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Fusarium Head Blight of Wheat

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Fusarium head blight (FHB) or scab was first reported in Nebraska in 1898. The disease affects small grains including wheat, barley, oats, triticale, and rye. FHB of small grains is caused primarily by the fungus *Fusarium graminearum* (sexual stage: *Gibberella zeae*). The fungus is a facultative parasite, that is, it normally exists as a saprophyte but can live as a parasite on plants, causing disease. In addition to causing damage to heads, it also may infect roots and crowns and often is, together with other soilborne fungi, the cause of seedling blights and root and crown rots. *F. graminearum* also causes stalk and ear rots in corn.

FHB epidemics occur sporadically in Nebraska due to a variable climate. The disease tends to occur during years with high rainfall during the grain filling period. FHB epidemics occurred in Nebraska in 1982 and again in 1995. In 2007, epidemics of FHB occurred in south central and eastern Nebraska, and the disease was observed in rain-fed and irrigated wheat fields as far west as Ogallala. Because *F. graminearum* survives on crop residues and in the soil, it occurs statewide. Therefore, the potential exists for FHB outbreaks anywhere in the state where heavy rainfall occurs prior to and during flowering of wheat, or where wheat fields are irrigated.

Symptoms

On immature wheat heads (spikes), one or more spikelets (*Figure 1*) or the entire head (*Figure 2*) appears prematurely whitened or bleached. Initial symptoms generally are visible near the middle of the head (*Figure 1*) on the first florets to flower but can occur anywhere on the head. Premature bleaching progresses with time to most or all the spikelets, causing the entire head to be bleached. The bleached heads are readily visible in a green field (*Figure 3*). Partial bleaching of a wheat head is a diagnostic symptom of FHB (*Figure 1*). Infection of the stem (peduncle) immediately below the head also may occur, causing a brown or purple discoloration (*Figure 4*). If the peduncle is infected early, the entire head becomes sterile. The fungus sporulates on infected spikelets and glumes during prolonged wet weather. This results in pink to salmon-orange spore masses, also diagnostic of FHB (*Figure 2*).

Bleached spikelets are sterile or contain kernels that are shriveled and/or appear chalky white or pink (*Figure 5*). These kernels are often referred to as *Fusarium*-damaged kernels (FDK), scabby kernels, or “tombstones.” Apparently healthy kernels (*Figure 5*) also may be infected, especially if infection occurred late in kernel development.

Bleached or white heads also can result from other diseases or pests, but these are easily distinguished from

Figure 1. A wheat head with Fusarium head blight symptoms on a few spikelets.

Figure 2. Pink to salmon spore mass of *Fusarium graminearum* on a completely blighted wheat head.

Figure 3. Wheat heads bleached by Fusarium head blight are readily visible in a green field.

bleached heads resulting from FHB. White heads resulting from take-all, a disease caused by *Gaeumannomyces graminis*, a soilborne fungus, occur in patches, often on plants that are stunted and which also have prematurely dead foliage. Glume blotch caused by the fungus *Stagonospora nodorum* also discolors heads, but the

Figure 4. Infection of the stem (peduncle) by Fusarium head blight (right). Left: healthy wheat head.

Figure 5. ***Fusarium*-damaged wheat kernels (left) and healthy kernels (right).**

discoloration appears chocolate brown rather than white. White heads caused by the wheat stem maggot occur on isolated plants. Pulling on the head causes it and the peduncle to easily detach from the stem at the point of stem maggot damage, whereas white heads from FHB infection do not easily detach when pulled.

The Pathogen

F. graminearum is cosmopolitan. Although the fungus is found mainly on wheat, corn, and barley, it can also occur on other annual and perennial hosts. *F. graminearum* in agar culture appears gray, pink, brown, or burgundy (*Figure 6*). The fungus can grow on most agar media. Cultures form red pigments in agar. The temperature optimum for growth in culture ranges from 75°F to 79°F. *F. graminearum* produces asexual spores known as macroconidia (*Figure 7*) primarily in fruiting structures known as sporodochia (singular: sporodochium). Macroconidia of *F. graminearum* are slender, thick-walled, curved to straight, tapered at both ends, with five to seven septa or partitions (*Figure 7*). Macroconidia are 41-60 x 4.5-5.0 micrometers (μm) in size when 5-septate. Globose chlamydospores (thick-walled asexual resting spores) are produced mainly in macroconidia, but may also form in mycelia. Chlamydospores are one means by which *F. graminearum* survives unfavorable conditions. The sexual stage of *F. graminearum* (*G. zeae*) produces perithecia (sexual fruiting structures) superficially on wheat heads. Perithecia are dark purple or black and form abundantly on corn stubble (*Figure 8*) as well as in culture (*Figure 9*). Perithecia can survive for more than 16 months on corn and wheat residue under field conditions. Within the perithecia, ascospores (sexual spores) develop within sacs known as asci (singular: ascus, *Figure 10*). Each ascus contains eight ascospores that have zero to three septa (*Figure 10*). Ascospores measure 20-29 x 3.5-4.5 μm. Conidia, chlamydospores, and ascospores are microscopic; they can be seen with the aid of a compound microscope.

