WHEAT
Diseases and Pests
a guide for field identification (2nd Edition)

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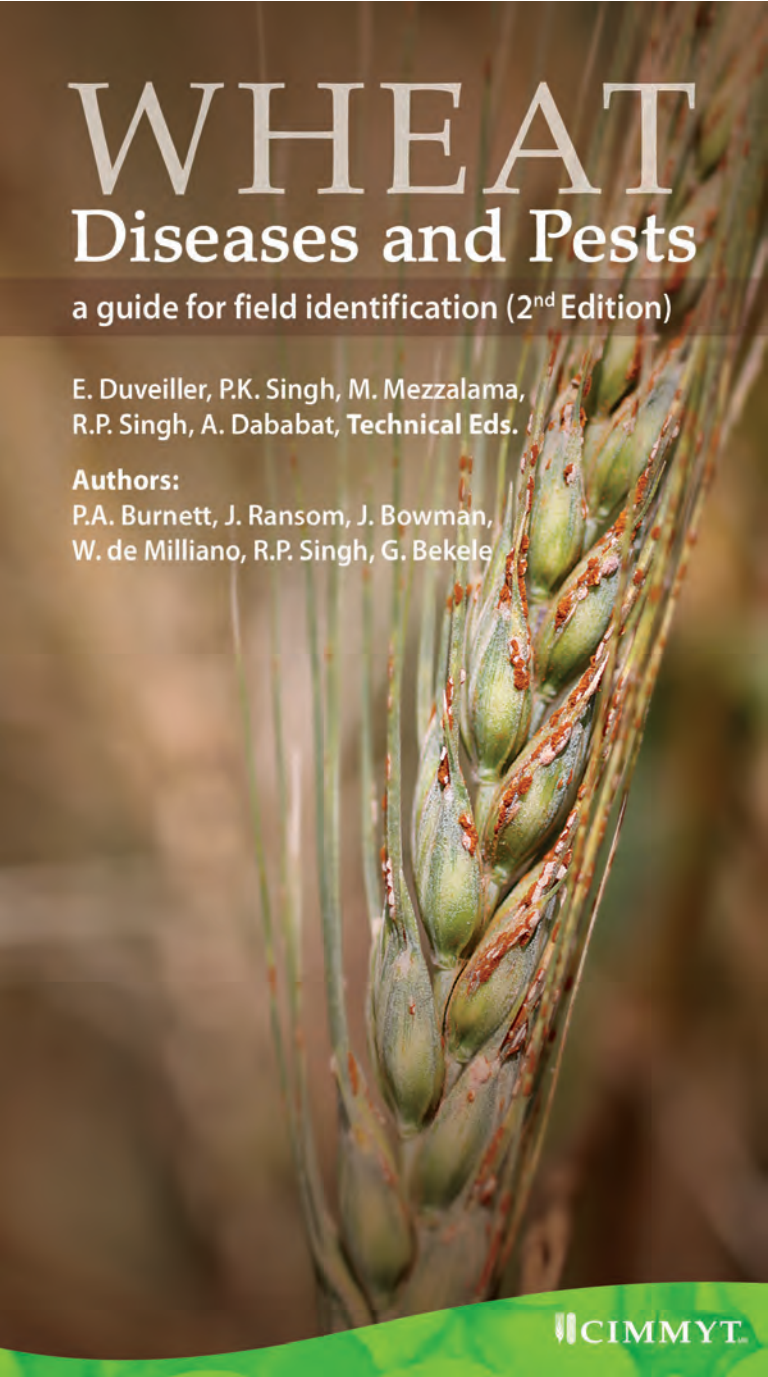

CIMMYT

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CIMMYT MR
International Maize and Wheat Improvement Center

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Preface

This booklet is designed as a quick guide for identifying wheat and triticale diseases in the field. It is intended primarily for agricultural researchers, technicians, and farmers in developing nations, but will also be of value to others. The text comprises a brief description of the major wheat and triticale diseases, insect pests, nematodes, physiologic and genetic disorders, and mineral and environmental stresses. Complementing this text and as an aid to identification are numerous color photographs[1], drawings[2] and, in the center of the booklet, a brief diagnostic key. In the case of specific causal organisms, the perfect stage name or telemorph (when known) is followed by the imperfect stage name or anamorph in parentheses. While most of the diseases, pests, disorders, or stresses included can be economically significant, some are not and are presented only because they are unique or might be confused with more economically significant problems.

[1]/ All photographs compliments of CIMMYT staff, except for photo 61, contributed by the Department of Plant Sciences and Plant Pathology, Montana State University, USA; photo 64, contributed by C.C. Gill, Agriculture and Agri-food Canada, Winnipeg, Manitoba, Canada; and photo 77, contributed by J.H. Hatchett, USDA-ARS, Kansas State University, Manhattan, Kansas, USA.

[2]/ Line drawings are reproduced from "New Zealand Pest and Beneficial Insects" (ed. R.R. Scott) with the kind permission of Lincoln College, New Zealand.

Fungal Diseases

Fungi differ from other plants in that they have no chlorophyll and thus lack photosynthetic capability. Instead of manufacturing their own food, fungi absorb nutrients from either living or dead host tissue. Fungi are dispersed in many ways: they may be seed- or soil-borne, or they may be spread by way of wind, water (rain or irrigation), insects, animals, and humans.

Infection by fungal pathogens depends on several factors: the susceptibility of the host, the density of inoculum, and ambient temperature, as well as other environmental factors. Free water on the host plant surface is also usually required. While some fungi attack only one or a few host species, others attack many. Symptoms and disease development are a function of the host-parasite interaction. Symptoms may be similar or distinct, depending on the fungi involved. Positive identification of fungi should therefore be primarily based on their morphology, although the use of molecular tools is helpful for some groups. Unless otherwise reported, the fungi included in this field manual cause diseases in bread wheat, durum wheat, and triticale.

Leaf Rust (Brown Rust)

Puccinia triticina Eriks.

Symptoms: Pustules are circular or slightly elliptical, smaller than those of stem rust, do not usually coalesce, and contain masses of orange to orange-brown urediospores. Infection sites are found primarily on the upper surfaces of leaves and leaf sheaths (1), and occasionally on the neck and awns.

Development: Primary infections are usually light and develop from wind-borne urediospores that may have travelled long distances. The disease can develop rapidly when free moisture is available and temperatures are near 20°C. Successive generations of urediospores can be produced every 10-14 days if conditions are favorable. As plants mature, or when environmental conditions are not favorable, masses of black teliospores may become evident (2).

Hosts/Distribution: Leaf rust can affect wheat, triticale, and many other related grasses. The disease is found wherever temperate cereals are grown. The alternate hosts are *Thalictrum, Isopryum, Anemonella*, and *Anchusa* spp.

Importance: Severe early infections can cause significant yield losses, mainly by reducing the number of kernels per spike, test weights, and kernel quality.

1

2

Stem Rust (Black Rust)

Puccinia graminis Pers. f. sp. *tritici* Eriks. & E. Henn. and *P. tritici-duri* Viemmot-Bourgin

Symptoms: Pustules (containing masses of urediospores) are dark reddish brown, and may occur on both sides of the leaves, on the stems, and on the spikes (3). With light infections the pustules are usually separate and scattered, but with heavy infections they may coalesce. Prior to pustule formation, "flecks" may appear. Before the spore masses break through the epidermis, the infection sites feel rough to the touch; as the spore masses break through, surface tissues take on a ragged and torn appearance.

Development: Primary infections are usually light and develop from wind-borne urediospores that may have travelled long distances. The disease can develop rapidly when free moisture (rain or dew) and moderate temperatures prevail. If temperatures average about 20°C or more, the first generation of urediospores will be produced in 10-15 days. As plants mature, masses of black teliospores may be produced.

Hosts/Distribution: Stem rust can affect wheat, barley, triticale, and many other related grasses; it is found wherever temperate cereals are grown. The alternate hosts are *Berberis* and *Mahonia* spp.

Importance: If infection occurs during the early crop stages, the effects can be severe: reductions in tillering and losses in grain weight and quality. Under favorable conditions, complete crop loss can occur. This disease has re-emerged as a major threat with the occurrence of the very virulent Ug99 strain, leading to major international research efforts to obtain new sources of resistance.

3

Stripe Rust (Yellow Rust)

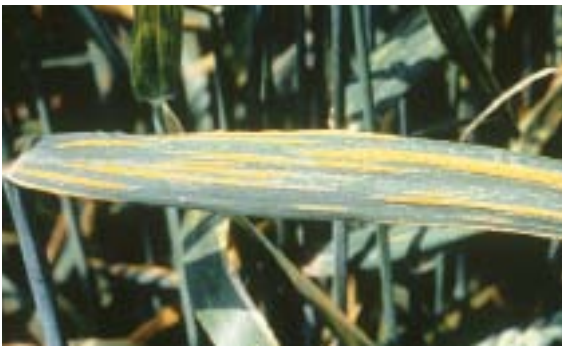
Puccinia striiformis Westend f. sp. *tritici*

Symptoms: The pustules of stripe rust, which contain yellow to orange-yellow urediospores, usually form narrow stripes on the leaves (4). Pustules also can be found on leaf sheaths, necks, and glumes (5).

Development: Primary infections are caused by wind-borne urediospores that may have travelled long distances. The disease may develop rapidly when free moisture (rain or dew) occurs and temperatures range between 10-20°C. At temperatures above 25°C, the production of urediospores is reduced or ceases and black teliospores are often produced (6).

Host/Distribution: Stripe rust can attack wheat, barley, triticale, and many other related grasses. The disease is found in all highland and/or temperate areas where cereals are grown. No alternate host was known until it was found on common barberry and several other *Berberis* spp. in 2010 in the USA. The alternate host *Berberis vulgaris* (European barberry) was historically an important source of inoculum in North America and Europe, but is now rare since the implementation of barberry eradication laws. However, some regions where barberry is common, particularly in East Europe and West Asia, may facilitate continued cyclic rust infection and evolution of new combinations of virulence.

Importance: Severe infections can cause yield losses, mainly by reducing the number of kernels per spike, test weights, and kernel quality.



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Common and Dwarf Bunt
(Stinking Smut; Common Smut)

Common bunt or stinking bunt is caused by two fungi: *Tilletia tritici* (Bjerk.) G. Wint.
(syn. *T. caries*) and *T. laevis* Kühn. (syn. *T. foetida*)

Dwarf bunt is caused by *T. controversa* Kühn

Symptoms: The main symptoms caused by these species are fungal structures called "bunt balls", which resemble kernels but are completely filled with black teliospores. The bunt balls of common bunt are about the same size and shape as the kernels they replace (7); those of dwarf bunt are nearly spherical (8). When bunt balls are crushed, they give off a fetid or fishy odor. Infected spikes tend to be bluish green (or darker) in color, and the glumes tend to spread apart slightly. Bunt balls often become visible after the soft dough stage (9, 10). A slight reduction in plant height is typical of common bunt, while a pronounced reduction in height is typical of dwarf bunt.

