowering Dates and Weather Variables

Flowering dates, which provided the basis for quantifying pre- and post-flowering weather data, were estimated as follows. The mean heading date (Zadoks stage 55) for entries in state variety trials was calculated, and five days were added to estimate mean flowering dates (Zadoks stage 65; Table 1). By inference from the flowering dates at variety trial sites, approximate mean flowering dates were generated for each surveyed county. This methodology was certainly imprecise, because the range of heading dates among commonly grown varieties in the Southeast is about 7 days. However, the imprecision due to quantifying weather variables based on a mean flowering date should have only made it more difficult to find significant correlations between FHB impact scores and weather factors.

Hourly temperatures, relative humidities (RH), and hours of precipitation were obtained (ZedX Inc., Bellefonte, PA) for surveyed counties for the period from 7 days prior to estimated mean flowering until 30 days after flowering (*data not shown*). 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. Tallies were made of hours of conducive temperature (59 to 86°F) and conducive RH (> 90%) (5).

For 62 counties, correlation analyses were conducted for weather variables and FHB impact scores. The analyses were performed with SAS PROC CORR (SAS Institute Inc., Cary, NC). No significant correlation was found between conducive temperature or hours of precipitation and FHB impact for the 7 days pre-flowering. A significant negative relationship was found for conducive temperature during the 10 days post-flowering; i.e., conducive temperature was negatively correlated with FHB impact, although the correlation coefficient was low ($r = -0.344$, $P = 0.006$).

By contrast, a significant positive correlation was found between FHB impact and hours of precipitation in the 10-day ($r = 0.47$, $P = 0.0001$), 20-day ($r = 0.59$, $P < 0.0001$), and 30-day ($r = 0.62$, $P < 0.0001$) post-flowering periods. Conducive RH in the 10 days post-flowering was also positively correlated with FHB impact, with a low correlation coefficient ($r = 0.38$, $P = 0.002$), and, as might be expected, RH was strongly correlated with precipitation in the same period ($r = 0.63$, $P < 0.0001$).

Table 1. Mean flowering dates (Zadoks stage 65) at official variety trials in five southeastern states in 2003.

State	Site	Mean estimated flowering date[x]
Maryland	Beltsville	19 May
	Wye	24 May
	Quantico	14 May
Virginia	Orange	13 May
	Warsaw	11 May
North Carolina	Salisbury[y]	3 May
	Kinston	24 April
South Carolina	Clemson	3 May
	Blackville	17 April
Georgia	Griffin	10 April
	Plains[z]	15 April
	Tifton	4 April

[x] Flowering was estimated as 5 days following mean heading date.

[y] Based on three representative varieties.

[z] Approximately two-week delay in planting.

FHB Effects on Production

Data on yield, production, and wheat prices for surveyed counties and states were obtained for the years 1993-2003 from the USDA National Agricultural Statistics Service (NASS). Total wheat production for 2003 in southeastern states was substantially lower than the 10-year average, the more so the farther north one went (Table 2). Correlation analysis using SAS PROC CORR indicated that, for the 62 surveyed counties, yield as a percentage of the 10-year average yield was significantly negatively correlated with estimated FHB impact in 2003 ($r = -0.588$, $P < 0.0001$).

Table 2. Total 2003 winter wheat production in five southeastern U.S. states as compared to the 10-year average.

State	Yield		Production	
	2003 mean (bu/acre)	% of 10-yr average[a]	2003 total (1000 bu)	% of 10-yr average[x]
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

[x] 1993-2002.

FHB was not responsible for 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 more or less significant roles depending on locale. When harvest is delayed, it is difficult to distinguish FHB-related reductions in yield and test weight of grain from the effects of weathering after physiological maturity.

In an effort to separate the FHB effect from those of other factors, 2003 yield as a percentage of the 10-year average yield was regressed on estimated FHB impact for the 62 counties, using SAS PROC REG. When the FHB effect was removed, 2003 yields averaged 90% of the 10-year average, with the regression equation being:

yield as % of 10-year average = 97.9% - 7.9%(FHB impact estimate)

Production losses due to FHB were calculated based on the estimated FHB effect on yield and test weight. Economic losses due to FHB were estimated using mean statewide wheat prices reported by NASS: $3.15 in Maryland, $2.95 in Virginia, and $2.90 in North Carolina. Although scattered reports were received of North Carolina wheat abandoned due to FHB, it was impossible to make overall estimates of acreage unharvested due to FHB.

