Puccinia graminis: Life cycle, symptoms and control measures

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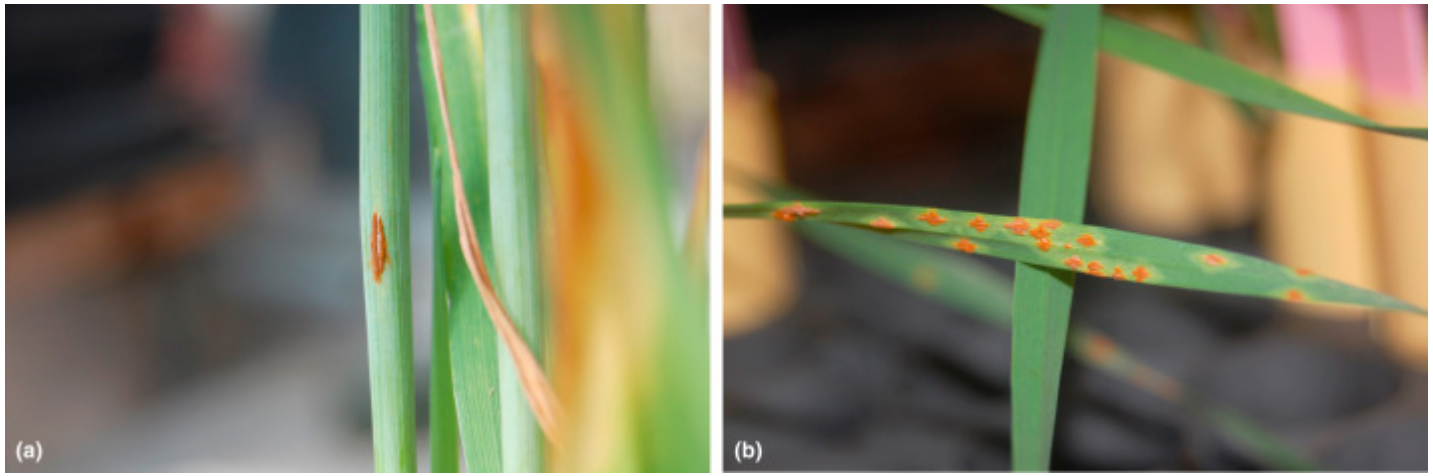
- DISEASE: **Stem rust (black rust)**
- PATHOGEN: ***Puccinia graminis* f. sp. *tritici***
- HOSTS: **Wheat and barley, common barberry (and some additional *Berberis*, *Mahoberberis*, and *Mahonia* spp.)**
- Stem rust was once the most feared disease of cereal crops. It is not as damaging now due to the development of resistant cultivars, but outbreaks may occur when new pathogen races arise against which the existing kinds of resistance are ineffective.
- Stem rust remains an important threat to wheat and barley and, thus, to the world food supply.
- Anton deBary first demonstrated the heteroecious life cycle of a rust fungus with *Puccinia graminis*, the causal agent of stem rust.



Symptoms and Signs

- **On wheat and other grass hosts:**
- Plants do not usually show obvious disease symptoms until 7 to 15 days after infection when the oval pustules (uredinia) of powdery, brick-red urediniospores break through the epidermis (Figures 1, 2).
- Microscopically, these red spores are covered with fine spines (Figures 3, 4).
- The pustules may be abundant and produced on both leaf surfaces and stems of grass hosts.
- Later in the season, pustules (telia) of black teliospores begin to appear in infected grass species (Figure 5).
- Microscopically, teliospores are two celled and thick walled (Figure 6).