Development: Spores lying dormant in the soil or on seed germinate and infect emerging seedlings. Infection is favored by cool temperatures during germination. The disease develops systemically, with visible symptoms appearing after heading.

Hosts/Distribution: Wheat and (less commonly) triticale are affected by these diseases, as are several other related grasses. Common and dwarf bunts can occur worldwide. Both are limited to temperate climates; dwarf bunt occurs in areas that have prolonged snow cover.

Importance: Considerable yield losses can occur when susceptible cultivars are grown or chemical seed treatments are not used.

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Karnal Bunt (Partial Bunt)

Tilletia indica Mitra

Symptoms: Karnal bunt is not easily detected prior to harvest, since it is usual for only a few kernels per spike to be affected by the disease. Following harvest, diseased kernels can be easily detected by visual inspection: a mass of black teliospores replaces a portion of the endosperm, and the pericarp may be intact or ruptured (11). Diseased kernels give off a fetid or fishy odor when crushed.

Development: Karnal bunt is a seed- or soil-borne, floral infecting disease. Inoculum (teliospores) on or near the soil surface germinate, producing sporidia, which are carried by wind to the floral structures. These sporidia in turn germinate and penetrate the glumes, rachis, or the ovary itself. The fungus enters the newly formed kernel and develops in the intercellular space between the endosperm and seed coat. The degree of disease establishment and development depends on environmental conditions from spike emergence through grain filling.

Hosts/Distribution: Karnal bunt can affect wheat, triticale, rye, and several other related grasses, but not barley. The disease is endemic in the Indian subcontinent and has been observed in Mexico and the USA.

Importance: Karnal bunt is a relatively minor disease. Actual losses in yield are minimal, but the disease is on the quarantine lists of many countries and therefore of importance in world grain trade.

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Loose Smut

Ustilago tritici (Pers.) Rostr.

Symptoms: The entire inflorescence, except the rachis, is replaced by masses of smut spores (12). These black teliospores are often blown away by the wind, leaving only the bare rachis and remnants of other floral structures (13).

Development: Wind-blown teliospores that land on the flowers of wheat plants can germinate and infect the developing embryo of the kernel. The mycelium of the loose smut fungus remains dormant in the embryonic tissues of the kernel until the kernel begins to germinate. The mycelium then develops along with the growing point of the plant, and at flowering time replaces the floral parts of the spike with masses of black spores. Infection and disease development are favored by cool, humid conditions, which prolong the flowering period of the host plant.

Hosts/Distribution: The disease can occur wherever wheat is grown.

Importance: Yield losses depend on the number of spikes affected by the disease; incidence is usually less than one percent and rarely exceeds 30 percent of the spikes in any given location.

12

13

Flag Smut

Urocystis agropyri (G. Preuss) J. Schröth

Symptoms: Masses of black teliospores are produced in narrow strips just beneath the epidermis of leaves, leaf sheaths, and occasionally the culms. Diseased plants often are stunted, tiller profusely, and the spikes may not emerge. A severe infection usually induces the leaves to roll, producing an onion-type leaf appearance. The epidermis of older diseased plants tends to shred, releasing the teliospores (14).

Development: Germinating kernels or very young seedlings are infected by germinating spores on the seed or in the soil. The disease continues to develop systemically and the black subepidermal strips of teliospores become visible near heading. Infection is favored by low soil moisture and cool soil temperatures.

Hosts/Distribution: Bread wheats are the primary hosts of flag smut fungi, and the isolates attacking bread wheat tend to do so exclusively. There are few reports of flag smut on durum wheats and triticales. The disease is found in most winter wheat areas and in cool, fall-sown spring wheat areas.

Importance: Flag smut is not generally an economically important disease, but where present, yield losses can range from trace amounts to moderate levels (when susceptible cultivars are grown).

14

Powdery Mildew

Blumeria graminis (DC.) E.O. Speer f. sp. *tritici* E.J. Marchal

Symptoms: On all hosts, the first visible symptoms of this disease are white to pale gray, fuzzy or powdery colonies of mycelia and conidia on the upper surfaces of leaves and leaf sheaths (especially on lower leaves; 15), and sometimes on the spikes. Older fungal tissue is yellowish gray (16). This superficial fungal material can be easily rubbed off with the fingers. Host tissue beneath the fungal material becomes chlorotic or necrotic and, with severe infections, the leaves may die. Eventually, black spherical fruiting structures (cleistothecia) may develop in the mycelia, and can be seen without magnification.

Development: The development of powdery mildew is favored by cool (15-22°C), cloudy, and humid (75-100% relative humidity) conditions.

Hosts/Distribution: The fungus has a high degree of host specificity. Isolates infecting wheat do so exclusively; the same appears to be true for isolates infecting barley, oats, and rye. Further specialization exists in the form of races. Powdery mildew occurs worldwide in cool, humid, and semi-arid areas where cereals are grown.

Importance: Powdery mildew can cause major yield losses if infection occurs early in the crop cycle and conditions remain favorable for development so that high infection levels are reached before heading.

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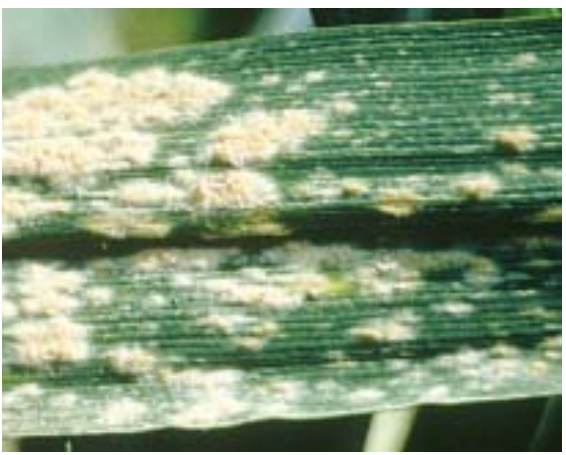

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Septoria Diseases

Septoria tritici blotch

Mycosphaerella graminicola (Fuckel) J. Schroth in Cohn (syn. *Septoria tritici*)

Stagonospora nodorum blotch

(syn. Septoria glume blotch)
Phaeosphaeria nodorum (E. Müller) Hedjaroude (syn. *Stagonospora nodorum*)

Stagonospora avenae blotch

Stagonospora avenaria (G.F. Weber) O. Eriksson f. sp. *triticea*

Symptoms: Initial infection sites tend to be irregular in shape, oval to elongated chlorotic spots or lesions. As these sites expand, the centers of the lesions become pale, straw colored, and slightly necrotic, often with numerous small black dots (pycnidia; 17). The lesions of Septoria tritici blotch tend to be linear and restricted laterally (18), while those of Stagonospora nodorum blotch (19; page 23), and Stagonospora avenae blotch are more lens shaped. All above-ground plant parts can be affected. Light infection produces only scattered lesions, but heavy infection can kill leaves, spikes (20 is S. nodorum; page 21), or even the entire plant. Identification of species in the field can be difficult, and microscopic examination is often necessary.

17

18

Development: Initial infections tend to be on the lower leaves, progressing to the upper leaves and spikes if environmental conditions remain favorable. Cool temperatures (10-15°C) and prolonged wet, cloudy weather favors the development of these diseases.

Hosts/Distribution: These are primarily diseases of wheat, but other cereals are somewhat susceptible. The diseases are limited to temperate wheat-growing areas where cool and moist conditions prevail.

Importance: If these diseases reach severe levels prior to harvest, major losses can occur through seed shriveling and lower test weights.

19

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Spot Blotch
(syn. Helminthosporium Leaf Blight; Foliar Blight)

Cochliobolus sativus (Ito and Kurib.)
Anamorph *Bipolaris sorokiniana* (Sacc.) Shoem.
(syn. *Helminthosporium sativum*)

Symptoms: Lesions caused by this disease are elongated to oval in shape and are generally a dark brown color. As lesions mature, the centers often turn a light brown to tan color, surrounded by an irregular dark brown ring (21 on leaf; 22, 23 on spike). The lesions expand, coalesce, and result in death of the leaf.

Development: Primary infections tend to be on the lower leaves, beginning as chlorotic flecks or spots. These infection sites enlarge, turn dark brown, and often coalesce. When the disease is severe, affected leaves or leaf sheaths may die prematurely.

Hosts/Distribution: Spot blotch affects wheat, triticale, barley, and most grasses. It is found worldwide but is especially prevalent in more humid and higher rainfall areas.

Importance: If infection occurs early in the crop cycle and conditions remain favorable for development, complete defoliation is possible. Major reductions in yield and severely shriveled kernels will then result.

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23

Tan Spot (Yellow Spot)

Pyrenophora tritici-repentis (Died.) Dreches.
Anamorph *Dreschslera tritici-repentis* (Died.) Shoemaker

Symptoms: At first, lesions appear as tan to brown flecks, which expand into large, irregular, oval- or lens-shaped tan blotches with a yellow or chlorotic margin (24). As these spots coalesce, large blotches are formed. The development of a dark brown to black spot in the center of the lesion is characteristic of the disease. As the disease progresses, entire leaves, spikes, and even whole plants may be killed.

Development: Initial infections come from diseased crop debris in the soil or from diseased grass hosts. Usually the lower leaves are infected first, and the disease progresses to the upper leaves and leaf sheaths if conditions are favorable. This disease develops over a wide range of temperatures and is favored by long periods (18 hours or more) of dew or rain.

Hosts/Distribution: Tan spot can affect wheat and several related grasses; triticale, barley, and rye are less frequently affected. The disease is found in the major temperate wheat-growing areas.

Importance: When severe, tan spot can cause premature death of the leaves, thereby reducing yield by lowering test weights and producing a high degree of kernel shriveling. This disease has become more important with the increased adoption of minimum and/or no-till agronomic practices, which leave crop debris in place.

24

Alternaria Leaf Blight

Alternaria triticina Prasada & Prabhu

Symptoms: Small, chlorotic, oval- or elliptical-shaped lesions appear and, as they enlarge, these lesions become irregular in shape. The chlorotic borders of the lesions may become diffuse and turn light to dark brown in color (25). Lesions are difficult to distinguish from those caused by *Helminthosporium* spp. Infection usually starts on the lower leaves, but symptoms can be found on all plant parts.

Development: The fungus survives as conidia on seed or as mycelia within seed. Sporulation on lower leaves provides inoculum that can be dispersed by wind, leading to secondary spread of the disease. Seed-borne inoculum often results in spike infections late in the crop cycle. High humidity or irrigation, as well as warmer temperatures (20-25°C) favor infection and disease development.

Hosts/Distribution: Bread wheat and durum wheat, as well as several related grasses, are the primary hosts. The disease is common in the eastern and central areas of the Indian subcontinent.

Importance: Alternaria leaf blight can be very severe if environmental conditions are favorable for disease development. Major losses can result when susceptible cultivars are grown.

