

California Pest Rating Proposal for *Puccinia graminis* Pers.: Pers. 1794

Stem rust of cereals

Current Pest Rating: C

Proposed Pest Rating: C

Domain: Eukaryota, Kingdom: Fungi, Phylum: Basidiomycota,
Subphylum: Pucciniomycotina, Class: Pucciniomycetes,
Order: Pucciniales, Family: Pucciniaceae

Comment Period: **08/26/2021 through 10/10/2021**

Initiating Event:

In June 2021, the USDA's Black Stem Rust program was selected for review by the Regulated Domestic Pest Program Evaluation Committee (RDPPEC). The RDPPEC is an independent body that assesses whether USDA PPQ domestic programs are meeting their goals, and whether the goals remain realistic and feasible. A pest rating has not been written for the pathogen responsible for stem rust, *Puccinia graminis* (sensu lato). The risk to California from *P. graminis* is described herein and an official pest rating is proposed.

History & Status:

Background: The United States experienced devastating cereal stem rust epidemics caused by *Puccinia graminis* in the first half of the 20th century that greatly reduced grain yields. Combatting this disease became a national priority for the country. It was recognizing early on that cereals were the primary host and barberries were the alternate host. The USDA lead barberry eradication programs for northern cereal-producing states. The programs were successful in reducing the frequency and severity of disease. Breeding of cereals with genetic resistance to stem rust has proven even more effective and in 1981, the USDA ended funding for barberry eradication, turning this program over to the states. By 1990, the barberry eradication efforts had essentially ceased. A federal quarantine is still maintained against sales of stem rust-susceptible barberry in states that were part of the barberry eradication program. A barberry testing program was established to ensure that only barberry species and varieties, such as the ornamental Japanese barberry (*Berberis thunbergii*), that are resistant to stem

rust will be grown in the quarantine areas

(https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/barberry/ct_barberry).

Puccinia graminis is one of the most widely studied plant pathogens. Thousands of papers have been published on the ecology, epidemiology, and host–parasite interactions of this rust from research conducted throughout the world (CABI-CPC, 2021). Stem rust is an obligate pathogen requiring a living host for its reproduction and survival. It is a heteroecious, macro- or long cycle rust that has five spore stages and the pathogen alternates between cereals (i.e. wheat, barley and rye), and barberries (i.e. common barberry, *Berberis vulgaris*, and other *Berberis*, *Mahonia*, and *Mahoberberis* species). The cereal is the primary host, producing the repeating stage II urediniospores and stage III teliospores. Teliospores overwinter in straw and debris, and germinate in the spring, producing stage IV basidiospores that infect young barberry leaves. Then the barberry produces stage 0 spermatia and receptive hyphae. This is the gametic stage, with +/- mating types which are self-sterile. This is where plasmogamy and dikaryotisation take place when compatible mating types combine, producing new genotypes. Stage I aeciospores develop on the barberry leaves. Aeciospores are binucleate and move short distances with wind and rain to infect cereal plants.

Symptoms on cereals include huge numbers of orange, erumpent rust pustules primarily on the stems and leaf sheaths. These pustules produce thousands of powdery urediniospores. Urediniospores can autoinfect the same cereal plant or move long distances with air currents to other cereal plants. Multiple cycles of infection, sporulation, and re-infection can produce very destructive epidemics in cereal fields within a few weeks. Late in the season, pustules on cereals convert from producing only urediniospores to producing urediniospores and teliospores.

In cold climates that grow spring cereal crops, *P. graminis* survives as overwintering teliospores which produce basidiospores in the spring that only infect barberries. When barberry bushes are close to cereal fields, they can serve as foci for infections that lead to early season epidemics with extra time for repeated cycles of urediniospores to form. Barberry is the host where sexual reproduction of stem rust occurs, which can give rise to new pathogenic races of the fungus.

Wheat (*Triticum aestivum*) is a very important host for stem rust in the United States. In warm climates, winter wheat is planted in late fall and harvested in early summer. Young wheat plants are infected in the fall by urediniospores from infected volunteer wheat plants growing in the area, or from spores produced on late-maturing wheat plants still in the fields. This allows stem rust epidemics to occur even if barberry is not present. The mild climate along the coast of the Gulf of Mexico allows the urediniospores to survive and spread in the winter. Prevailing southerly winds in the spring carry inoculum north into the central Great Plains. Weather in the Great Plains is usually too cold for winter wheat, but when spring wheat emerges, it can be infected by windborne urediniospores carried over long distances and with the jet stream. Urediniospores from the southern U.S. and northern Mexico move via what is now called the "Puccinia Pathway", blowing up from the south and infecting crops sequentially at more and more northern latitudes until the rust reaches the northern limit for wheat in

Canada. Barberry plants do not become infected in the South because stem rust teliospores will not germinate unless exposed to extended periods of freezing temperatures.