Yields in most surveyed counties in Maryland, Virginia, and North Carolina were greatly decreased in 2003 from the 10-year average (Table 3), with the largest decrease occurring in Maryland, where yields in 10 counties were reduced an average of 21.6 bu/acre from the 10-year average (example field in Fig. 4). Regression analysis and interviews suggested that growers in most surveyed counties in South Carolina and Georgia, with the exception of those in the northwest corner of Georgia (Fig. 3), did not suffer significant reductions in yield or economic losses attributable to FHB (*data not shown*).

Fig. 4. Wheat field with high FHB incidence at Queenstown, MD, in 2003 (J. Costa, University of MD).

Table 3. Estimates of mean FHB impact and associated winter wheat yield and test weight losses in 2003 for 40 counties in Maryland, Virginia, and North Carolina.

State	County	Est. FHB impact[v]	Yield (% of 10-yr avg.)[w]	Estimated losses to FHB in 2003[x]		
				Yield (bu/ acre)	Prod- uction (1000 bu)	Value ($)
Maryland	Caroline	4	60.5	16.4	283.1	827,960
	Cecil	4	64.2	15.8	66.3	273,970
	Dorchester	4	61.7	17.8	260.1	629,165
	Kent	4	54.0	23.2	361.5	1,017,056
	Queen Anne's	4	54.8	21.9	612.5	1,711,180
	Somerset	4	70.0	12.5	59.6	153,163
	St. Mary's	3.5	70.8	10.5	87.9	174,710
	Talbot	4	60.1	17.4	281.6	755,799
	Wicomico	4	69.2	11.8	54.3	122,928
	Worcester	4	67.9	13.3	140.1	344,794
	Mean		63.3			
	10-county production loss total					6,010,716
	Test weight loss estimate[y]					2,155,065
	MD 10-county pre-milling loss total					8,165,791
Virginia	Accomack	1	73.8	9.6	168.0	369,603
	Caroline	1	71.8	11.9	86.2	250,238
	Charles City	3	79.0	7.4	59.9	126,397
	Chesapeake	4	53.7	20.9	77.4	172,863
	Essex	3.5	67.3	13.8	194.2	391,030
	New Kent	3	83.3	4.0	16.9	36,558
	Northampton	3	77.3	7.7	106.8	216,285
	Northumberland	3	79.2	6.8	133.0	210,242
	Surry	3	77.2	7.5	135.6	70,495
	Westmoreland	3	82.4	4.8	58.6	110,160
	Mean		74.5			
	10-county production loss total					1,953,870
	Test weight loss estimate[y]					300,725
	VA 10-county pre-milling loss total					2,254,595

(continued)

Table 3. (continued)

State	County	Est. FHB impact[v]	Yield (% of 10-yr avg.)[w]	Estimated losses to FHB in 2003[x]		
				Yield (bu/ acre)	Prod- uction (1000 bu)	Value ($)
North Carolina	Alexander	3	94.2	--[z]	--[z]	--[z]
	Beaufort	2.5	83.5	3.1	84.2	252,376
	Catawba	1	74.8	7.3	6.2	59,179
	Cleveland	1	83.9	2.8	38.3	41,744
	Davidson	4	62.4	12.8	20.7	74,519
	Davie	4	72.1	8.0	57.5	69,237
	Duplin	2	84.8	2.0	31.2	104,841
	Guilford	1	49.3	18.1	83.2	263,004
	Iredell	4	90.7	--[z]	--[z]	--[z]
	Lincoln	1	68.2	10.2	20.8	82,890
	Mecklenburg	4	68.5	10.0	24.7	34,898
	Perquimans	3	86.0	2.1	131.7	14,992
	Randolph	4	56.2	15.7	116.2	136,313
	Robeson	2.5	93.5	--[z]	--[z]	--[z]
	Rowan	4	85.7	2.1	129.1	34,072
	Sampson	1	94.3	--[z]	--[z]	--[z]
	Tyrell	2	52.2	20.2	320.0	710,146
	Union	4	62.4	13.3	326.7	963,386
	Washington	2	87.6	1.2	69.0	34,162
	Wayne	2.5	94.6	--[z]	--[z]	--[z]
	Mean		77.3			
	20-county production loss total					2,875,759
	Test weight loss estimate[y]					196,105
	NC 20-county pre-milling loss total					3,071,864
	40-county pre-milling loss total					13,492,250

[v] Estimates based on interviews with researchers, extension agents, millers and growers. Scale is based on percentage of growers in a county with visible symptoms and/or DON problems, with 1 = 0% to 4%, 2 =5% to 14%, 3 = 15% to 49%, and 4 = 50%+.