25

Fusarium Leaf Blotch
(Pink Snow Mold; Fusarium Patch)

Monographella nivalis (Schaffnit) E. Müller
Anamorph *Microdochium nivale* (Fr.)
Samuels & I.C. Hallett

Symptoms: The blotching caused by this organism becomes evident on leaves at about late-joint to early-boot growth stage. Young lesions occur as oval to elliptical, grayish green mottled areas, usually located where the leaf bends (26). Lesions enlarge rapidly, developing into large, "eyespot" blotches with bleached or light gray centers. Leaves tend to split or shred, beginning at the centers of the lesions (27). The fungus can also cause seedling blight, foot rot, head scab (28) and, in winter cereals, pink snow mold.

Development: Spores are produced on crop debris left on or near the soil surface. These spores are transmitted to leaves by wind or by splashing rain. Disease development is favored by cool, moist weather.

Hosts/Distribution: Generally, the disease affects durum wheat and triticale more than bread wheat or rye; oats and barley appear to be immune. Reports indicate that the disease is restricted to East Africa, the highland areas of Mexico, the Andean region of South America, and parts of southern China.

Importance: Severe disease development can cause complete defoliation, resulting in poor grain development, shriveling, and low test weights (29).

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Fusarium Head Blight (Scab)

Fusarium spp.
Gibberella zeae Anamorph *F. graminearum* Schwabe

Symptoms: Infected florets (especially the outer glumes) become slightly darkened and oily in appearance (30). Conidiospores are produced in sporodochia, which gives the spike a bright pinkish color (31, 32). Infected kernels may be permeated with mycelia and the surface of the florets totally covered by white, matted mycelia.

Development: Several species of *Fusarium* can attack the spikes of small grain cereals; the ovaries are infected at anthesis and infection is favored by warm and humid weather during and after heading. Temperatures between 10-28°C are required for infection. Once primary infection has occurred, the disease can spread from floret to floret by mycelial growth through the spike structure.

Hosts/Distribution: All small grain cereals may be affected by this disease. *Fusarium* spp. are present in nearly all soils and crop residues.

Importance: Severe levels of infection can cause yield losses of more than 50 percent and significant reductions in grain quality. Kernels from diseased spikes are often shriveled. Harvested grain containing more than five percent infected kernels can contain enough mycotoxin to be harmful to humans and animals.

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Ergot

Claviceps purpurea (Fr.:Fr.) Tul.
Anamorph *Sphacelia segetum* Lev.

Symptoms: At flowering, infected florets produce a yellowish, sticky, sweet exudate (containing conidia) that is visible on the glumes. As the spike matures, kernels of infected florets are replaced by brown to purplish black fungal structures (sclerotia or ergot bodies; 33). These ergot bodies can reach 20 mm in length (34).

Development: The primary infection originates from ascospores in fruiting bodies produced by sclerotia from the previous year's crop. Ascospores infect the florets, which then produce the sticky exudate. Insects are attracted to the sweet exudate, and carry the conidia to healthy florets in the same spike or to adjacent spikes. Rainy or humid conditions favor the production of exudate and spores. An ergot body develops in each infected floret; these fungal structures can survive in the soil from one season to the next, and under dry conditions they can remain viable for many years. Sclerotia require cold temperatures before they can germinate.

Hosts/Distribution: Ergot is found in all small grain cereal crops, especially if sterility occurs for some reason (e.g. frost). Sterile florets tend to open and thus become more liable to infection. The disease is more prevalent in cool, humid climates.

Importance: Yield losses tend to be small, but losses due to discounted grain quality can be significant and occur worldwide.

33

34

Black Point (Kernel Smudge)

Associated with various fungi (e.g. C. *sativus, Alternaria* spp., *Fusarium* spp.) and physiological circumstances

Symptoms: The pericarps of maturing wheat kernels turn dark brown to black, with the discoloration usually restricted to the germ-end of the kernel (35; 36 is healthy seed). If caused by *Alternaria* spp., the dark color affects only the pericarp; if caused by *C. sativus* or *Fusarium* spp., the germ may be invaded and injured or killed. There are other fungi that can cause black point, but the three noted here are the most common.

Development: Usually, kernels are infected by these fungi during the dough stage. If humid weather prevails for a few days to a week just prior to harvest, the incidence of infection will increase and black point will develop in many cultivars.

Hosts/Distribution: Wheat is the principal host; triticale and several related grasses also can be affected. Distribution is worldwide, wherever small grain cereals are grown.

Importance: Losses are due mainly to discounted prices paid for discolored grain; if *Fusarium* spp. or *C. sativus* are involved, the viability of the seed also may be reduced.

35

36

Downy Mildew (Crazy Top)

Sclerophthora macrospora (Sacc.) Thirumalachar et al.

Symptoms: Diseased plants tiller profusely; they have short, erect, irregular, or crooked yellowish-green culms, and the leaves are thick, erect, and usually in whorls (37). Tillers die prematurely or never head. If formed, the heads may be branched, and some of the floral tissues grow into leaf-like structures (38).

Development: In cereals the disease is generally associated with water-logged or excessively irrigated fields. Development is enhanced if temperatures range between 10-25°C. Infection may be initiated by inoculum in the soil or from diseased weed hosts; water must be present for infection to occur. Symptoms are most obvious during the tillering/stem elongation growth stages of the host plant.

Hosts/Distribution: The fungus has a broad host range, including small grain cereals, maize, sorghum, and most grasses. It may be found wherever soils become water-logged or are poorly drained.

Importance: Small, localized epidemics can occur when conditions are favorable. There have been no reports of widespread and destructive epidemics.

37

38

Take-All

Gaeumannomyces graminis (Sacc.) Arx & D. Olivier var. *tritici* J. Walker

Symptoms: This fungus causes rotting of the roots and lower stems. Basal stem and leaf sheath tissues, as well as roots, may turn a shiny black color (39). When examined with a hand lens (10x), dark fungal hyphae may be found on the subcrown internode beneath the old leaf sheaths. Coarse, black runner hyphae are conspicuous on roots. Severe disease development is indicated by stunted plants with whitened stems and spikes (40). When infection occurs early in the crop cycle, the number of tillers is often reduced and spikes are often sterile.

Development: The fungus persists on crop debris in the soil. Initial infections come from contact with hyphae or ascospores in the soil. Infection can occur throughout the crop cycle, but is favored by cool (12-18°C) soil temperatures, and alkaline or nutrient deficient soils. Nitrate also appears to enhance disease development. Infections of the roots occurring in the fall and early spring generally progress to the crown and lower stem tissues; infections occurring later in the crop cycle cause less damage since they usually are confined to the roots.

Hosts/Distribution: The take-all fungus displays a degree of specialization for wheat, triticale, and several related grasses. The disease appears to be restricted to temperate wheat-growing areas.

Importance: Take-all is widespread in mono-cropped areas and has been known to cause considerable yield losses in winter wheat and fall-sown spring wheat areas, especially where liming or minimum tillage is practiced.

39

40

Eyespot (Foot Rot; Strawbreaker)

Oculimacula acuformis (Boerema, Pieters & Hamers) and Crous and Gams
Anamorph *Helgardia acuformis* (Nirenberg) Crous and Gams
O. yallundae (Wallwork and Spooner) Crous and Gams
Anamorph *H. herpotrichoides* (Fron.) Crous and Gams

Symptoms: The most obvious symptoms of this disease are the eye-shaped, elliptical lesions produced on the internodes of the lower stem (41). The lesions are bordered by dark brown to greenish brown rings, have straw-colored centers, and frequently develop on the leaf sheath at soil level. These lesions may coalesce and lose their distinct "eye-spot" appearance. When disease development is severe, the stem or culm may break near the ground or at the lesion, where the stem is weakened (42). Symptoms do not appear on the roots.

Development: Primary infection occurs from conidia or mycelia produced on crop debris on or near the soil surface; contact with the developing coleoptile or basal areas of young culms is required. The fungus is limited to the basal areas of the plant. Disease development is favored by cool, damp weather, and by high humidity at the soil level.

Hosts/Distribution: Wheat, triticale, rye, oats, and other related grasses can be affected by the disease, with wheat being the most susceptible. Winter wheat and fall-sown spring wheat are more frequently damaged. Eyespot occurs in cool, moist climates where fall-sown cereals predominate.

Importance: Eyespot may kill individual tillers or even whole plants. More commonly, yield losses result from reduced kernel size and number, and from lodging.

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Sharp Eyespot

Rhizoctonia cerealis Van der Hoeven

Symptoms: The primary symptoms of sharp eyespot are the lesions that develop on basal leaf sheaths; these lesions are similar to those caused by *Oculimacula acuformis* (eyespot). Sharp eyespot lesions are more superficial and more sharply outlined than those typical of eyespot. The margins are dark brown with pale, straw-colored centers (43). The mycelia often present in the centers of lesions are easily removed by rubbing. Roots can also be affected, usually becoming brown in color and reduced in number. The disease can cause stunting and a reduction in the number of tillers.

Development: Infection is highly dependent upon environmental conditions. Disease development is favored by dry, sandy soils, cool temperatures, and high humidity. The fungus persists in soil and in crop debris, and invades root and crown tissues.

Hosts/Distribution: *R. cerealis* has perhaps the widest host range of any pathogen, attacking most cultivated crops; virtually all members of the Graminae family are susceptible. It is a ubiquitous fungus, present almost everywhere in soil and crop debris.

Importance: The disease is usually more severe in fields that are continuously sown to cereals, especially winter wheat. However, no major or widespread epidemics have been reported.

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Common Root Rot

Cochliobolus sativus, *Fusarium* spp., and *Pythium* spp.

Symptoms: These fungi produce a darkening or browning of the root, crown, and basal culm tissues. Individual plants or groups of plants may lodge. White spikes are often visible just prior to normal physiological maturity (44). Infection early in the crop development can cause pre- or post-emergence "damping off" of seedlings (45). Since each fungus can attack a different plant part at a different growth stage, positive field identification of the causal agent is difficult.

Development: The roots or crown tissues are infected by conidia or mycelia present on crop debris. Infection by and development of common root rot (*C. sativus*) is favored by warm, dry soils when the plants are under stress. The root, foot, and crown rots caused by *Fusarium* spp. are generally favored by cooler, moist soils; wet soils favor *Pythium* spp.

Hosts/Distribution: These diseases affect all major small grain cereals grown in temperate regions of the world.

Importance: Major epidemics have not been reported. However, localized losses can result from thinned stands, a decrease in the number of tillers, and from reductions in head size and test weights.

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Sclerotium Wilt (Southern Blight)

Sclerotium rolfsii Sacc.

Symptoms: If infection occurs early in the crop cycle, pre- or post-emergence "damping off" of seedlings can result. Diseased tissues will frequently have white, fluffy fungal mycelia on the surface (46), which often permeate the soil surrounding the plant. Subsequent disease development results in rotted culms, crowns, and roots, and the eventual death of the plant; this leads to the appearance of "white heads" or spikes in the green crop (47). Sclerotia are commonly found on the crown tissues, culms, or near the soil surface (48). Young sclerotia are whitish and turn brown to dark brown with age.

