**Puccinia striiformis**  
*(Wheat Stripe Rust)*

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**Background Information**

**Common Names:**  
Stripe rust; yellow rust

**Scientific Name:**  
*Puccinia striiformis* f. sp. *tritici*

**Synonyms:**  
*Dicaeoma glumarum, Puccinia glumarum, Puccinia rubigo-vera, Puccinia straminis, Puccinia striiformis, Trichobasis glumarum, Uredo glumarum*

**Taxonomy:**  
Kingdom: Fungi; Phylum: Basidiomycota;  
Class: Urediniomycettes; Order: Uridenales;  
Family: Pucciniaceae

**Crop Hosts:**  
Wheat (*Triticum aestivum*),  
Barley (*Hordeum vulgare L.*)

**Introduction**

Wheat stripe rust disease, caused by *Puccinia striiformis* f. sp. *tritici*, is one of the most important fungal diseases of wheat worldwide. Infection can occur anytime during the wheat lifecycle from the one-leaf stage to plant maturity. The pathogen infects the green tissues of the plant, forming linear rows of small yellowish rust pustules on the leaf or in the spike (Figure 1). Infected plants develop symptoms about one week after infection and sporulation starts about two weeks after infection (Chen 2005). Infection can result in characteristic necrotic stripes or elongated spots along the length of the leaf, weakening the plants by diverting water and nutrients from the host (Chen 2005).

**Known Distribution**

 Stripe rust occurs throughout wheat production areas on all continents except Antarctica (Figure 2). In North America, stripe rust has been a major problem in the United States and Canada (Chen 2005). Prior to 2000, stripe rust epidemics mainly occurred in western Canada and the Pacific Northwest region of the United States; after 2000, the disease became prevalent in eastern Canada and the central United States (Chen 2005) (Figure 3). The reasons for this change in spatial distribution are unclear. Some have proposed that the rust underwent rapid evolution before it could invade the warmer southern states (Chen 2005; Milus and Seyran 2006; Wellings et al. 2009). However, the climatic conditions in the southern United States closely match those of areas within *P. striiformis*’ historical native range in Eurasia. An alternative explanation for the invasion lag, at least in the United States, is that the rust had to disperse against the dominant wind systems.

In South America, stripe rust causes frequent yield losses in Chile (Germán et al 2007). In Europe, stripe rust has been the most common wheat rust throughout France, the Netherlands, Germany, Denmark and the United Kingdom; in the central and western Asia and northern Africa (CWANA) region, at least three widespread epidemics have occurred since the 1970s; and in east and south Asia, stripe rust is a serious problem in India,
Pakistan and China (Solh et al. 2012). Stripe rust was first introduced into Australia in 1979 (O’Brien et al. 1980; Wellings 2007) and then spread into New Zealand in 1980, presumably dispersed by winds from southeastern Australia (Wellings and McIntosh 1990; Viljanen-Rollinson et al. 2002).

In Africa, stripe rust was first reported in Zambia in 1958 (Angus 1965, cited in Chen 2005). It took more than thirty years for it to be reported in South Africa. It is now widespread throughout South Africa and the areas of northern Africa where there is a Mediterranean climate, and the high elevation areas of eastern Africa experiencing a warm temperate climate (russtracker.cimmyt.org).

![Figure 2. Wheat areas of the world where stripe rust has been a problem (reproduced based on Roelfs et al. 1992 and russtracker.cimmyt.org).](image)

![Figure 3. Wheat stripe rust losses in the United States (selected years 1960-2010, produced by authors based on USDA CDL small grain rust losses data from http://www.ars.usda.gov/main/docs.htm?docid=10123).](image)
Description and Biology

*Puccinia striiformis* has a complex lifecycle, the completion of which requires both a primary host and an alternate host (Figure 4). The asexual (uredinal) stage of the disease occurs on the primary hosts (wheat, barley and some other grasses), causing epidemics through the cycling and spreading of urediniospores when conditions are favourable. The completion of the sexual (aecial) stage of the pathogen’s lifecycle occurs on the alternate barberry (*Berberis* spp.) hosts (Jin et al. 2010).

Disease epidemics are mostly affected by moisture, temperature, and wind. Moisture affects spore germination, infection, and survival (Chen 2005), and a dew period of at least three hours is required for germination and infection (Rapilly 1979). Temperature affects spore germination and infection, latent period, sporulation, spore survival, and host resistance (Chen 2005). *Puccinia striiformis* thrives in cool climates, so stripe rust mainly occurs throughout wheat production areas in temperate regions and areas of high elevations in tropical regions. The primary method of long-distance dispersal is via windblown urediniospores (Rapilly 1979), although dispersal across oceans is less likely as stripe rust spores are sensitive to UV radiation (Roelfs et al. 1992) leaving open the prospect of human-mediated dispersal in these instances (Wellings 2011).