Fusarium Head Blight Risk Factors in Winter Wheat

- Excessive moisture before and during flowering
- Warm, wet spring
- Irrigation
- Planting wheat after corn
- Planting wheat after wheat
- No-till or reduced tillage
- Susceptible cultivars

Disease Cycle

F. graminearum overwinters as chlamydospores or mycelia in the soil or in host crop residues which serve as a source of primary (initial) inoculum in the spring. The fungus also can survive on wheat seed. Primary inoculum mainly consists of ascospores produced in perithecia, which form on crop residues in the spring as

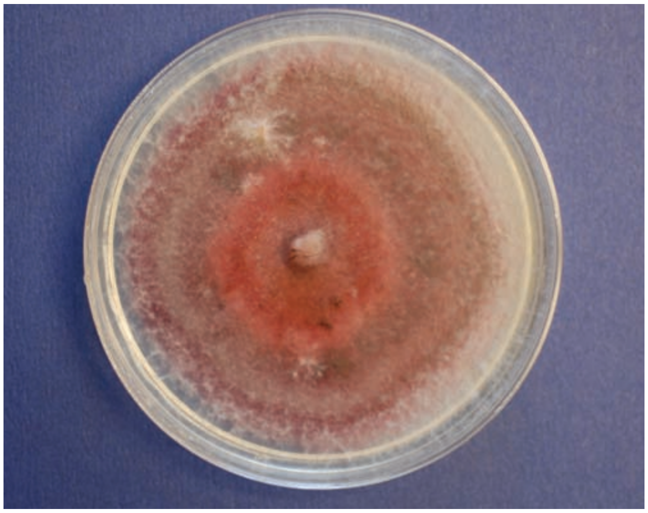

Figure 6. *Fusarium graminearum* **growing in culture.**

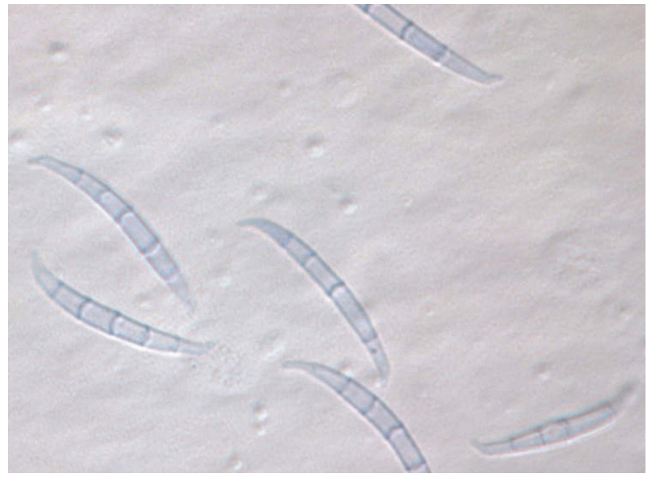

Figure 7. Macroconidia of ***Fusarium graminearum*****.**

Photo credit: Dr. Erick De Wolf, Kansas State University.