Development: *S. rolfsii* can attack the plant at any stage of development. Fungal mycelia on crop debris or sclerotia serve as primary inoculum. Infection and disease development are favored by warm (20°C +) temperatures, excessive moisture, and acidic soils.

Hosts/Distribution: Most cereals and grasses, plus many broad-leaf plant species, are susceptible, and the fungus is widespread in tropical and subtropical environments.

Importance: The disease is seldom a problem in traditional wheat-growing areas.

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Wheat Blast

Magnaporthe oryzae/Pyricularia grisea.
Also reported as 'Piricularia' or 'Bruzone' (in Portuguese), caused by *Magnaporthe grisea* (Hebert) Barr (anamorph *Pyricularia grisea* (Cooke) Sacc.)

Symptoms: Most damage results from infection of the rachis (49) and often, all the spikelets above the infection point turn white. Foliar parts may be infected although severe epidemics on ears occur with no symptoms on leaves (50). Lesions on leaves, culms, and glumes resemble those of rice blast, and are elliptical to elongated with white to light brown centers and dark gray to reddish-brown borders. Sporulation occurs on the underside of leaves. Seeds infected during the early stages of development are severely shriveled and usually killed. Those infected later may appear healthy and provide a primary source of disease inoculum.

Development: The epidemiology of wheat blast is still largely unknown. Moderate to warm temperatures and heavy continuous rainfall seem to be important factors favoring epidemics. Disease development on spikes can be rapid, with up to 100 percent of ears becoming bleached in around two weeks, whereas leaves appear green and symptomless. This suggests infection by airborne inoculums. Wheat blast is seed-transmitted. The transmission rate depends on the time of infection in relation to heading; it is higher when seed infection occurs later in the grain-filling period.

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Hosts/Distribution: The wheat blast pathogen *M. grisea* found in South America does not originate from rice and is different from the rice pathogen. It seems to have originated from a tropical grass and alternate hosts play a role in the fungus survival.

Importance: Wheat blast is prevalent in warmer wheat-growing areas of Latin America and has been increasing in incidence. The disease is seldom a problem in dry seasons but a devastating epidemic in 2009 caused 100 percent losses in large parts of Parana, Brazil, highlighting the risk posed by wheat blast under climate change scenarios.

Black Molds

Alternaria, Cladosporium, Stemphylium, Epicoccum, and other species

Symptoms: The typical symptom is the blackened appearance of mature or dead spikes, caused by a superficial accumulation of mycelia and sporulating fungal tissue (51; page 52).

Development: When wet or humid weather occurs at or near crop maturation, or when plants are heavily infested with aphids, or when plants die prematurely, they may be invaded by one or more of these fungi. Technically, black molds do not constitute a disease, since the fungi are saprophytic and invade only dead or dying plant tissue.

Hosts/Distribution: Black molds affect any kind of dead or dying plant tissue; distribution is worldwide.

Importance: Black molds are not generally economically important. Under humid or rainy conditions, the fungi can invade mature kernels, causing discoloration, black point, or smudge.

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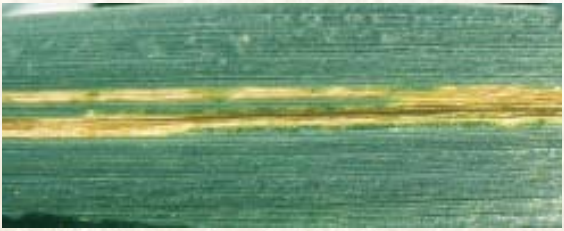
Bacterial Diseases



Bacterial plant pathogens are small unicellular rods from 1-3 mm in length. They do not have a well-defined nucleus, nor a nuclear membrane. Bacteria are spread by insects, air currents, splashing rain, and by mechanical means. Free moisture is usually necessary for infection, and penetration of host tissue occurs through wounds or stomatal openings. These pathogens invade the vascular system or intercellular spaces in host tissue, and necrosis results from toxins produced or enzymatic activity of the bacteria.

Bacterial Stripe (Black Chaff)

Xanthomonas campestris pv. *translucens*
(Jones et al. 1917) Dye 1978

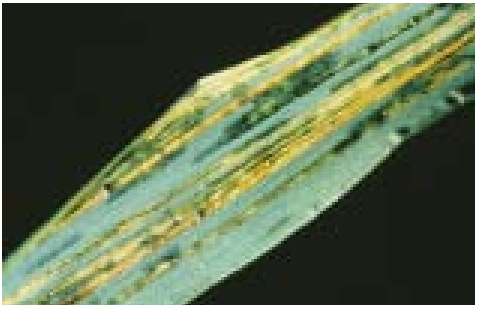
Symptoms: Bacterial stripe and black chaff are both caused by the same organism; the site and extent of the symptoms depends on the strain of the bacterium, the affected cultivar, and environmental conditions. Black chaff occurs primarily on the glumes (52); bacterial stripe occurs primarily on the leaves and/or leaf sheaths (53). Initial symptoms are narrow chlorotic lesions or stripes that have a watersoaked appearance; droplets of sticky yellowish exudate may appear with extended periods of rain or dew (54). The exudate dries to form crusty droplets or a translucent film on the surface of affected tissues. The film may crack and give a scaly appearance. If infection occurs early in the crop cycle, the spike may be infected (55), resulting in sterility; when the disease is severe, entire leaves or spikes may be killed.

Development: The bacterium can be seed borne and persists on crop residues in the soil, tolerating warm as well as freezing temperatures. Free moisture is required for infection and spread of the disease. Infection occurs through stomata and broken epidermal tissue. The disease is spread by splashing rain, plant contact, and insects.

Hosts/Distribution: These diseases occur worldwide on all small grain cereals and many grasses.

Importance: Bacterial stripe and black chaff rarely cause significant damage, even though symptoms often may be extensive.

52



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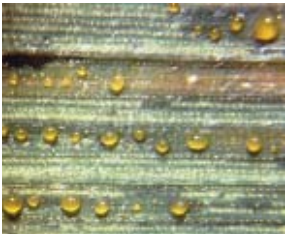

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Basal Glume Rot and Bacterial Leaf Blight

Pseudomonas syringae pv. *atrofaciens*
Pseudomonas syringae pv. *syringae*

Symptoms: The leaves, culms, and spikes of wheat and triticale can be infected. Infections begin as small, dark green, water-soaked lesions that turn dark brown to blackish in color. On the spikelets, lesions generally start at the base of the glume and may eventually extend over the entire glume (56). Diseased glumes have a translucent appearance when held toward the light. Dark brown to black discoloration occurs with age. The disease may spread to the rachis, and lesions may also develop on the kernels (57). Under wet or humid conditions, a whitish gray bacterial ooze may be present. Stem infections result in dark discoloration of the stem; leaf infections result in small, irregular, water-soaked lesions. Symptoms can be confused with those of other bacterial diseases, genetic melanism (false black chaff), Stagonospora nodorum blotch (Septoria glume blotch), and frost damage.

Development: The pathogen survives on crop debris, as well as various grass hosts. It is disseminated by splashing rain or by insects, and can be seed borne.

Hosts/Distribution: The disease can affect all small grain cereal crops; distribution is worldwide.

Importance: Basal glume rot is not usually economically important, but is frequently reported in humid cereal-growing areas.

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Bacterial Spike Blight
(Gummosis)

Rathayibacter tritici (Carlson and Vidaver 1982) Zgurskaya et al. 1993
Clavibacter iranicus (Carlson and Vidaver 1982) Davis et al. 1984

Symptoms: Yellow exudate on the spikes is indicative of bacterial spike blight. When dry, the exudate is white. Often the spikes and necks will emerge as a distorted, sticky mass (58). Early leaves may also be wrinkled or twisted. This bacteria is associated with the nematode *Anguina tritici* in some regions.

Development: The bacteria persists in organic material in the soil. It attacks wheat when it comes in contact with the plant apex within the leaf whorl, and this transmission is often facilitated by the nematode *A. tritici*.

Hosts/Distribution: Wheat is the only cultivated host, though some wild grasses are susceptible to attack. The disease is frequently reported in the Asian Subcontinent.

Importance: Bacterial spike blight is not economically important.

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Viral Diseases

Viruses are the smallest pathogens presented in this field guide. The infectious viral particle is called a virion, which is a stable, non-multiplying stage by which the virus is transferred from one plant to another. Viruses multiply in the host plant, and transmission may occur via several means: by insects and mites (especially sucking insects, such as aphids), by nematodes, by seed, by pollen, by fungi, by soil, and mechanically. Viral diseases are often difficult to detect because infected hosts may not display visible symptoms, or symptoms may closely resemble those of various physiological disorders or genetic abnormalities. Identification can be facilitated by determining which vectors are present and the host range; in many cases, positive identification requires the use of an electron microscope and serological techniques.

Barley Yellow Dwarf

Genus *Luteovirus, Barley yellow dwarf virus* (BYDV)

Symptoms: The symptoms of BYDV vary with the affected crop cultivar, the age of the plant at the time of infection, the strain of the virus, and environmental conditions. Symptoms are often masked by or confused with other problems. Affected plants show a yellowing (59) or reddening (on oats and some wheats) of leaves, stunting, an upright posture of thickened stiff leaves (60), reduced root growth, delayed (or no) heading, and a reduction in yield. The heads of affected plants tend to remain erect and become black and discolored during ripening due to colonization by saprophytic fungi.

Development: Temperatures of approximately 20°C are favorable for disease development and symptoms appear approximately 14 days after infection.

Vectors/Hosts/Distribution: The term BYDV includes several related viruses that are all aphid transmitted. Over 20 species of aphids may act as vectors. BYDV is probably the most widely distributed viral disease of cereals in the world; it attacks not only wheat, but also barley, triticale, oats, and many other grass species.

Importance: Infections occurring early in the crop cycle can result in yield losses of more than 20 percent, and much larger losses have been recorded.

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Barley Stripe Mosaic

Genus *Hordeivirus, Barley stripe mosaic virus (BSMV)*

Symptoms: Depending on the host genotype and environmental conditions, symptoms can vary from very mild stripe mosaic to lethal necrosis (61), and are easily confused with barley stripe disease (*Pyrenophora graminea*). Infected plants produce small, shriveled seed. Plants grown from these seeds can be severely stunted and may also exhibit resetting and excessive tillering.

Development: Temperatures between 24-30°C favor disease development.

Vector/Hosts/Distribution: No known vectors transmit BSMV. The virus is transmitted through seed, pollen, or direct leaf contact. The main route of natural spread of the virus in the field seems to be by plant-to-plant contact. Transmission of BSMV through seed to progeny is highest when transmission occurs via both ovule and pollen, though host genotype, virus strain, and environmental factors also affect the number of infected progeny. Seed transmission is not common in wheat. Natural known hosts are barley, wheat, and wild oat, though other species have been infected experimentally.

Importance: BSMV is rare in wheat and causes negligible economic losses. Yield losses are proportional to the level of infection in the seed lot. Efficient seed transmission means that BSMV has a high phytosanitary importance.