Stripe rust infections can occur at any point in the host plant’s lifecycle, from the end of the heading stage to the late milk stage, causing stunting of plants and thereby reducing yield. The most critical stage is the early milk stage in which yield losses increase rapidly (Murray et al. 1994). If a severe infection occurs very early in the host’s lifecycle, stripe rust can cause 100 percent yield losses (Chen 2005). Because cool temperatures are more conducive to stripe rust development, higher temperatures during grain development decrease yield losses attributable to the disease (Murray et al. 1994).

Host Crops and Other Plants

The primary crop hosts of stripe rust are wheat (*Triticum* spp.), a few barley cultivars (*Hordeum vulgare*) and triticale (*X Triticosaceale*). Shrubs of the *Berberis* species were recently discovered to be alternate hosts (Jin et al. 2010).

Potential Distribution

A CLIMEX model was developed for *Puccinia striiformis* using the CliMond 1975H historical climate dataset (Kriticos et al. 2012; Sutherst et al. 2007). The Ecoclimatic Index (EI) depicts the relative climatic suitability of areas for year-round persistence of the pathogen (i.e., establishment); the Annual Growth Index (GIa) indicates relative climatic suitability for growth (i.e., infection/outbreak). The CLIMEX parameters (Table 1) were fitted based on the biology of the stripe rust pathogen and adjusted according to known distributions. The general methodology used to fit the model, along with an accessible guide to interpretation of CLIMEX models is provided by Beddow et al. (2010).

![Figure 4. Wheat stripe rust life cycle (reproduced based on Jin et al. 2010)](image)

### Table 1. CLIMEX Parameter Values for *Puccinia striiformis*

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM0</td>
<td>lower soil moisture threshold</td>
<td>0.2</td>
</tr>
<tr>
<td>SM1</td>
<td>lower optimum soil moisture</td>
<td>0.4</td>
</tr>
<tr>
<td>SM2</td>
<td>upper optimum soil moisture</td>
<td>1.5</td>
</tr>
<tr>
<td>SM3</td>
<td>upper soil moisture threshold</td>
<td>2.5</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DV0</td>
<td>lower threshold</td>
<td>3 °C</td>
</tr>
<tr>
<td>DV1</td>
<td>lower optimum temperature</td>
<td>12 °C</td>
</tr>
<tr>
<td>DV2</td>
<td>upper optimum temperature</td>
<td>16 °C</td>
</tr>
<tr>
<td>DV3</td>
<td>upper threshold</td>
<td>30 °C</td>
</tr>
<tr>
<td>Cold Stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTCS</td>
<td>cold stress temperature threshold</td>
<td>-4 °C</td>
</tr>
<tr>
<td>THCS</td>
<td>temperature threshold stress accumulation rate</td>
<td>-0.01 week⁻¹</td>
</tr>
<tr>
<td>Dry Stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMD5</td>
<td>soil moisture dry stress threshold</td>
<td>0.2</td>
</tr>
<tr>
<td>HDS</td>
<td>stress accumulation rate</td>
<td>-0.005 week⁻¹</td>
</tr>
<tr>
<td>Hot-Wet Stress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTHW</td>
<td>Hot-Wet Threshold Temperature</td>
<td>30 °C</td>
</tr>
<tr>
<td>MTHW</td>
<td>Hot-Wet Threshold</td>
<td>0.3</td>
</tr>
<tr>
<td>PHW</td>
<td>Hot-Wet Stress rate</td>
<td>-0.005 week⁻¹</td>
</tr>
<tr>
<td>Threshold Heat Sum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDD</td>
<td>number of degree days above DV0 needed to complete one generation</td>
<td>200 °C days *</td>
</tr>
<tr>
<td>Irrigation Scenario</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 mm day⁻¹ as top-up throughout the year</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The Annual Threshold Heat Sum (PDD) was calculated using the minimum survival temperature of -4 °C, the optimal temperature 16 °C and a period of 10 days for one generation: (16 °C-(-4 °C))×10 days = 200 degree days.

The Temperature Index parameters were based primarily on the environmental conditions described by Roelfs et al. (1992, Table 2), with the optimum temperature parameters ranging from 12 °C to 16 °C, and the lower and upper thresholds for growth set at 3 °C and 30 °C, respectively. The claim of Roelfs et al. (1992) of an upper threshold for growth of *P. striiformis* of approximately 20 to 23 °C is at odds with observations of other authors. Coakley (1988) stated that temperatures above 25 °C...
reduced disease severity and Georgievskaja (1966, cited by Rapilly 1979) noted that *P. striiformis* can only tolerate 38 °C peak temperatures for a very short period of time. Daily maximum temperatures ≥32.4 °C were found to be lethal for *P. striiformis* survival over 10 days (Tollenaar and Houston 1967) and temperatures above 33 °C stop sporulation (Rapilly 1979). Dennis (1987) investigated the heat tolerance of spores and latent and sporulating infections, noting that spores could survive for up to 5 days at a constant 40 °C, but infections could only survive for 5 hours at 40 °C. Accordingly, DV3 was set at 30 °C, reasoning that reduced population growth rates are still achievable somewhat above Coakley’s 25 °C, but population processes start shutting down at higher temperatures. This parameter should be treated as being approximate.