Figure 1

Figure 2

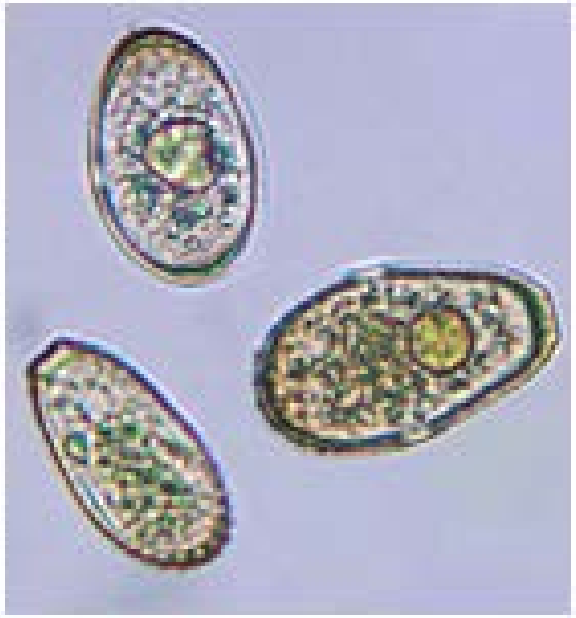


Figure 3

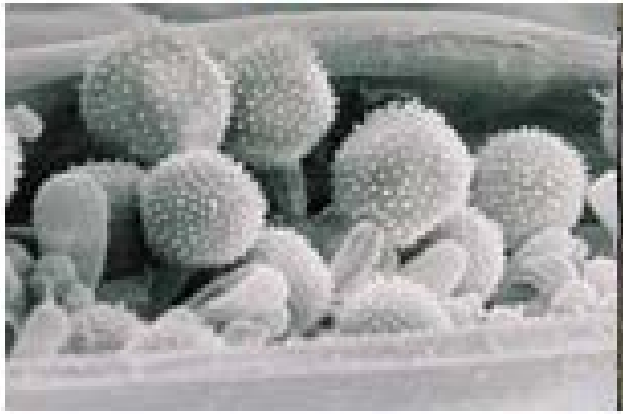


Figure 4

Figure 5

Figure 6

Pathogen Biology

- **Rust fungi are obligate parasites**. In nature, they require living host tissue for growth and reproduction; they cannot exist as saprophytes.
- In the absence of living host tissue, they survive as spores.
- In most rust fungi, only the teliospores are adapted to survive apart from a living host plant for more than a few months under field conditions.
- ***Puccinia graminis* is heteroecious.** This word describes rust fungi that require two unrelated host plants, such as wheat and barberry, to complete their life cycle.
- ***Puccinia graminis* is macrocyclic**, producing all five spore stages:
  - basidiospores,
  - pycniospores (spermatia),
  - aeciospores,
  - urediniospores (uredospores),
  - teliospores.
- Anton deBary, in 1865, first recognized the nature of the heteroecious life cycle, but the role of each spore stage was not completely understood until John Craigie, a Canadian scientist, studied the pathogen in 1927.

… Pathogen Biology

- Although stem rust is caused by a single species of fungus, *Puccinia graminis*, there is considerable genetic variation within the species.
- In 1884, Eriksson discovered host-specific subspecies or "special forms" of the fungus.
- Each special form is designated in Latin as a *forma specialis* or "f. sp."
- All of the *formae speciales* have an identical appearance, but vary in host range.
- The pathogen that causes stem rust of wheat (*Triticum aestivum*) is *Puccinia graminis* f. sp. *tritici*.
- Other *formae speciales* include *P. graminis* f.sp. *secalis*, causal agent of stem rust of rye (*Secale cereale)*, and *P. graminis* f.sp. *avenae*, causal agent of stem rust of oat (*Avena sativa*).
- Both *Puccinia graminis* f. sp. *tritici* and *P. graminis* f.sp. *secalis* cause stem rust in barley.
- About 1916, E.C. Stakman and others determined that within *P. graminis* f. sp. *tritici* are further genetic subdivisions called races. Later, races were found within other *formae speciales* as well.

Disease Cycle and Epidemiology

- The disease cycle of wheat stem rust starts with the exposure of each new wheat crop to spores of *Puccinia graminis* f. sp. *tritici*, which are the primary inoculum.
- The source of the first spores that infect the new wheat crop differs depending on the region in which the wheat is grown.
- In warm climates, wheat is planted in late fall and harvested in early summer.
- The first spores to infect the young wheat plants in the fall are urediniospores.
- They generally come from infected volunteer wheat plants.
- Seed spilled in the field or on roadsides at harvest time often sprout and produce scattered volunteer plants.
- These plants can become infected from spores produced on late-maturing wheat plants still in the field.
- The infected volunteer wheat plants serve as a bridge that carries *P. graminis* f. sp. *tritici* through the summer to the next fall-sown crop of wheat.