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Guide to Diagnosis

Symptoms

Leaf or leaf sheath

- Raised pustules with yellow, orange or black spores (pp. 2, 4, 6, 14, 48)
- Superficial white, pinkish or grayish fungal tissue (pp. 16, 30)
- Superficial dark fungal tissue (pp. 22, 34, 51)
- Dark fungal fruiting bodies within brownish grey lesions (p. 18)
- Flecks (pp. 2, 4, 6, 16, 22, 24, 72, 80, 96, 114)
- Spots (pp. 24, 110, 112, 114, 132)
- Lesions or blotches resembling halos with constrasting colored borders (pp. 2, 4, 6, 24, 48, 110, 122)
- Other types of blotches (pp. 25, 56, 72, 132, 134)
- Yellow to grey-white exudate (pp. 54, 56)
- Yellowing, chlorosis, necrosis, stunted growth (pp. 14, 38, 40, 42, 44, 46, 62, 64, 68, 76, 90, 100, 102, 104, 120, 124)
- Reddening, stunted growth (pp. 62, 64, 68, 106, 120)

Symptoms

- Deformed, curled, rolled, twisted or thickened leaves and/or leaf sheaths (pp. 14, 36, 72, 96, 100, 122, 128)
- Chewed, tattered, eaten or missing leaves (pp. 76, 94)
- Chewed longitudinal stripes (pp. 78, 94)

Stem or leaf sheath

- Raised pustules with yellow, orange, brown, or black spores (pp. 2, 4, 6)
- Superficial white, pinkish, or grayish fungal tissue (p. 16)
- Black, shiny fungal tissue beneath leaf sheath (p. 38)
- Brownish, elongated distinct eye-shaped lesions (pp 40, 42)
- Uniform tan-brown discoloration (p. 44)
- Brown to black blotches or stripes (pp. 18, 54, 110)
- Lodging, broken stems (pp. 22, 40, 42, 82, 84, 86, 134)

Root or crown

- Darkish rots, lesions (pp. 38, 44, 106)

Symptoms

- White to black fruiting bodies (p. 46)
- White mycelium (pp. 44, 46)
- Shiny black crown node (p. 38)
- Deformed, knotted or stubby roots (pp. 102, 104, 106, 124)
- Attached white or brown galls, cysts or nodules (pp. 102, 104)
- Severed or chewed roots (pp. 76, 88, 90)

Head

- Entire spike black, transformed into a powdery mass (p. 12)
- Raised pustules with yellow, orange, brown or black spores (pp. 2, 4, 6)
- Superficial white, pinkish or greyish fungal tissue (pp. 16, 30)
- Superficial dark fungal tissue (p. 51)
- Brown, black or purple blotches or streaks on glumes (pp. 18, 22, 24, 54, 112)
- Yellow exudate (pp. 54, 58)

Symptoms

- Entire head white, forced ripening, seeds shrivelled or absent- (pp. 2-51, 62, 74, 84, 86, 122, 134)
- Head is twisted or otherwise distorted, may not emerge from leaf sheath (pp. 36, 58, 72, 100, 122, 132, 134)

Seed

- Discolored with a change in shape, size and/or texture
  - Color black; seed transformed into a powdery mass (p. 12)
  - Color gray to black; seed easily crushable and has strong odor (pp. 8, 10)
  - Color brown to black; seed hard (p. 32)
  - Partially discolored; seed contains black, powdery spores, strong odor when crushed (p. 10)
- Seed discolored only (pp. 26, 30, 34, 51, 100)

Entire Plant

- Patches of stunted or damaged plants throughout the field (pp. 38, 40, 42, 44, 46, 62, 64, 68, 88, 102, 106, 126, 128, 130)
- Dwarf clumping (p. 116)

Wheat Streak Mosaic Virus

Symptoms: Infected plants are stunted with mottled green- and yellow-streaked leaves. Streaks are parallel, but often discontinuous (62). Isolates give a symptom range from mild mosaic to severe chlorosis, and severely affected plants may produce sterile heads or die prematurely. Symptoms vary with wheat cultivar, virus strain, time of infection, and environmental conditions. Symptoms are not usually apparent in autumn-sown plants, or in early spring, but become noticeable when temperatures rise above 10˚C. Symptoms on a crop often appear at the edge of the field, next to wheat volunteers.

Development: Plants infected between tillering and first node often do not produce seed, while those infected between first node and booting typically have reduced seed size. Infected seedlings often die prematurely, while later infection cause progressively less damage with only slight losses.

Vector/Hosts/Distribution: WSMV is transmitted by wheat curl mites (*Aceria tosichella* and *Aceria tulipae*). Seed transmission was not thought to occur until recently, when the virus was unequivocally shown to be transmitted to a small but consistent proportion of seedlings grown from WSMV-infected wheat plants. The virus affects wheat, maize, millet, and various grasses in Canada, USA, Mexico, Europe, China, Iran, Jordon, Kazakhstan, Syria, Turkey, Uzbekistan, and Australia. The disease is severe in areas with a year-round continuum of host plants.

Importance: WSMV has a high phytosanitary and economic importance. It is widely distributed, with seed transmission, and losses can vary from insignificant to complete.

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Insect Pests

Wheat and triticale can be attacked by a great many insects. Fortunately, only a few insect species are of major importance, causing severe damage over large geographical areas; most species are only occasional pests and/or are not geographically widespread. The "pest status" of many of species is not always well documented.

Aphids (various species)

Symptoms: Aphids are nearly transparent, soft-bodied sucking insects (63). When present in sufficient numbers, aphids can cause yellowing and premature death of leaves. They exude drops of sugary liquid known as "honeydew", which may cause tiny scorch marks on the foliage and tends to encourage the development of sooty molds. The feeding of *Schizaphis graminum* (64) is especially damaging, resulting in the development of necrotic areas sometimes accompanied by purpling and rolling of the infested leaves. The feeding of *Diuraphis noxia* produces long white stripes on the leaves (65), leaf rolling, postrate growth habit, and sterile heads.

Life Cycle: The life cycles of aphids involve winged (slates), wingless (apterous), sexual, and asexual forms. When feeding on cereals, the females of most aphid species reproduce asexually (without being fertilized), giving rise to nymphs rather than eggs.

Hosts/Distribution: Species commonly found on cereals throughout the world include:

- *Rhopalosiphum padi*
- *R. maidis*
- *Sitobion avenae*
- *Schizaphis graminum*
- *Metopoliphium dirhodum*
- *Diuraphis noxia*

Importance: Aphids are important and widespread pests on cereal crops. When feeding in sufficient numbers, they can cause significant damage. In addition. The species listed above may act as vectors of barley yellow dwarf virus.

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Stink Bugs (various species)

Symptoms: Adult stink bugs feed on stem tissue or developing kernels (66). Saliva from this insect is toxic to the plant, and a single feeding puncture can kill a stem. Feeding on kernels during the milk dough stage will destroy the kernel, while feeding during later development stages will badly shrivel the grain. Feeding on the developing head may cause partial or total sterility. Adult stink bugs have a shield-shaped body (67) and emit a disagreeable odor when crushed.

Life Cycle: Stink bugs over-winter as adults and may diapause. They tend to hibernate under dead leaves and grass. In the spring they migrate to cereal hosts, mate, and lay eggs at various places on the plant. These hatch into nymphs that feed on the plant. Mild winters and low rainfall seem to favor outbreaks of the insect.

Hosts/Distribution: Stink bugs will feed on most cereals and grasses, as well as a large range of weeds (depending on the species). Stink bugs are of major economic importance in Asia Minor.

Importance: Losses due to stink bugs are highly variable and depend on the density of the insects, weather conditions, and duration of the crop growing period. Losses are due primarily to reduced baking quality.

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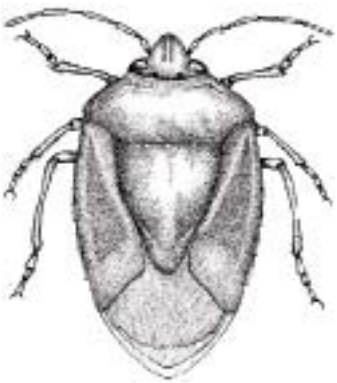

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Armyworms, Cutworms, and Stalk Borers (various species)

Symptoms: The primary symptom is defoliation of the plant. Larvae feed on leaves, chewing from the edges to the midrib, or on the heads of cereal plants. Heavy infestations can be very destructive; larvae may climb the plant and sever the neck just below the head. Some species may be found feeding at the soil surface, others underground feeding on roots, and still others feeding inside the stem. Stalk borer larvae tend to bore into stalks and stems and feed within the plant.

Life Cycle: Adult cutworms (68) and armyworms (69) are moths, and the females lay eggs on leaves and leaf sheaths near the ground. These eggs hatch within a few days and initially the larvae (70, cutworm; 71, armyworm) feed close to where they hatch. The larvae are found in cracks in the soil or under rocks during the day, feeding at night or early in the morning. In damp weather, they may feed all day.

Hosts/Distribution: Larvae are generally omnivorous in attacking grasses. Species of these insects are found in most cereal-growing areas of the world.

Importance: Cutworms and armyworms sporadically cause severe damage; when they do, they can devastate large areas. Damage to no-till and minimum-till wheat crops by stalk borers has increased dramatically over the past few years.

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Cereal Leaf Beetle

Oulema melanopus L.

Symptoms: Adult beetles are 4-5 mm long, have a black head, light brown thorax, and a shiny blue-green wing cover with parallel lines of small dots (72). Larvae are a dull to bright yellow color, but soon take on the appearance of a slimy, globular, black mass due to the mound of fecal material they produce and accumulate on their backs (73, 74). The most prominent symptom of cereal leaf beetle infestations is the distinct, longitudinal stripes on leaves (75); these stripes are produced by the feeding of adult beetles and of larvae.

Life Cycle: The insect produces one generation per year. Adults begin their feeding activity in the spring; they lay yellow eggs, either singly or in small chains, covering them with a sticky film that holds the eggs in place. Pupation takes place in the soil and the adults emerge in summer. Adults overwinter underneath plant debris on the soil surface, in leaf sheaths and ears of standing maize, or under the bark of trees.

Hosts/Distribution: Cereal leaf beetles can be a problem on fall-sown cereals. Wheats with hairy leaves are affected less.

Importance: Significant yield losses can occur in winter wheat and fall-sown spring wheat. Yield losses of 14 percent to more than 25 percent have occurred with natural infestations.

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Thrips (various species)

Symptoms: Thrips are small (1 mm long), brown or black insects with a tapering, segmented abdomen. They have piercing and sucking mouthparts and usually have two pairs of narrow wings. They are usually found behind the sheath of the flag leaf, feeding on the stem (76). However, leaves, stems, and heads may be attacked. Adults and nymphs both can cause damage and, if present in large numbers, may cause the tissue on which they are feeding to take on a silver coloration.