Despite the *Puccinia* pathway bringing urediniospores, barberry eradication has had significant positive effects on disease suppression. A single barberry plant can produce billions of aeciospores, so their removal reduces early season inoculum. By eliminating the sexual cycle, mutation of urediniospores is now the only source of genetic variation. And epidemics are delayed by several weeks in northern wheat producing areas of the continent because there is a time delay of urediniospores from the south reaching the fields later vs. ascospore released early in the spring from barberries (Roelfs, 1982).

The taxonomy of the cereal rusts is complicated by morphological variation and specialization on numerous different hosts. Several subspecies and varieties or formae speciales (f. sp.) are recognized in the literature. According to the nomenclature of Savile (1984), there are three distinct morphological forms: subsp. *graminis* var. *graminis*; subsp. *graminis* var. *stakmanii*; and subsp. *graminicola*. Others prefer the f. sp. nomenclature based on host specialization, often using f. sp. *avenae* for the rust affecting oats, f. sp. *secalis* for the rust affecting rye, and f. sp. *tritici* for the rust affecting wheat. The f. sp. designations can be further subdivided into numerous races or pathotypes. Nomenclature is further complicated by numerous overlapping host ranges. For example, f. sp. *tritici* is recognized for its pathogenicity to *Triticum* spp. but also has many other important hosts, including species of *Agropyron*, *Elymus*, *Hordeum* and *Bromus* (Savile, 1984; Farr and Rossman, 2021).

Hosts: Farr and Rossman (2021) in the USDA fungal database list 775 fungus-host combinations for *P. graminis* and its synonyms. CABI (2021) estimates more than 410 graminaceous species in 79 genera are known hosts for the *P. graminis* sensu lato. There are host lists with over 70 species of *Berberis*, and there are several species of *Mahonia* and *Mahoberberis* (*Berberis* x *Mahonia*), with many species having resistant or susceptible varieties that are alternate hosts (Roelfs, 1985).

Symptoms: Infections on cereal hosts occur mainly on stems and leaf sheaths, with occasional infections on leaf blades and glumes. The first visible symptom is a small chlorotic fleck, which appears a few days after infection. Eight to ten days later, a pustule is formed by rupture of the host epidermis from pressure from the growth of a mass of brick-red urediniospores. These uredinial pustules are generally linear or diamond shaped, and may grow up to 10 mm long. Late in the season, production of urediniospores is augmented with production of a layer of black teliospores, causing the stems of heavily infected plants to appear blackened late in the season (Bockus, 2010).

On the barberry host, pycnia appear mainly on the upper leaf surfaces of young leaves. They are often in small clusters and exude pycniospores in a sticky honeydew. Within 10 days, cup-shaped structures filled with orange-yellow, powdery aeciospores break through the lower leaf surface. The aecial cups are yellow and elongate and sometimes extend up to 5 mm from the leaf surface (Schumann and Leonard, 2000; Leonard, and Szabo, 2005)

Transmission: Rust spores (all stages) are mostly carried by wind. *Puccinia graminis* has spread worldwide wherever its hosts are grown. The pathogen survives season-to-season on volunteer plants or naturalized, native, or weedy grasses. Local movement within the canopy is by turbulence and

deposition is by gravity. The pathogen survives by producing large numbers of urediniospores, 5000 spores per day per uredinium, with up to 1000 uredinia per stem possible. Long distance dispersal occurs when hot air currents lift the spores to 3000 m. At this altitude, spores can be transported hundreds of kilometers by wind. The spores can be efficiently scrubbed from the air by rain (Watson and de Sousa, 1983; Roelfs, 1989). Stem rust is not seed borne (CABI, 2021).

Damage Potential: Urediniospores are produced 1-2 weeks after infection, leading to multiple generations of inoculum produced during a single growing season. One uredinium can produce 100,000 urediniospores. Explosive epidemics can occur during favorable weather resulting in losses of 50 to 70% over a region. If the primary inoculum is aeciospores from barberry, epidemics can begin very soon after emergence of the young cereal plants and lead to many more secondary cycles (Schumann and Leonard, 2000; Leonard and Szabo, 2005).