- In regions with temperate climates, wheat may be planted either in the fall (winter wheat) or the spring (spring wheat) depending on the severity of the winters.
- The first rust spores to infect wheat in the spring in temperate regions may be aeciospores from barberry, the alternate host, or urediniospores from infected wheat in distant regions with milder winters.
- Therefore, we describe two disease cycles for stem rust - with or without barberry.

- **Uredinial Stage**
- The uredinial, or red summer, stage is initiated by germination of a urediniospore on its grassy host, penetration, development of an intracellular mycelium with intracellular haustoria, and subsequent sporulation of uredinia to form new urediniospores.
- The recycling of the uredinial stage is the major means whereby the fungus initiates and perpetuates an epidemic.
- The urediniospores of *P. graminis* are dikaryotic (n+n), dehiscent, thick-walled and covered with spines. They are elliptical and about 20 x 30 µm.
- **Telial Stage**
- As infected plants mature, urediniospore formation ceases and teliospore formation commences, either in the same, or in new (telia), fruiting structures.
- At this stage, the infections become black, hence the name black rust.
- The ontogeny of teliospores is the same as urediniospores, but the teliospores remain attached.
- The teliospores are two-celled, thick-walled (with up to five wall layers) and are thickened at the apical end.
- Teliospores are important because they are constitutionally dormant, enabling the fungus to survive severe cold or drought.
- The mature teliospore represents the only true diploid state of the fungus.

Figure 1

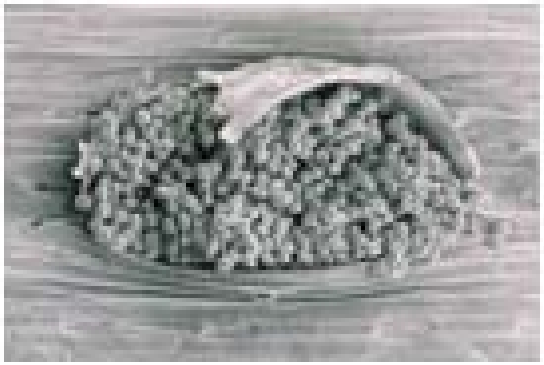


Figure 2

Figure 3

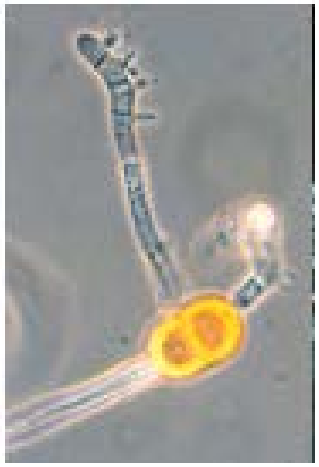
Figure 4

Figure 5

Figure 6

Basidiospore Stage

- The germination of teliospores and subsequent meiosis in the basidium results in the formation of haploid basidiospores.
- Four basidiospores, two of each opposite mating types, are produced from each basidium.
- If basidiospores are deposited on the surface of the alternate host (mainly *Berberis vulgaris*) they germinate, penetrate directly through the host epidermis and form a haploid mycelium.
- The fungus is most capable of infecting *Berberis* only when the leaves are young and tender.
- The fruiting structure, formed as a result of basidiospore infection, is called a pycnium.



Spermatial Stage

- The pycnia are normally formed on the adaxial leaf surface, often in clusters.
- The important features of the pycnia are the formation of flexuous (receptive) hyphae and haploid spermatia.
- The spermatia, produced successively from the terminal ends of sporophores, are exuded in a nectar.
- The nectar attracts insects, which in addition to splashing rain drops, serve to transport the spermatia to flexuous hyphae of the pycnia of opposite mating types, where fusion occurs.

Aecial Stage

- Following union of the opposite mating types, dikaryotization occurs.
- The spermatial nuclei migrate to the protoaecium, where mitosis occurs, the nuclei reassort into dikaryons and the aecial structure forms.
- The aecia of *P. graminis* are elongated, cylindrical structures.
- The ornamented, dikaryotic aeciospores are produced successively in chains from the aeciosporophores.
- The aeciospores infect the grassy host, completing the fungal life cycle.
- Aeciospores differ from urediniospores, which also infect wheat, in their appearance - slightly warty rather than spiny - and in the way in which they are formed - in chains in an aecium rather than on individual stalks in a uredinium.