Life Cycle: Eggs are inserted into or attached to host tissue. The generation time is very short, and there may be 10 or more generations per year. Heavy rains will usually destroy a high proportion of the population.

Host/Distribution: Several thrips species live exclusively on cereals, and on forage or weed grasses.

Importance: Thrips rarely cause serious damage, and it is unusual to find infestations at such a level as to warrant control.

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Hessian Fly

Mayetiola destructor (Say)

Symptoms: Severe infestations of Hessian flies result in stunting of the plants, thin stands, lodging, and reduced yield. Injury is caused entirely by the larvae, which suck juices from plant tissues (77). If infestation occurs during jointing, infested stems will often break prior to maturity. The Hessian fly is 3-4 mm long, has a black head and thorax, and a pinkish or yellow-brown abdomen.

Life Cycle: Adult flies emerge in the spring from pupae that have overwintered in straw or stubble. The minute, oblong eggs are reddish in color and are laid in rows on the upper sides of leaves. The eggs hatch within one week; the white, legless larvae settle behind the leaf sheaths and suck the sap of the plant. They develop into translucent, pale green, slug-like maggots. The reddish brown pupae, commonly called "flag seed" because of their resemblance to the seed of the flax plant, are oval shaped, flattened, taper to a point, and are 3-5 mm long. They are found behind leaf sheaths, usually at a node.

Hosts/Distribution: The Hessian fly is mainly a pest of wheat, but it may attack barley, rye, and other grasses. This pest has been reported in most wheat-growing areas of the world.

Importance: This is one of the most destructive insect pests on cereals. Widespread outbreaks have occurred and, in some locations (such as North Africa and the USA), the pest recurs annually.

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Wheat Stem Maggot

Meromyza americana Fitch

Symptoms: When young tillers are attacked in the fall or early spring, the tillers usually die; infested plants show the "white head" condition typically produced by stem-boring insects (78). The adult flies are about 6 mm in length, and pale green to yellow with dark stripes.

Life Cycle: Wheat stem maggot larvae overwinter in cereal plants or grasses (79). The females lay small white eggs, one per stem, near the sheath of the flag leaf; the larvae burrow into and consume the interior of the stem, killing the upper part of the stem and the head. There are normally three generations per year; one in the spring, one in the summer, and a third in the early autumn that overwinters as larvae.

Hosts/Distribution: In addition to wheat, host crops include rye, barley, and other grasses. There are a number of other flies in various parts of the world that attack wheat in a similar fashion and produce the same kind of damage.

Importance: In infested fields, 10-15% of plants may be injured. Damage can be severe in some years, but the insect seldom causes widespread damage. However, heavy infestations of individual wheat stands may kill a significant portion of the tillers.

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Sawfly

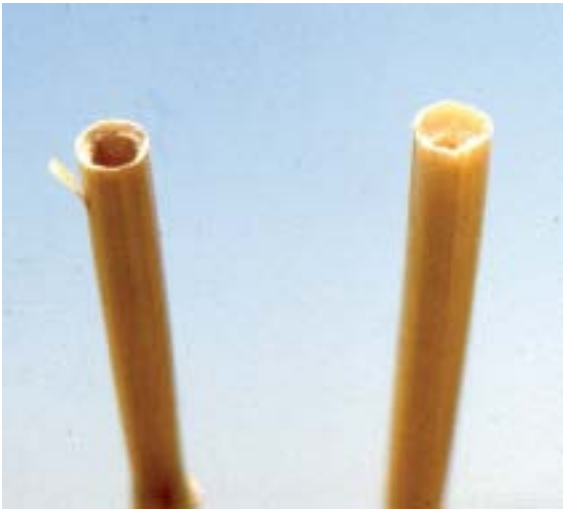
Cephus cinctus Norton

Symptoms: Damage by sawflies includes premature yellowing of the head and shriveling of the grain. The larvae girdle the stem (80) and, later in the crop cycle, lodging is common.

Life Cycle: Sawflies produce one generation per year. The larvae overwinter in the straw (81) and pupate in the spring. Adult sawflies are small, fly-like wasps and appear from late spring to midsummer. The females deposit small white eggs in the upper nodes of stems just below the heads. Upon hatching, the legless white larvae bore into the stem and tunnel downward, feeding on the pith of the stem. When they have completed their feeding, they descend further and girdle the stem base.

Hosts/Distribution: Nearly all cultivated cereals and native grasses act as hosts, although wheat is preferred. Fall-sown cereals are more commonly attacked. Wheat lines with solid or partially solid stems are much less susceptible to attack. The wheat stem sawfly is a major problem in the Mediterranean Basin.

Importance: Sawfly can cause significant damage in some years, but infestations are usually discontinuous.



80

81

White Grubs (various species)

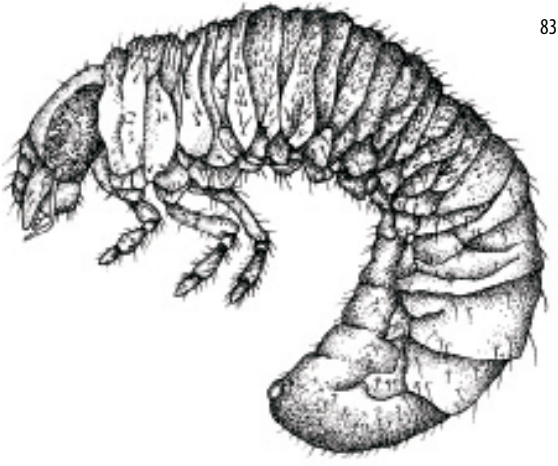
Symptoms: White grubs can partially or completely sever the roots of the host plants. This causes patches of wilting and dying wheat plants (especially at the seedling stage), symptoms that could be attributed to root rots. However, when stunted patches are observed, the surrounding soil should be examined for the larvae (82). When fully grown, the largest of these larvae may be several centimeters long and nearly one centimeter thick. The larvae have three pairs of legs on their thorax (83).

Life Cycle: White grubs are the larvae of May or June beetles. Eggs are deposited in the soil and the hatched larvae feed on roots. The duration of the larval stage varies from species to species.

Hosts/Distribution: Many species of white grubs found throughout the world can attack wheat and many other plant species. Cereal crops may suffer significant damage if seeded into heavily infested grasslands.

Importance: When the roots are not completely destroyed, the plants may survive, but are stunted and fail to produce heads. However, the distribution and extent of attack is not uniform.

82



83

Wireworms (various species)

Symptoms: Wireworm damage is very similar to that caused by other soil-inhabiting chewing insects; the only sure means of identifying wireworms as the causal agent is to find them in association with the damaged seedlings (84). The name "wireworm" refers to the tough, wire-like appearance of the larvae. They are 20-30 mm long and are often smooth, hard, and highly polished. They have three pairs of legs (85), and their color may vary from a rich cream to shades of brown.

Wireworm larvae may attack wheat as soon as the crop is seeded, eating the endosperm of the kernels and leaving only the seed coat. A common sign of wireworm attack is the wilting and/or death of a number of adjacent plants, either in a row or patch. The stems of affected seedlings will be chewed just above the seed.

(continued)

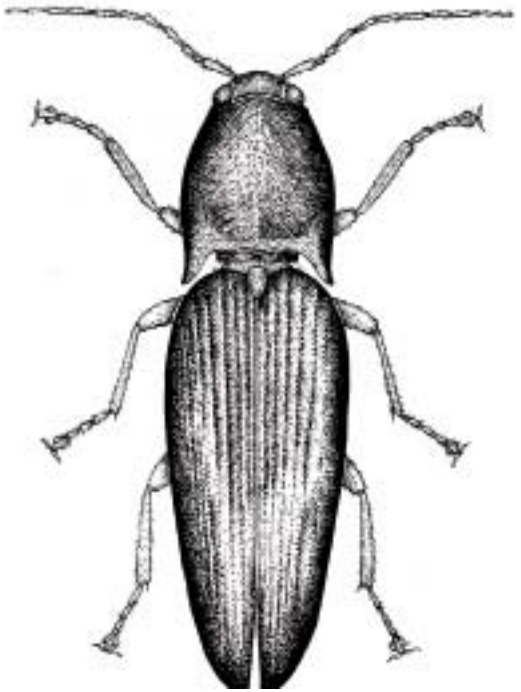
84

85

Life Cycle: Wireworms are the larvae of click beetles, of which there are many species. The adult beetles (86) lay eggs in the soil, usually in the spring, and the larvae may take several years to develop prior to pupating, depending on species. Generations overlap so that all stages and sizes of larvae may be found in the soil at the same time.

Hosts/Distribution: Many species of wireworms are found throughout the world, all of which can attack wheat. These larvae are capable of attacking many different plant species as well.

Importance: Wireworms are among the most damaging soil-infesting insects. Damage is usually most severe where wheat has been seeded after fallow or after a number of years of grass.



Slugs, Snails, Grasshoppers, and Crickets (various species)

Symptoms: Slugs and snails (87) can feed on the endosperm of germinating seed, bite seedlings off at ground level, and graze older plants, chewing longitudinal stripes on the leaves (88). This gives the adult plant a frayed appearance. Grasshoppers (89) and crickets cause damage that is very similar to that caused by cutworms and armyworms.

Hosts/Distribution: All these insects will attack a large range of plant species, including cereals. Distribution is worldwide.

Importance: These insects usually are localized in their distribution, but can cause a great deal of damage to individual stands of wheat.

87

88

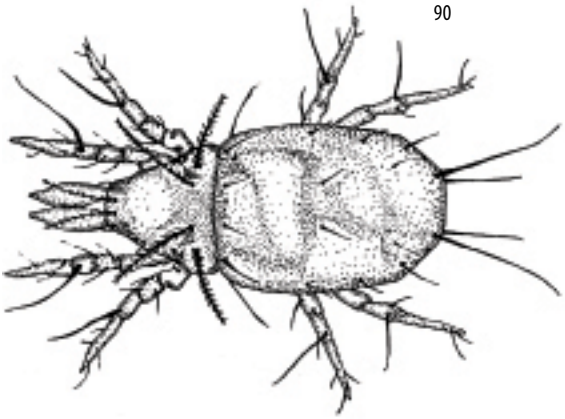
89

Mites (various species)

Symptoms: Adult mites are usually less than 1 mm long, and most of the plant-inhabiting species have sucking mouth parts. Mites are not insects. Adults typically possess four pairs of legs (90), while larvae have only three pairs. However, the wheat curl mite, *Eriophye tulipae* (syn. *Aceria tulipae*), has only two pairs of legs. When present in large numbers, mites cause a silvery flecking on leaves (91). Some species may produce webs and/or may cause infested plants to be severely stunted, to head poorly, and to turn white. Individual mites are so small that they can scarcely be seen with the unaided eye. Even so, if an infested leaf is held over a piece of white paper (folded to form a trough) and tapped sharply several times, hundreds of mites will fall onto the paper and can be seen moving about.

Hosts/Distribution: Mites can be found wherever cereals are grown.