Figure 8. Perithecia of ***Gibberella zeae*****, the sexual stage of** ***Fusarium graminearum*** **on a corn stalk.**

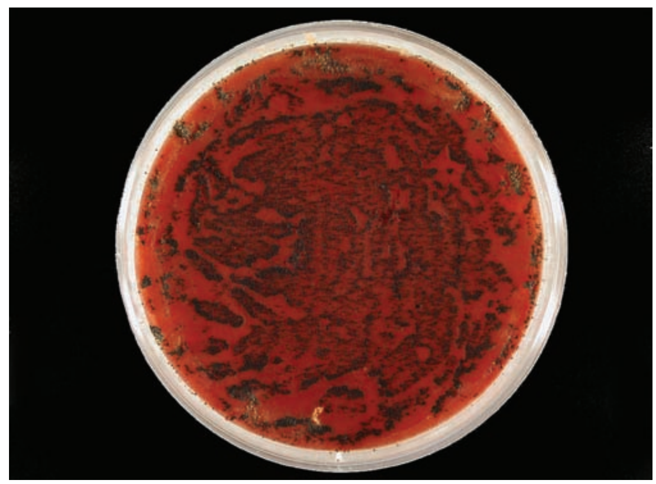

Photo credit: Dr. Frances Trail, Michigan State University.

Figure 9. Perithecia of ***Gibberella zeae*****, the sexual stage of** ***Fusarium graminearum*****, on carrot agar.**

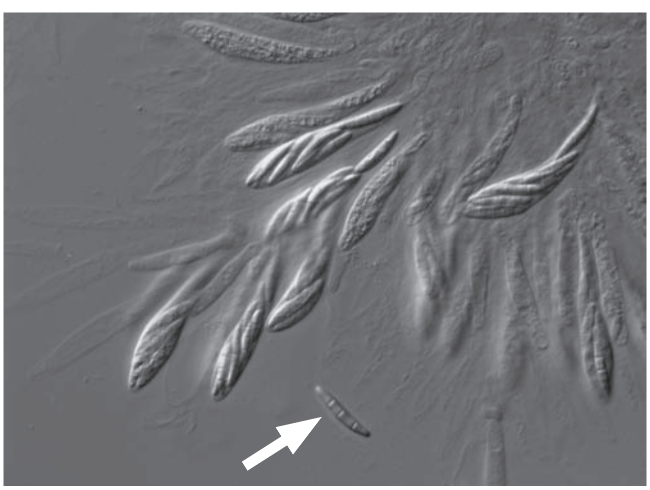

Photo credit: William Rittenour, Graduate Student, Department of Plant Pathology, University of Nebraska–Lincoln.

Figure 10a. Asci (singular: ascus) and an ascospore (arrow) of ***Gibberella zeae*****, the sexual stage of** ***Fusarium graminearum*****.**

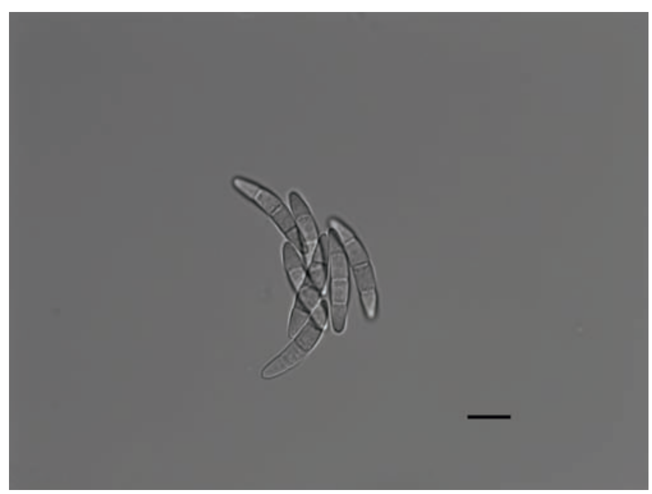

Photo credit: William Rittenour, Graduate Student, Department of Plant Pathology, University of Nebraska–Lincoln.

Figure 10b. Ascospores of ***Gibberella zeae*****, the sexual stage of** ***Fusarium graminearum*****.**

temperatures warm up. In the spring, ascospores and/or conidia are released from crop residues and spread by wind or splashing water. They land on wheat heads and during wet, warm weather they germinate and infect glumes, flower parts, or other parts of the head. Infections occur mostly during anthesis (stage at which anthers rupture and shed pollen during flowering), partly because pollen and anthers serve as a food base for the germinating spores. Wheat heads are susceptible from anthesis until the soft dough stage. Infections that occur during anthesis are the most damaging. During warm temperatures (77°F to 86°F) and wet conditions, blight symptoms develop within two to four days after infection. Therefore, an apparently healthy crop can show symptoms suddenly (*Figure 3*). Later in the growing season or after harvest, perithecia may form on wheat heads. FHB is considered a monocyclic or one-cycle disease, that is, after the initial or primary infection, little or no secondary infection occurs by conidia formed on infected heads. FHB is favored by prolonged wet, warm weather prior to and during anthesis. Excessive rainfall during the growing season and especially during a one- to three-week period prior to anthesis can lead to epidemics of FHB. The disease usually is more severe in irrigated (*Figure 11*) than rain-fed fields.