[w] Average for 1993-2002.

[x] FHB effect estimated from regression (see text). Production losses include reduced yield, but not acres unharvested, losses while cleaning wheat for seed, nor losses to millers. Economic losses are based on USDA NASS statewide mean prices per bu: MD $3.15, VA $2.95, and NC $2.90.

[y] Includes only losses in counties ranked 3 to 4 in FHB impact; see text for calculations.

[z] Where 2003 production exceeded no-FHB estimates based on the 10-year average, no estimate of FHB-related losses was possible.

Data for 2003 on test weight losses due to FHB are unavailable. As test weight drops, the price per bushel that elevators and millers pay growers also drops. When test weights fall below 55 or 56 lb/bu, the grain must be sold as feed wheat at a substantially reduced price. The price differential between food and feed wheat varies greatly over time and by geographic location. In Maryland, the price paid for wheat for flour averaged around $3.00/bu in 2003, whereas growers received just $0.80/bu for wheat used in chicken feed. In North Carolina, the differential ordinarily varies between $1 and $2 per bu.

Test weight-related losses in Table 3 are based on a $2.20/bu differential for food versus feed wheat for Maryland, and a $1.00/bu differential for Virginia and North Carolina. The estimates only include counties ranked 3 to 4 in FHB impact. Thus, actual total FHB-related losses due to decreased test weight were substantially higher in these states. The estimates in Table 3 are based on the authors' assessment from interviews that 50% of the crop fell below the food-grade cut-off in Maryland, and 25% in Virginia and North Carolina. In each state, 50% of the test-weight associated loss was attributed to FHB.

The losses due to FHB effects on yield and test weight that could be estimated in 40 surveyed counties in Maryland, Virginia, and North Carolina totaled over $13.4 million (Table 3). In 2003, those 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, and included at least some abandoned acreage in the North Carolina Piedmont. FHB is thought to cause an average 2- to 5-bu/acre yield loss in North Carolina Coastal Plain wheat fields in most years (B. Ashford, *personal communication*).

Besides affecting yield and test weight, severe FHB takes a toll on seed wheat production by increasing the "cleanout" rate, i.e., wheat rejected in the process of conditioning seed. The rejected wheat fails to receive a premium of approximately $0.30 to $0.60/bu, and must be sold for feed grade, not food grade. 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 average increase due to FHB of at least 6% in the cleanout rate occurred on a statewide basis in Maryland, Virginia, and North Carolina in 2003 (D. Morris, D. Whitt, and M. Fountain, respectively, *personal communication*). Assuming an average of $1.50/bu loss on the rejected wheat, this resulted in a minimum of $172,500 in losses to growers in the three states. To that must be added higher handling and conditioning costs, and long-term effects on yield.

Impact of DON in the Southeast

The mycotoxin DON had a far-reaching effect on the southeastern U.S. wheat industry in 2003. This impact was still being felt in late 2004, as elevators that had accepted DON-contaminated wheat in 2003 were unable to reduce this inventory sufficiently to receive corn and soybeans on the normal timetable the following year.

Southeastern U.S. millers incurred higher costs in 2003 due to the need to test more wheat than usual for DON, and due to the additional handling and cleaning procedures needed to improve grain quality. Rejection of large numbers of wheat loads severely decreased the amount of local grain available to fulfill contracts, forcing mills to begin acquiring grain early from distant sources at high shipping costs. 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.