Importance: Mites generally are not an important problem, with the exception of the wheat curl mite, which is a vector of wheat streak mosaic virus (WSMV).



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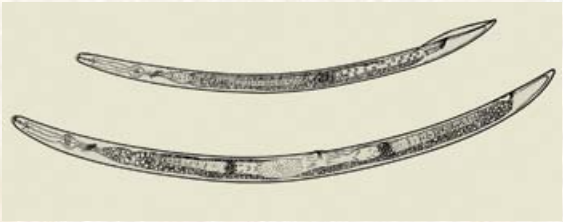
91

Nematodes



Nematodes, also known as nemas or eelworms, are unsegmented round worms that inhabit soil and water in great numbers. Some species are parasitic on plants. All nematodes develop from eggs and pass through a succession of larval stages (usually four) prior to adulthood. Reproduction may be sexual or parthenogenic. Nematodes are dispersed in soil, running water, and plant parts. Some species have a resting stage that will withstand desiccation.

Nematode feeding reduces plant vigor and induces lesions, rots, deformation, and gall and root knots. Infested fields appear uneven, usually with distinct patches of stunted plants.

Seed Gall Nematode

Anguina tritici (Steinbuch) Chitwood

Symptoms: Distorted leaves and stems are evident prior to heading. As diseased plants approach maturity, galls are formed in the florets, replacing the kernels (92). The galls are similar in shape to the seed they replace and are dark brown in color (93). Large numbers of motile larvae are present within the galls and become active after the galls have been moistened. These nematodes can act as vectors of *Clavibacter tritici*.

Development: Seed galls are dispersed along with seed during planting and harvest. In moist soil, seed galls release thousands of larvae. Wet weather favors larval movement and the infestation process. The nematode invades the crown and basal stem area, finally penetrating floral primordia. There they mature and produce large numbers of eggs. Seed galls develop in undifferentiated floral tissues.

Hosts/Distribution: The seed gall nematode parasitizes wheat, triticale, rye, and related grasses; though it primarily affects wheat. It is found in the Near and Middle East, the Indian subcontinent, eastern Europe and, occasionally, in North America.

Importance: This nematode is rarely of economic importance.

92

93

Cereal Cyst Nematode

Heterodera spp.

The three most reported cereal cyst nematode species are *Heterodera avenae*, *H. filipjevi*, and *H. latipons*. Each species consists of different pathotypes.

Symptoms: Cereal cyst nematodes are more readily detected on seedlings than on adult plants. The roots of infested plants develop frequent branches (94) and swellings (cysts). The cysts are off-white when young, turning dark brown as they age. Seedlings infected by nematodes often are invaded by soil-borne pathogens, especially root and crown rots.

Development: Larvae in moist soil penetrate roots (95) near the growing point and grow into adults. Cell enlargement, root swelling, and root branching occur as the nematodes mature. Cysts are formed as the nematodes continue to develop into egg-producing adults.

Hosts/Distribution: Most cereal crops and related species can be affected by cereal cyst nematodes. They are found in most cereal-growing regions of the world, especially in newly cultivated areas that were previously in pasture. *Heterodera* species cannot be hosted by non-cereal crops, therefore using crop rotation can reduce damage by these nematodes.

Importance: Significant yield losses can occur when initial nematode populations are high. This nematode penetrates almost all wheat cultivars, but some do not support cyst formation.

94

95

Root Knot Nematode

Meloidogyne spp.

Symptoms: Infestations of root knot nematodes are characterized by the formation of small knots or galls near the tips of the roots. Above ground, infested plants are stunted and chlorotic, and may appear wilted under hot conditions. The symptoms are sometimes confused with those of nutrient deficiency. Excessive branching of affected roots sometimes occurs (96). Factors such as nutritional deficiencies, poor drainage, and soil-borne diseases can conceal the presence of nematodes.

Development: Root knot nematodes usually invade plants in the spring or early summer. Each root knot contains one or more females, which produce large egg masses within their saclike bodies. By midsummer the eggs are extruded and the nematodes overwinter as eggs. Usually there is one generation per year.

Hosts/Distribution: Root knot nematodes have a very wide host range, including all small grain cereals. Several *Meloidogyne* species (such as *M. naasi*, *M. artiellia*, *M. chitwoodi*, *M graminicola*, and *M. incognita*) attack cereals. Optimum conditions for development occur under favorable conditions of temperature, moisture, and aeration.

Importance: The damage caused by root knot nematodes depends on the number of infective juveniles present in the soil. All winter and spring wheat cultivars seem to be compatible hosts of this nematode. In extreme attacks, seedlings may be killed.

96

Root Lesion Nematode

Pratylenchus spp.

Symptoms: Above-ground symptoms of root lesion nematodes are often indistinct and difficult to identify, but include poor vigor, stunted growth, poor tillering, and wilting in response to moisture stress (97). Often, crop growth in an infected field will be irregular or patchy. Below ground, cereal roots will display generalized root browning, with lesions rapidly coalescing to produce extensive areas of discoloration. Lesions are only readily observed on the roots in the very early stages of infection. Lateral roots will be reduced in both length and number, and the root system may be thin and poorly branched or appear necrotic.

Development: Root lesion nematodes (RLN's) are migratory endoparasites that may reproduce and then re-infest the roots several times per cropping season. Adult and juvenile root lesion nematodes have the ability to move within and between roots and soil, and will often, after a root has been damaged, migrate in favor of a fresh site. As they move through the roots, RLN's feed on the plant cell cytoplasm, killing the cell and creating lesions, therefore promoting the invasion of other fungal and bacterial diseases.

Hosts/Distribution: Root lesion nematodes have worldwide distribution, with a wide host range including field, horticultural, and ornamental crops, as well as grass and broad-leaf weeds.

Importance: *Pratylenchus thornei* is the most studied species in wheat, and can cause yield losses of up to 85 percent. Damage is greater in conditions of moisture stress and often occurs on lighter soil types with poor water holding capacity.

97

Physiologic and Genetic Disorders

Abnormal plant development may be due to physiologic or genetic disorders, nutrient deficiencies, and environmental stresses and irritants. Physiological leaf spots, blotches, and chlorosis of leaves may occur for many reasons. Some forms of chlorotic streaks, spotting, and necrosis are genetically inherited (such as chlorotic flecking and brown necrosis), resulting from chromosomal instability or certain nonviable genetic combinations (hybrid necrosis). Genotypes may differ greatly in their predisposition to develop spotting and in the physical appearance of the spots.

Physiological Leaf Spot

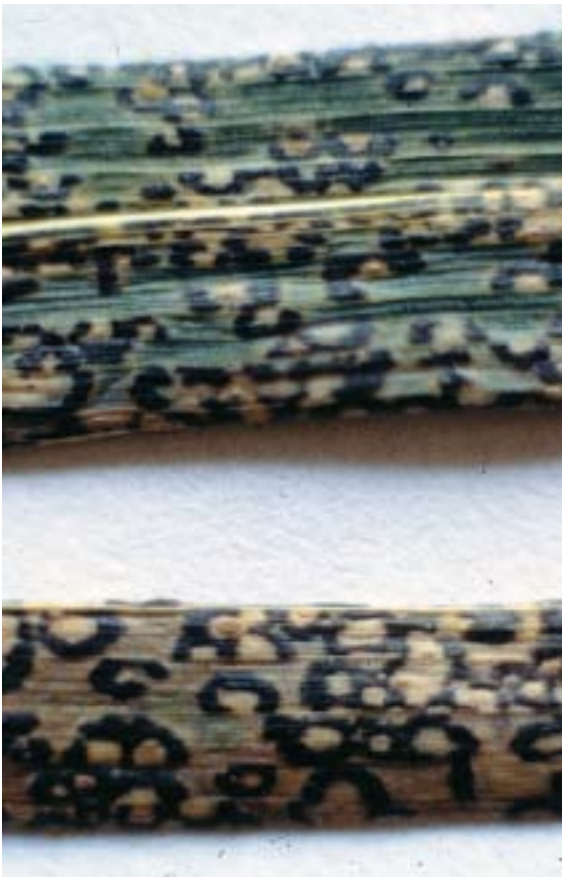
Symptoms: When no pathogen can be identified as the cause of leaf spotting (98), the symptom may be caused by a physiological disorder or a mineral deficiency (for example, manganese deficiency).

Development: "Splotch" of winter bread wheats and durum wheats is reported as a physiological leaf spot; the spots begin appearing during heading and increase in size and number toward the top of the plant. Spotted plants are otherwise normal. Leaf spots may also occur when cool, cloudy, and moist weather is followed by hot, sunny weather, or as a result of large fluctuations in temperature.

Hosts/Distribution: The occurrence of physiological leaf spots is related to variety and its interaction with the environment.

Importance: Usually not a serious problem; ongoing breeding efforts tend to eliminate genotypes prone to spotting.

98



Melanism and Brown Necrosis
(Pseudo Black Chaff)

Symptoms: Melanism occurs as brownish black to dark purple spots, streaks, or blotches on the leaf sheaths, stems (99), and/or glumes, and results from a high production of melanoid pigments in some genotypes. The dark brown pigmentation usually develops on the glumes (100) and peduncles. Melanism and brown necrosis may be confused with bacterial black chaff or Septoria glume blotch. The homogenous distribution of symptoms all along the wheat usually makes pseudo black chaff easily recognizable. Symptoms are usually more intense on the side of the spike that is more exposed to sunlight (UV effect).

Development: Symptoms develop under certain environmental conditions, in particular with cloudy, humid weather and a high intensity of ultraviolet light (high elevations). Melanism appears to be linked with the stem rust resistance genes from "Hope" and H44.

Hosts/Distribution: Melanism occurs wherever wheat is grown, but is more pronounced in high radiation, high humidity environments.

Importance: Generally not a serious problem; some crosses exhibit severe necrosis and yield is affected.

99

100

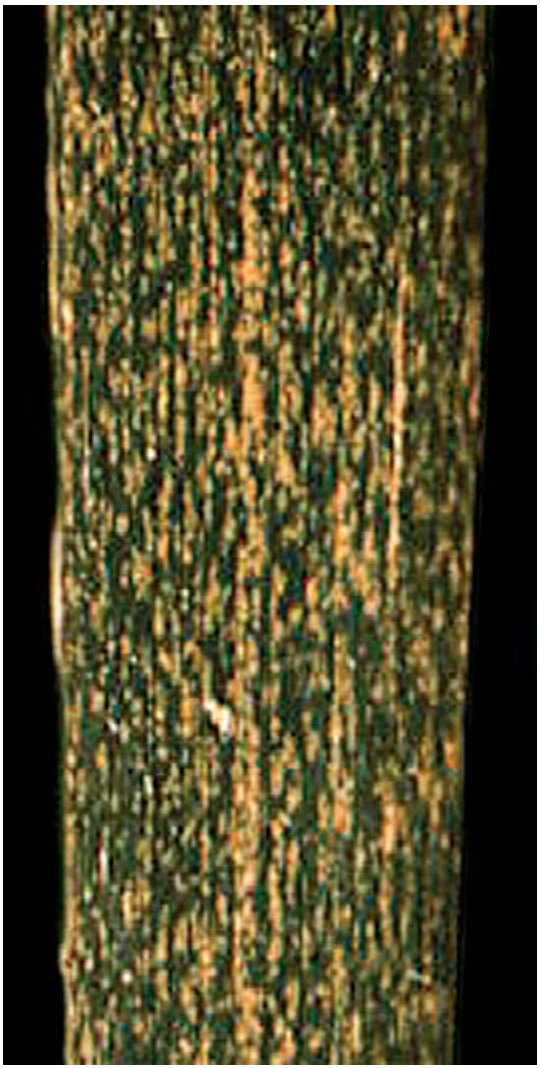
Genetic Flecking

Symptoms: Numerous diseases cause chlorotic flecking, but "self-inflicted" or genetically controlled flecking is a common occurrence in small grain cereals. The flecks may vary from small pinpoints to large blotches (101). In some cases, leaves may be a pale green color, which may be a genetic trait for low chlorophyll content.