Figure 11. Fusarium head blight in an irrigated field.

Disease Assessment

FHB is quantified by estimating disease incidence (percentage of affected plants) and average disease severity (percentage of blighted spikelets on the head). Multiplying percent incidence by percent severity and dividing by 100 gives the disease index which is an estimate of overall disease intensity. A disease incidence of 60 percent and a disease severity of 50 percent will give a disease index of 30 percent. Incidence and severity usually are estimated visually. FHB can be quantified with good accuracy by assessing severity on a large random sample of spikes (taken randomly from the entire area or field) and using the same sample to calculate incidence, average severity, or frequencies of various classes of severity.

Effects of Fusarium Head Blight on Grain Quality in Winter Wheat

- Limited marketability of *Fusarium*-damaged grain
- Low test weight
- Contamination by mycotoxins
- Reduced milling quality
- Reduced end product quality
- Reduced germination
- Decreased feed consumption by livestock
- Feed refusal by livestock

Effects on Grain Quality

Fusarium-damaged kernels (FDK). The extent of damage to kernels depends on disease severity on wheat heads. Higher disease severity results in a larger extent of damage to kernels. Marketability of *Fusarium*-damaged wheat is limited by adverse effects of the damage on milling performance, flour properties, and end product quality. *Fusarium*-damaged kernels are shriveled and have low test weight which together with a high proportion of damaged kernels results in downgrading of *Fusarium*-damaged wheat. In addition, *Fusarium*-damaged grain may contain mycotoxins (see next section). Sometimes, *Fusarium*-damaged kernels can be removed by cleaning or setting the harvest combine to blow out "chaffy" seed. *Fusarium* damage significantly reduces milling quality by lowering flour yield and baking quality, increasing ash content, discoloring flour, and causing odors. The loaves of bread made with *Fusarium*-damaged wheat have an open texture and reduced volume, along with an ugly gray/green cast.

Germination. If *Fusarium*-infected or damaged (scabby) grain is used as seed for the next crop, poor stands, poor vigor, and/or seedling blights can occur. In a laboratory germination test of grain samples from fields, elevators, and a grain inspection facility in south central and eastern Nebraska in 2007, germination of grain with high levels of FDK was very low (*Figure 12*) compared to germination of grain with low levels of FDK (*Figure 13*). Average germination in the grain sample with the highest percentage (71 percent) of FDK was 51 percent.

Figure 12. Poor germination of wheat grain with a high percentage of *Fusarium*-damaged kernels.

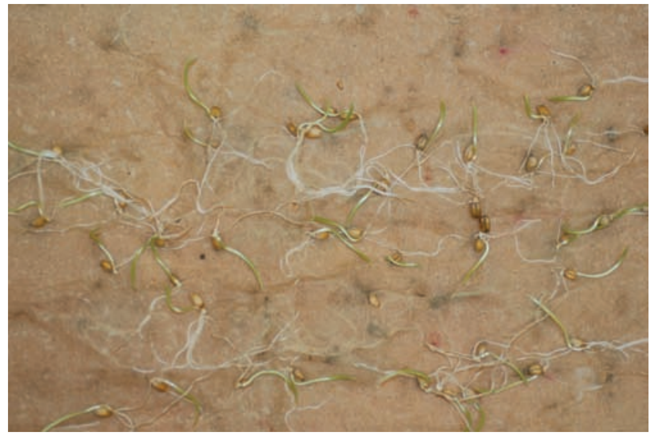

Figure 13. Germination of wheat grain with a low percentage of *Fusarium*-damaged kernels.

Mycotoxins

Mycotoxins found in Nebraska wheat infected by FHB usually are vomitoxin (deoxynivalenol, DON) and zearalenone. Vomitoxin has been found more prevalently and usually at higher concentrations. Zearalenone generally has not been found without vomitoxin, but vomitoxin has been found without zearalenone.

Both mycotoxins may be present in the grain or wheat heads and can lead to lower prices paid or refusal to purchase the grain at the elevator. Elevators check for mycotoxin levels with prepackaged kits or by sending grain samples to established laboratories. In many grain purchasing contracts, the allowed level of mycotoxins is stipulated. Vomitoxin has been found in straw, but it is not certain if it was the straw itself that was contaminated or if the straw contained parts of contaminated wheat heads.