Figure 7 Figure 8 Figure 9

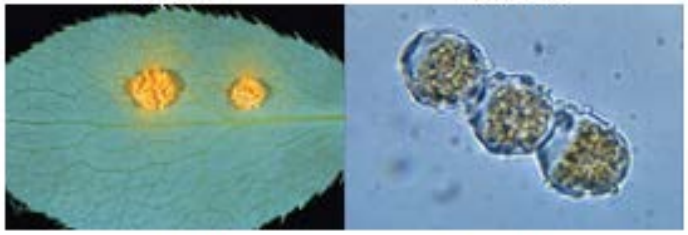
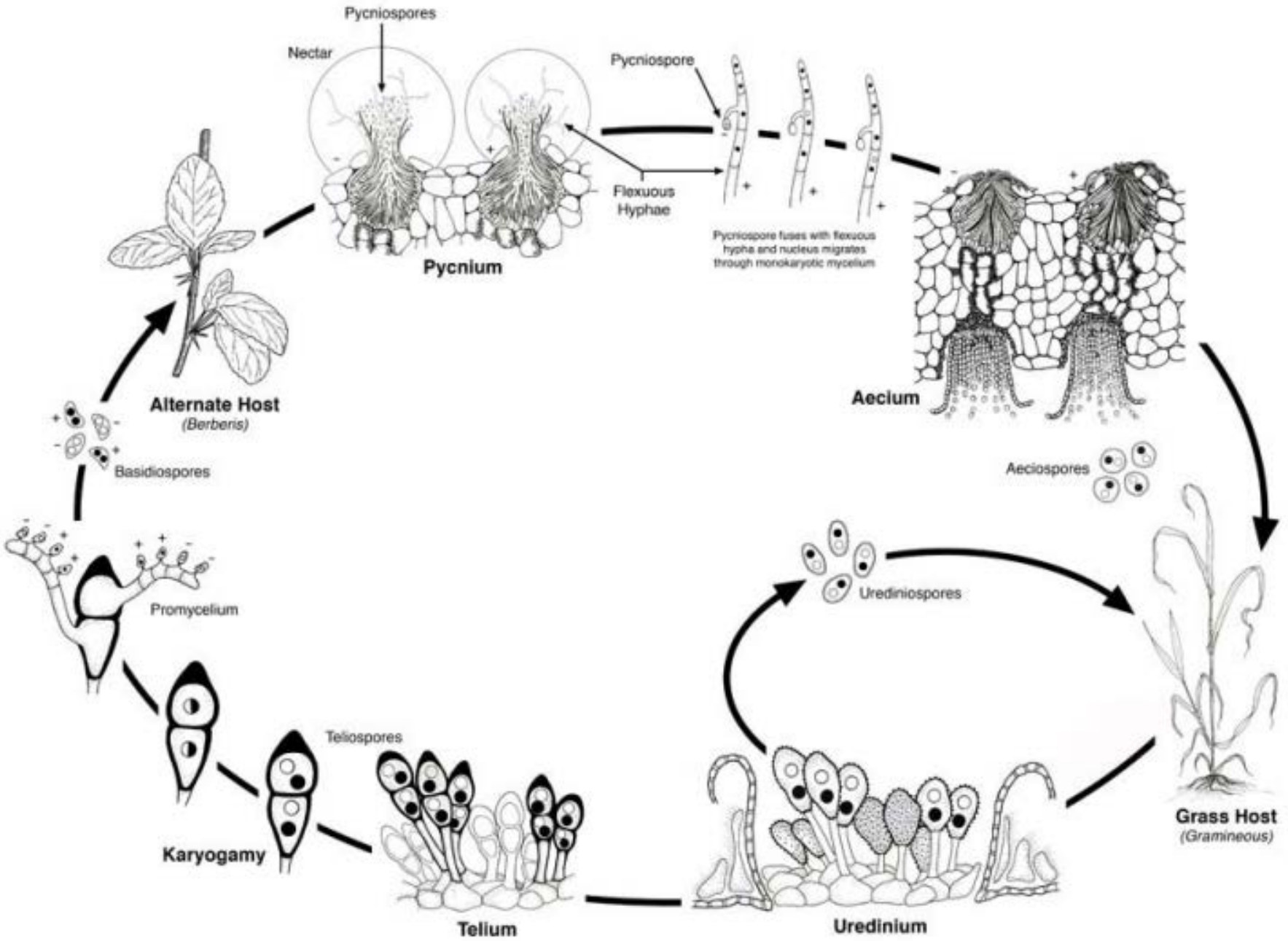