Rust pathogens generally do not kill their hosts. The growth and reproduction of the fungus diverts nutrients from the plant tissues that would otherwise be used for vegetative growth and grain development. Pustules breaking through the epidermal tissue make it difficult for plants to control transpiration, leading to desiccation. Secondary infection by other pathogens can occur. Rust infection can lead to the production of shriveled grains. Stem infection weakens the stems, so plants lodge in winds and rain. Severe lodging hinders mechanical harvesting (Schumann and Leonard, 2000; Leonard and Szabo, 2005).

Worldwide Distribution: *Puccinia graminis* occurs in most parts of the world on wild grasses and on cultivated cereals. An accurate geographic distribution to the subspecies or f. sp. level is difficult to determine as they may affect different crops in different regions differently.

Official Control: *Puccinia graminis* is on the USDA's harmful organism list for Indonesia, Mexico, Norway, Svalbard and Jan Mayen, and Timor-Leste, and is a quarantine pest in the United States and Canada. The USDA maintains a federal quarantine in the conterminous 48 states plus the District of Columbia to prevent interstate movement of regulated articles which includes all plants of the genera *Berberis*, *Mahoberberis*, and *Mahonia* not listed as rust-resistant under §301.38-2, and any plant of the genera *Berberis*, *Mahoberberis*, and *Mahonia* grown from seed and having less than two years' growth. California has no restrictions on the intrastate movement of the Federally regulated articles.

California Distribution: There are records across the state on grasses and cereals in these genera (all in the family Poaceae): *Agrostis*, *Alopecurus*, *Ammophila*, *Deschampsia*, *Elymus*, *Festuca*, *Hierochloa*, *Holcus*, *Hordeum*, *Lamarckia*, *Leymus*, *Lolium*, *Nassella*, *Melica*, *Phalaris*, *Phleum*, *Poa*, *Puccinellia*, *Secale*, *Sphenopholis*, *Stipa*, *Torreyochloa*, *Triticum*, and *Vulpia*. Many are listed only as *P. graminis*, some are assigned subsp. or f. sp. An alternate host, *Mahonia pinnata* (wavyleaf barberry), is also recorded without a specific county location. (French, 1989; CDFA PDR Database, 2021). There are three formae speciales in California with different host ranges: *P. graminis* f. sp. *tritici* (wheat), *P. graminis* f. sp. *secalis* (barley), and *P. graminis* f. sp. *avenae* (oat) (Davis and Jackson, 2007).

California Interceptions: None.

The risk *Puccinia graminis* would pose to California is evaluated below.

Consequences of Introduction:

- 1) Climate/Host Interaction:** Stem rust is favored by warm daytime highs (25-30°C) and mild nights (15-20°C). Spores require free water for germination. Lack of moisture could be a limiting factor in the development of epidemics in California, but the pathogen is likely to survive wherever the hosts can be grown.

Evaluate if the pest would have suitable hosts and climate to establish in California.

Score: 3

- Low (1) Not likely to establish in California; or likely to establish in very limited areas.
- Medium (2) may be able to establish in a larger but limited part of California.
- **High (3) likely to establish a widespread distribution in California.**

- 2) Known Pest Host Range:** The host range covers many genera and species in the Family Poaceae, in addition to *Berberis*, *Mahonia*, and intergeneric crosses.

Evaluate the host range of the pest.

Score: 3

- Low (1) has a very limited host range.
- Medium (2) has a moderate host range.
- **High (3) has a wide host range.**

- 3) Pest Reproductive Potential:** This pathogen can produce explosive epidemics on susceptible hosts. Aeciospores and urediniospores are generated in extremely large numbers and repeating cycles of secondary infection allow for exponential increase of disease. Spores are wind-borne.

Evaluate the natural and artificial dispersal potential of the pest.

Score: 3

- Low (1) does not have high reproductive or dispersal potential.
- Medium (2) has either high reproductive or dispersal potential.
- **High (3) has both high reproduction and dispersal potential.**

- 4) Economic Impact:**

Stem rust was once the most feared disease in most wheat-growing regions of the world. References in literature and art from antiquity relate epidemics of cereal diseases as punishment for sins. The Roman festival of Robigalia was to protect cereal crops through prayer and sacrifice. Through breeding for resistance, application of fungicides, and removal of barberries, there has not been a significant wheat stem rust epidemic in the United States since 1974, however, new

pathogenic races can arise that can overcome currently deployed resistance genes.

Evaluate the economic impact of the pest to California using the criteria below.

Economic Impact: A, B

- A. The pest could lower crop yield.**
- B. The pest could lower crop value (includes increasing crop production costs).**
- C. The pest could trigger the loss of markets (includes quarantines).
- D. The pest could negatively change normal cultural practices.
- E. The pest can vector, or is vectored, by another pestiferous organism.
- F. The organism is injurious or poisonous to agriculturally important animals.
- G. The organism can interfere with the delivery or supply of water for agricultural uses.