Vomitoxin is not very poisonous but it is associated with vomiting, feed refusal and decreased feed consumption in swine, which can affect animal performance. Cattle are very resistant to the effects of vomitoxin; pigs are more sensitive. There have been reported effects in dogs which consumed vomitoxin-contaminated food.

Zearalenone is a chemical that acts similarly to the female sex hormone estrogen and excessive exposure can disrupt the estrus cycle. Swine are more sensitive than are cattle and other ruminants. Exposure to zearalenone does not cause abortion. It can cause precocious puberty in sexually immature females and feminization of male animals.

Recommendations for using vomitoxin- and zearalenone-contaminated feed are listed in *Table I*. The recommendations are not regulatory and are not enforced by government agencies.

Table I. Recommendations for using vomitoxin- and zearalenone-contaminated feed.

Vomitoxin (deoxynivalenol, DON)-contaminated grain and grain products		*Zearalenone in diets*	
Swine	5 ppm, ≤ 20% of diet	Prepubertal gilts	< 1 ppm
Ruminating beef, feedlot cattle older than 4 months, chickens	10 ppm, ≤ 50% of diet	Sexually mature sows, bred sows	< 3 ppm
		Young boars	< 20 ppm
Other species	5 ppm, ≤ 40% of diet	Mature boars	< 200 ppm
Reference: FDA advisories, 1982 & 1993		Virgin heifers	< 10 ppm
		Reference: Osweiler, G. D. (1996) Toxicology, the National Veterinary Medical Series, Williams & Wilkins, Media, PA: 421	

Influence of Crop Rotation

In addition to wheat and other small grain crops, *F. graminearum* also causes diseases on other Nebraska crops including corn and sorghum. These crops may be used in a crop rotation with wheat thereby providing a continuous host and increasing the potential for carry-over of the pathogen into subsequent seasons. Corn has been identified as a particularly suitable host for *F. graminearum.* This is a concern for wheat production in Nebraska. Corn occupies more acres than any other crop in the state and the large number of planted acres increases the risk of FHB outbreaks in years with high rainfall because the fungus is a common and widespread corn pathogen. *F. graminearum* causes numerous diseases of corn, including seed rot, seedling blight, and stalk and ear rots, which increases inoculum in the field.

Research has been conducted to evaluate the impact of crop rotation on FHB development. FHB incidence and severity were less in wheat following soybean than in wheat following corn. Similarly, the concentration of DON in continuous wheat was less than half of that in wheat following corn, further supporting the use of a strict crop rotation sequence where FHB is a problem. The use of FHB susceptible crops in rotations with wheat and the short time between crops increases disease risk.

Research also has been done to investigate the effect of tillage on FHB. Incidence and severity of FHB were greater in chiseled and no-till plots than in moldboard plowed plots. Buried wheat residue decomposed faster than that on the soil surface. After two years, only 2 percent of buried residue remained, in contrast to 25 percent of the residue on the soil surface. The quantity of infected corn residue to a depth of 4 inches was positively correlated with DON accumulation; correlation was higher for residue remaining on the soil surface.

Breeding for Resistance

The Future of Cultivar Development. In the future, we expect cultivars with much better tolerance to be released because commercial and public breeding programs in Kansas, Nebraska, and South Dakota all have hard red winter wheat breeding programs trying to identify lines with less disease and lower levels of mycotoxins. In the past, the major challenge was the episodic and opportunistic nature of FHB tolerance breeding. Selections and information to growers were based upon when the rains came, how long they lasted, and which cultivars were flowering when it rained. Now, the breeding programs put out inoculum in mist nurseries to ensure the presence of the pathogen and high moisture during flowering which allows the collection of more reliable data on released and advanced experimental lines. In addition, harvested seed from these disease nurseries is ground and sent to national laboratories for mycotoxin testing. This research is funded in part by the U.S. National Wheat and Barley Scab Initiative, a national effort to combat this disease.