As an example, Mennel Milling in Virginia generally outsources wheat from Ohio to complete contractual needs. However, FHB limited the wheat supply in 2003 even in southern Ohio. The company was then forced to source wheat from Michigan at an increased freight cost of $200,000. 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 $0.50/bu. Bartlett Mills generally starts outsourcing wheat from Ohio in January to February, after exhausting local

supplies, in order to complete contracts. In 2003, Bartlett was forced to begin outsourcing in September or October. Mid-State Mills ceased sourcing wheat from North Carolina early in the season and began drawing grain from as far away as Ontario, Canada.

Summary and Implications for Disease Management

Historically, FHB was not perceived as a serious threat to small grain production in the U.S. Southeast. The 2003 epidemic demonstrated that FHB could be a major problem in wheat as far south as northern Georgia, although abnormally abundant and prolonged rainfall may be necessary for a severe epidemic in a region where spring temperatures are often above optimum for *F. graminearum*.

Our analyses suggest that post-flowering rainfall may have been the most important weather variable driving the 2003 epidemic in the Southeast. However, controlled studies are needed to draw firm conclusions. This is especially true because we had to rely upon estimated disease levels and estimated average flowering dates, rather than direct observations of per-field disease and genotype-specific flowering. Nevertheless, weather conditions in the 7 days prior to flowering do not appear to have played as significant a role as post-flowering weather, and were not likely to have been a good predictor of FHB severity in the Southeast in 2003.

In 2003, abundant rain and high humidity in the post-flowering period may have enhanced fungal growth from infections that occurred during flowering, or facilitated late infections, or both. The appearance of high DON levels in relatively asymptomatic crops in various parts of the U.S. (2,6) underscores that critical information is still lacking about the conditions under which this seemingly contradictory situation occurs.

In parts of the mid-and south-Atlantic region, no-till production has become the norm, with corn a consistent part of the rotation. DON is commonly detected in corn silage samples from the Piedmont region of North Carolina (Forage Laboratory, NC Department of Agriculture and Consumer Services), suggesting that *F. graminearum* inoculum is widely present. Even in the coastal plains of North Carolina, where conventional tillage still predominates, longtime observers believe that FHB has gradually increased in incidence (B. Ashford, *personal communication*). These factors, together with the serious consequences of DON contamination, indicate that more attention should be paid to FHB forecasting and monitoring in the Southeast. The apparent lack of correlation between pre-flowering weather conditions and estimated FHB severity in 2003 may mean that it will be challenging to provide economically useful forecasts to wheat growers in the region. However, even forecasts based on post-flowering conditions might encourage a more effective process of DON management, both before and after harvest.

Acknowledgments

Literature Cited

1. Anonymous. 2003. FHB plagues wheat in eastern U.S. U.S. Wheat and Barley Scab Initiative. Fusarium Focus 5:8.
2. Del Ponte, E. M., Fernandes, J. M. C., and Bergstrom, G. C. 2003. Fusarium head blight and deoxynivalenol accumulation in wheat inoculated at developmental stages from flowering through grain maturation. Pages 129-132 in: Proceedings of the National Fusarium Head Blight Forum. S. M. Canty, J. Lewis and R. W. Wards, eds. Mich. State Univ., East Lansing.
3. DeWolf, E. D., Madden, L. V., and Lipps, P. E. 2003. Risk assessment models for wheat Fusarium head blight epidemics based on within-season weather data. Phytopathology 93:428-435.

4. Dill-Macky, R., and Jones, R. K. 2000. The effect of previous crop residues and tillage on Fusarium head blight of wheat. Plant Dis. 84:71-76.

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

6. Shaner, G., and Buechley, G. 2003. Relation between head blight and grain quality in the Indiana FHB epidemic of 2003. Pages 178-181 in: Proceedings of the National Fusarium Head Blight Forum. S. M. Canty, J. Lewis and R. W. Wards, eds. Mich. State Univ., East Lansing.

7. Stack, R. W. 2000. Return of an old problem: Fusarium head blight of small grains. The Plant Health Instructor doi:10.1094/PHP-2000-0622-01-RV.

8. Walker, S. L., Leath, S., Hagler, W. M., and Murphy, J. P. 2001. Variation among isolates of *Fusarium graminearum* associated with Fusarium head blight in North Carolina. Plant Dis. 85:404-410.

9. Windels, C. E. 2000. Economic and social impacts of Fusarium head blight: changing farms and rural communities in the northern Great Plains. Phytopathology 90:17-21.