Economic Impact Score: 2

- Low (1) causes 0 or 1 of these impacts.
- **Medium (2) causes 2 of these impacts.**
- High (3) causes 3 or more of these impacts.

- 5) Environmental Impact:** With a host range that includes many genera, including native and naturalized hosts, *Puccinia graminis* is established in the environment in California. Seed production is reduced in primary hosts. Barberries are import ornamentals and lose esthetic value when covered with yellow aecial cups. There are several *Berberis* (including *Mahonia*) species native to California (Calflora, 2021) some of which are cultivated as ornamentals (e.g. *B. aquifolium*, grape holly), and some of which are rare in the state. *Berberis vulgaris*, the most noted host species for stem rust, is planted as an ornamental and apparently rarely adventive, while *B. darwinii*, an exotic South American species, was presumably brought in as an ornamental and is now a naturalized invasive along the coast of northern and central California (Dr. R. Price, pers. comm., CDFA Primary Botanist).

Evaluate the environmental impact of the pest to California using the criteria below

Environmental Impact: A, E

- A. The pest could have a significant environmental impact such as lowering biodiversity, disrupting natural communities, or changing ecosystem processes.**
- B. The pest could directly affect threatened or endangered species.
- C. The pest could impact threatened or endangered species by disrupting critical habitats.
- D. The pest could trigger additional official or private treatment programs.
- E. The pest significantly impacts cultural practices, home/urban gardening or ornamental plantings.**

Environmental Impact Score: 3

- Low (1) causes none of the above to occur.
 - Medium (2) causes one of the above to occur.
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- High (3) causes two or more of the above to occur.

Consequences of Introduction to California for *Puccinia graminis*: High

Add up the total score and include it here. **14**

-Low = 5-8 points

-Medium = 9-12 points

-High = 13-15 points

- 6) Post Entry Distribution and Survey Information:** Evaluate the known distribution in California. Only official records identified by a taxonomic expert and supported by voucher specimens deposited in natural history collections should be considered. Pest incursions that have been eradicated, are under eradication, or have been delimited with no further detections should not be included.

There are historical and current reports from many California counties on a variety of hosts.

Evaluation is 'high'.

Score: -3

-Not established (0) Pest never detected in California or known only from incursions.

-Low (-1) Pest has a localized distribution in California or is established in one suitable climate/host area (region).

-Medium (-2) Pest is widespread in California but not fully established in the endangered area, or pest established in two contiguous suitable climate/host areas.

-High (-3) Pest has fully established in the endangered area, or pest is reported in more than two contiguous or non-contiguous suitable climate/host areas.

- 7) The final score is** the consequences of introduction score minus the post entry distribution and survey information score: (Score)

Final Score: *Score of Consequences of Introduction – Score of Post Entry Distribution and Survey Information = 11*

Uncertainty:

Novel strains or races of *P. graminis* are continually evolving, some with the ability to overcome currently deployed resistance genes (Stone, 2010). There is not a consensus on the conventions of naming of subspecies or formae speciales.

Conclusion and Rating Justification:

Based on the evidence provided above the proposed rating for *Puccinia graminis* is C.

References:

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***Comment Period: 08/26/2021 through 10/10/2021**

***NOTE:**

You must be registered and logged in to post a comment. If you have registered and have not received the registration confirmation, please contact us at [permits\[@\]cdfa.ca.gov](mailto:permits[@]cdfa.ca.gov).

Comment Format:

- ❖ Comments should refer to the appropriate California Pest Rating Proposal Form subsection(s) being commented on, as shown below.

Example Comment:

Consequences of Introduction: 1. Climate/Host Interaction: [Your comment that relates to "Climate/Host Interaction" here.]

- ❖ Posted comments will not be able to be viewed immediately.
- ❖ Comments may not be posted if they:

Contain inappropriate language which is not germane to the pest rating proposal;

Contains defamatory, false, inaccurate, abusive, obscene, pornographic, sexually oriented, threatening, racially offensive, discriminatory or illegal material;

Violates agency regulations prohibiting sexual harassment or other forms of discrimination;

Violates agency regulations prohibiting workplace violence, including threats.

- ❖ Comments may be edited prior to posting to ensure they are entirely germane.
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- ❖ Posted comments shall be those which have been approved in content and posted to the website to be viewed, not just submitted.
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Proposed Pest Rating: C