Development: Genetic flecking or blotching may develop at any point in the crop cycle, but is more apparent at later stages of plant development (especially in spring wheats).

Hosts/Distribution: Found in many genotypes of wheat.

Importance: Genetic flecking does not necessarily make a wheat genotype unsuitable for cultivation. Several commercial wheat cultivars have high yield potential and have been released despite genetic flecking.



101

Hybrid Necrosis (Dwarf Clumping)

Some forms of spotting and necrosis result from chromosomal instability or genetic aberrations; these disorders are known as hybrid necrosis. Affected plants show differing degrees of necrosis (102), often associated with stunting or dwarf clumping. Hybrid necrosis usually is observed in early generation material (103), and affected progeny are eliminated.

102

103

Mineral and Environmental Stresses

Poor plant growth often can be attributed to inadequate levels of essential plant nutrients. Nitrogen, phosphorous, and potassium are used by the plant in relatively large amounts, and are therefore the nutrients that are most commonly deficient. However, micronutrient deficiencies can occur as well. Many minerals in the soil, including those essential to the plant, can be toxic if the amount freely available in the soil is too high. The buildup of salts in the soil, insufficient water, extreme temperatures, and poor application of pesticides also can affect the growth and yield of a crop.

Nitrogen, Phosphorus, and Potassium Deficiencies

Nitrogen deficient wheat appears pale green (104) and lower leaves become yellow, usually from the tip to the sheath, followed by necrosis if the deficiency persists. Nitrogen deficiency is the most common and widespread nutrient deficiency in small grains.

Phosphorus deficiency usually results in stunted plants with fewer shoots (105), if the deficiency is mild. Severe deficiency often causes pale to yellowish red leaves, starting with the lower leaves and moving from the leaf tips inward. Affected tissue may turn brown and, with severe deficiency, eventually dies. Green portions of the leaves may be bluish-green and the base of the culms purple. The development of small heads is also a common symptom.

Potassium deficiency can be difficult to detect, and yield losses can occur long before visual symptoms appear. A severe deficiency will cause the shortening of internodes, and the tips and margins of the lower leaves will become dry and scorched.

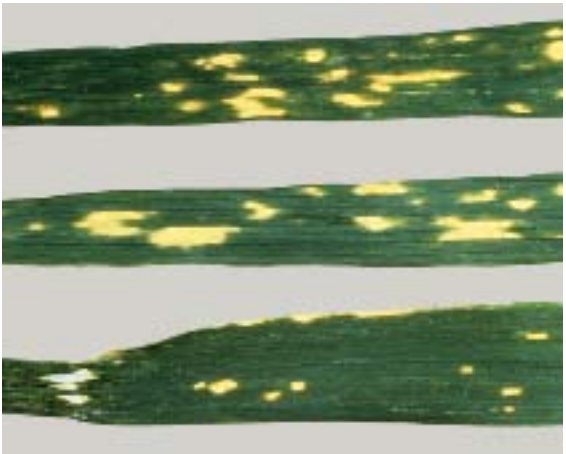
104

105

Minor Element Deficiencies

Manganese deficiency causes grayish necrotic spots or streaks to appear on the basal portion of the newest leaves. The necrotic spots may extend across the blade causing the upper portion of the leaf to kink or twist (106). Deficiency of manganese occurs most commonly in soils that are calcareous, extremely sandy, or high in organic matter. Oats are more sensitive than other small grain species. Foliar applications of manganese sulfate can alleviate this deficiency.

Copper deficiency symptoms include the discoloration of young leaf tips, followed by breaking and curling of the leaves (107). The plant may also produce bleached and sterile spikes. Often the spike does not emerge properly from the culm.



106

107

Aluminum Toxicity

Symptoms: High concentrations of aluminum will first reduce development of the roots, giving them a stubby appearance. They will often have a brownish color. Typical symptoms in the above ground portion of the plant are small leaves, and shortened and thickened internodes (108). It also is common for leaf tips to die and for old leaves to become yellow and brittle.

Development: This toxicity is associated with low soil pH, and it can be reduced by liming.

Hosts/Distribution: Though many minerals can be toxic to plants, the most common toxicity affecting wheat is caused by an excess of free aluminum. Genetic variability exists for aluminum tolerance within bread wheats and triticales (109).

Importance: Large areas of potentially productive land with acid soils (low pH) have toxic levels of free aluminum.

108

109

Salt Stress

Symptoms: Salt concentrations within a field are rarely uniform; therefore, one of the first symptoms indicating a salt problem is variability in crop growth within the field (barren spots are not uncommon; 110). Plants suffering from salt stress are stunted and dark blue-green in color, with tip burn and firing on the leaf margins. A soil test can rapidly confirm whether levels of salt in the soil are excessive.

Hosts/Distribution: All small grains are affected, but barley is more tolerant to high levels of salt than other small grain species.

Importance: In some areas, salt levels in the soil have limited yields for a long time; some poorly drained irrigated wheat areas are experiencing a buildup of salt that will eventually limit yields.

110

Moisture Stress

Symptoms: Moisture stress early in the crop cycle will stunt plants and reduce tillering and root development. Curling and rolling of leaves during midday also are symptoms of moisture stress (111). Moisture stress during the development of the spike can reduce the number of spikelets and florets, and severe stress may result in grain shriveling. Other critical periods occur during late booting and during seed set. Severe water stress during these periods can cause complete or partial sterility.

Distribution: Moisture stress occurs to some extent each year in most rainfed environments.

Importance: Yield is often reduced without the appearance of obvious visual symptoms.

111

Heat Stress

Symptoms: The effects of high temperatures are often associated with the effects of moisture stress, and the symptoms are difficult to separate (112). Moderately high temperatures increase the rate of plant development and reduce its rate of growth. The number and formation of spikelets and florets, as well as grain filling, are reduced, resulting in lower yields. The late-boot and seed-set stages are especially vulnerable and, in many areas, high temperatures are more likely to occur during these later stages of plant development. Very high temperatures will kill plants by denaturing proteins.

Importance: In many areas, the flowering to maturity period in wheat coincides with the beginning of hot, dry weather. If desiccating winds occur along with high temperatures, major reductions in yield may be experienced.

112

Herbicide Damage

Symptoms: Phytotoxicity can result from the poor application of most pesticides. The application of hormonal herbicides such as 2,4-D too early in the crop cycle can cause leaf curling and deformed spikes (113); application near anthesis can cause sterility. Residues from the application of triazines (such as atrazine) to the crop preceeding wheat can adversely affect wheat growth (114); symptoms are bleaching of the leaves followed by necrosis (115).

Development: Damage results when chemicals are applied in excessive amounts, at the wrong growth stage, or to the wrong species.

Importance: In small grain cereals, damage is generally limited; deformations seldom cause significant losses.

113

114

115

Frost Damage

Symptoms: Chlorosis of affected tissues is the common symptom. A light frost may only affect new tissue, resulting in a banding or striping on the leaves or spikes. A severe frost will kill affected tissue, which takes on a bleached white appearance (116). Sterility can result from frost occurring at flowering (117). The epidermis of the peduncle often becomes separated from underlying tissue.

Development: The freezing of plant tissue can occur at any stage of the crop cycle. Young or newly emerged tissue is the most susceptible to damage. Flowering parts are particularly sensitive.

Hosts/Distribution: All plants can suffer frost damage, and frosts can occur in most temperate wheat-growing regions.

Importance: Frost can be a serious problem if it occurs late in the crop cycle.

116

117

Glossary

Alternate host	A second host species required by some complete rusts and other organisms to their life cycle
Chlorosis	Yellowing or whitening of normally green plant tissue
Coalesce	To combine, to fuse or come together
Conidiophore	A threadlike stalk upon which conidia (spores) are produced
Conidium (pl. conidia)	Any asexual spore formed on a conidiophore
Diapause	A period of dormancy
Exudate	Gel-like accumulation of spores or bacterial ooze
Foot rot	Disease symptoms, such as discoloration, necrosis and decay, affecting the roots and basal portions of the plant or culm
Gall	A localized proliferation of plant or parasite tissue that produces an abnormal growth or swelling, usually caused by pathogenic organisms, nematodes, or insects
Honeydew	A sticky exudate (containing conidia) produced during one stage of the life cycle of *Claviceps purpurea*
Hypha (Pl. hyphae)	A tubular, threadlike filament of fungal mycelium
Immune	Not affected by pathogens
Inoculum	Spores or other diseased material that may cause infection

Lesion	A visible area of diseased tissue on an infected plant
Mosaic	A pattern of disease symptoms displaying mixed green and lighter colored patches
Mycelium (pl. mycelia)	A mass of hyphae that form the body of a fungus
Necrosis	Death of plant tissue, usually accompanied by discoloration
Pathogen	A microorganism that causes disease
Primary inoculum	Spores or fragments of a mycelium capable of initiating a disease
Pustule	A spore mass developing below the epidermis, usually breaking through at maturity
Resistance	Inherent capacity of a host plant to prevent or retard the development of an infectious disease
Sclerotium (pl. sclerotia)	A dense, compact mycelial mass capable of remaining dormant for extended periods
Senescence	The phase of plant growth that extends from full maturity to death
Spore	A minute reproductive unit in fungi and lower plant forms
Sporulation	The period of active spore production
Striate	Displaying narrow parallel streaks or bands
Susceptible	Being subject to infection or injury by a pathogen; non-immune

Symptom	A visible response of a host plant to a pathogenic organism
Telium (pl. telia)	Pustule containing teliospores
Teliospore	A thick-walled resting spore produced by rust and smut fungi
Tolerant	The ability of a host plant to develop vreproduce fairly efficiently while sustaining disease
Transmission	The spread of a disease agent among individual hosts
Urediospore	An asexual spore of the rust fungi
Vector	An organism capable of transmitting inoculum
Virulence	The relative ability of a microorganism to overcome the resistance of a host
Water soaked	Appearing wet, darkened, and partially transparent

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