The better tolerance found among released lines was initially "native" tolerance, lines without known genes or quantitative trait loci (QTL) that have been identified with better tolerance. Without efficient and reliable screening capabilities, these released lines represented the variation for unselected traits in the breeding programs (often very rare). However, many new sources of tolerance have been identified and "tagged" with molecular markers. An example is the *Fhb1* gene from the Chinese wheat, Sumai 3. The gene is widely used in the spring wheat region and is becoming more common in the soft and hard winter wheat region. Now, *Fhb1* has been backcrossed into a number of elite hard winter wheat lines which may or may not be released, but will serve as excellent parents for the next generation of released cultivars. In addition, a number of genes or QTL have been identified that explain the native tolerance making their use in breeding populations easier. Hence, phenotypic breeding is now coupled with molecular marker technology for efficient selection and better breeding progress for reducing the damaging effects of FHB. However, some lines phenotypically look as if they have low levels of disease but seem to have higher levels of mycotoxins. In this case, selecting for low mycotoxin levels using chemical assays is currently the only way to evaluate lines for low mycotoxin levels.

Managing Fusarium Head Blight in Winter Wheat

- Plant resistant/tolerant cultivars
- Plant cultivars with different flowering dates
- Rotate wheat with nonhost crops
- Avoid planting wheat after corn
- Avoid planting wheat after wheat
- Manage irrigation
- Apply a fungicide at early flowering
- Do not use *Fusarium*-damaged grain as seed
- Practice integrated pest management (IPM)

Management

The Importance of Cultivar Selection. Small grains cultivars differ in their tolerance to FHB, so it is important to carefully select your cultivars when trying to lessen the damaging effects of FHB. Some cultivars which have better FHB tolerance include Husker Genetics Brand Overland, Heyne, Agripro Brand Hondo, Karl 92, Arapahoe, and Goodstreak. Cultivars with higher susceptibility include 2137, Overley, Agripro Jagalene, and Harry. Research conducted in 2007 at the Agricultural Research and Development Center near Mead, Neb. and in Manhattan, Kan. showed that although Harry appeared to be more tolerant than 2137, it accumulated higher levels of mycotoxins. Wheat grain samples from heads with high FHB severity had higher mycotoxin levels than samples from heads with low FHB severity for both Harry and 2137.

As FHB is sporadic in Nebraska, caused by high rainfall before and during flowering, and found primarily in eastern and central Nebraska, it is also important to plant cultivars with different flowering dates if possible to reduce risk (it is rare that high moisture will occur throughout the flowering period for all of the cultivars grown in these regions).

Cultural Practices. Because FHB epidemics are initiated by inoculum produced on crop residues, reducing residue can reduce inoculum potential. Residue can be reduced by plowing and/or burning. However, these practices have disadvantages. Plowing can increase erosion and loss of valuable moisture and burning can lower air quality. A more practical cultural management practice in Nebraska is crop rotation. Rotating wheat with nonhost crops such as soybeans and alfalfa can reduce inoculum over time. Planting wheat after corn or sorghum should be avoided as these crops are hosts of FHB causing fungi. Corn residue survives longer than small grains residue. Therefore, FHB tends to be more severe in wheat planted after corn, especially in reduced or no-tillage cropping systems. Continuous cropping of wheat also should be avoided. Irrigation management to allow the crop canopy to dry between irrigations can reduce disease severity.

Fungicides. Two fungicides registered for control of FHB in Nebraska are prothioconazole (Proline) and propiconazole (Tilt). These fungicides suppress FHB. They do not completely control the disease. Fungicide application should be timed to protect the head. Optimal timing is at approximately 15 percent flowering (Feekes 10.51). Thorough coverage of heads is essential for maximum suppression of FHB.

If *Fusarium*-infected grain is used as seed, fungicide seed treatments can reduce seedling blights, but have no direct effect on FHB later in the growing season. Fungicide seed treatments also can reduce buildup of the FHB fungus in the soil.

Biological Control. Research by various investigators is under way to identify microorganisms which can suppress FHB. Certain bacteria and yeasts have been identified that are antagonistic to *F. graminearum*, but commercial formulations of these biocontrol agents are not available as of April 2008. Modes of action of biocontrol agents include competition, production of antibiotics, parasitism, induction of resistance in the wheat plant, and inhibition of toxin synthesis. Biological control of FHB may be targeted at preventing or disrupting head infection, pathogen spread within the head, development of seedling blights, pathogen survival on crop residues, or spore production by the pathogen.

Integrated Pest Management (IPM). Because of the lack of highly resistant or tolerant cultivars, integrating available FHB management strategies into an IPM program is the best approach to managing the disease. Using tolerant cultivars with different flowering dates, residue management, crop rotation, irrigation management, and judicial use of fungicides should all be integrated into an FHB management program.

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