Figure 10 Figure 11

Fig 7. Barberry plants.
Fig 8. Pycnia are often in small clusters and exude pycniospores in a sticky honeydew.
Fig 9-10. Cup-shaped structures filled with orange-yellow, powdery aeciospores break through the lower leaf surface.
Fig 11. Microscopically, aeciospores have a slightly warty surface.


Pycniospores
Nectar
Pycniospore
Flexuous Hyphae
Pycniospore fuses with flexuous hypha and nucleus migrates through monokaryotic mycelium
Pycnium
Aecium
Alternate Host
(Berberis)
Basidiospores
Aeciospores
Promycelium
Urediniospores
Grass Host
(Gramineous)
Teliospores
Karyogamy
Telium
Uredinium

Epidemiology

- Stem rust is favored by hot days (25-30ºC/ 77-86ºF), mild nights (15-20ºC/ 59-68ºF), and wet leaves from rain or dew.
- Both aeciospores and urediniospores require free water for germination as do the other spore stages.
- Infections occur through stomata.
- If disease develops in individual foci within a wheat field, the source of urediniospores is probably overwintering mycelia and/or uredinia.
- Rusted plants in foci from overwintering sources have heavy infection in lower leaves and less infection in the younger leaves formed higher on the wheat plants.
- In the absence of barberry or other alternate hosts, urediniospores are the only functional spores in the disease cycle of *P. graminis.*
- In tropical and subtropical climates, mycelium and urediniospores on volunteer wheat and noncrop grass hosts begin epidemics.
- Urediniospores are generally unable to survive harsh winter conditions.
- In the Northern Hemisphere, inoculum for spring wheat arrives from southern areas.

… Epidemiology

- In Southern Hemisphere, urediniospores arrive from milder areas in the north.
- Occasionally, *P. graminis* can overwinter in wheat volunteers, noncrop grass hosts, and winter wheat, but usually only where snow cover insulates both the wheat leaves and the fungal mycelium.
- One uredinium can produce at least 100,000 urediniospores.
- Explosive epidemics can occur during favorable environmental conditions, resulting in losses of 50 to 70% over a region.
- Stem rust causes cereal yield losses in several ways:
  - The fungus absorbs nutrients from the plant tissues that would be used for grain development in a healthy plant.
  - As pustules break through the epidermal tissue, it becomes difficult for the plant to control transpiration, so its metabolism becomes less efficient.
  - Desiccation or infection by other fungi and bacteria also can occur.
  - Interference with the vascular tissues results in shriveled grains.
  - Stem rust also can weaken wheat stems, so plants lodge, or fall over, in heavy winds and rain.

Disease Management

- **Barberry eradication:** An expensive and extensive barberry survey and eradication program was initiated in 1918 in the U.S. and continues to a limited extent today.
- **Cultural practices:** It has long been known that moisture on leaves and excessive foliar nitrogen favor infections by rust fungi.
- Farmers consider these factors in spacing, row orientation, and fertilizer schedules.
- Mixed cropping with suitable crops.
- **Genetic resistance:** Genetic resistance is the most commonly used and the most effective means to control stem rust.
- Grow resistant varieties like PBW 343, PBW 550, PBW 17
- **Chemical control:** Fungicides that inhibit the synthesis of sterols [i.e., sterol biosynthesis inhibitors (SBIs) or demethylation inhibitors (DMIs)] are particularly effective, but the cost of application is generally prohibitive for routine use in most wheat-growing areas in the U.S.
- Spray Zineb at 2.5 kg/ha or Propioconazole @ 0.1 %.