Warm dry conditions appear conducive for the survival of rust spores; hence no heat stress mechanism was employed. Warm wet conditions reduce spore viability in *P. striiformis* (Chen 6449), and Hot-Wet Stress appears to limit the range of *P. striiformis* in the tropics. While the mechanisms by which warm wet conditions actually limit the distribution of *P. striiformis* are unclear, a Temperature Threshold of 30 °C, combined with a Soil Moisture Threshold of 0.3 and a stress accumulation rate of 0.005 per week provide a suitable fit to the south-eastern United States range limits.

Cold Stress parameters were included to restrict the over-wintering survival, with -4 °C as the threshold. This is in broad agreement with Rapilly (1979) who considered that temperatures below -10 °C might limit the pathogen.

The Moisture Index parameters were mainly based on a set of CLIMEX model defaults. Because low soil moisture is not conducive for stripe rust development, we accounted for Dry Stress by setting the threshold to 0.2 and the stress accumulation rate to -0.005 per week.

In the United States, the EI map shows that stripe rust can persist year round in eastern Washington and Oregon (Figure 5). This accords with the observation that stripe rust can over-summer and over-winter in these regions and provide local inoculum each year (Chen 2005). However, our model also indicates suitable climates throughout the south-eastern states except for the coastal Gulf zone and the Florida panhandle, where Chen (2005) indicates an inability of the pathogen to over-summer. This discord may be due to a semantic difference with respect to the ability to oversummer. In the CLIMEX model employed here, we assume that *P. striiformis* survival includes spores which are able to survive periods of warm dry conditions. The weekly Growth Index (GIW) drops to zero in the south-eastern United States, but the modelled Hot-Wet Stress is insufficient to kill the populations there.

### Table 2. Temperature and moisture requirements for *P. striiformis*

<table>
<thead>
<tr>
<th>Stage</th>
<th>Minimum</th>
<th>Optimum</th>
<th>Maximum</th>
<th>Light</th>
<th>Free water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination</td>
<td>0</td>
<td>9-13</td>
<td>23</td>
<td>Low</td>
<td>Essential</td>
</tr>
<tr>
<td>Gernling</td>
<td>-</td>
<td>10-15</td>
<td>-</td>
<td>Low</td>
<td>Essential</td>
</tr>
<tr>
<td>Appressorium</td>
<td>-</td>
<td>(not formed)</td>
<td>-</td>
<td>Essential</td>
<td></td>
</tr>
<tr>
<td>Penetration</td>
<td>2</td>
<td>8-13</td>
<td>23</td>
<td>Low</td>
<td>Essential</td>
</tr>
<tr>
<td>Growth</td>
<td>3</td>
<td>12-15</td>
<td>20</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>Sporulation</td>
<td>5</td>
<td>12-15</td>
<td>20</td>
<td>High</td>
<td>None</td>
</tr>
</tbody>
</table>


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In the native range in the Middle East, the model accords with known distribution data (rusttracker.cimmyt.org). The model also agrees with observations that stripe rust can persist year-round in Europe (Roelfs et al. 1985) and China (Zeng et al. 2006). The modelled potential for year-round survival of stripe rust along the northwest, southwest, and southeast coasts of South America and parts of eastern and southern Africa could be the sources of inoculum for stripe rust epidemics that occur in those regions.

The CLIMEX Growth Index (GI_{A}) map shows the climate-suitable areas with top-up irrigation for stripe rust development if infection were to occur, typically via wind-dispersed inoculum that can travel over long distances (Figure 6). In the United States, the CLIMEX GI_{A} map agrees with the current known distribution of stripe rust epidemics in south central states and the central plains. The CLIMEX GI_{A} map also reveals that Europe is a suitable region for stripe rust infections. Southeastern and southwestern Australia are also projected to be suitable for stripe rust development, which agrees with the known occurrence data (Wellings 2007). In south Asia, the GI_{A} map indicates suitable climate for stripe rust in Pakistan, where stripe rust has been reported (Afzal et al. 2007; Roelfs and Bushnell 1985). In the rainfed version of the CLIMEX model used to generate the GI_{A} map in Figure 7, moisture is a limiting factor. However, there is a substantial amount of irrigated wheat production in this area. Once we allow for 2.5 mm per day of top-up irrigation (Figure 6), the mapped GI_{A} area concords closely with the reported occurrence of stripe rust in Pakistan.

The model results provide a good fit to the geographical distribution of stripe rust. In general, areas at risk of damage by \textit{P. striiformis} include all regions in which wheat is grown under conditions with high soil moisture or high natural dew formation. Stripe rust epidemics are related to both year-round survival and long-distance dispersal via wind. The CLIMEX model shows where stripe rust can persist year-round (EI) versus where the disease can develop (GI_{A}) if inoculum arrives via long-distance dispersal. These spatially calibrated climate suitability and inter-seasonal persistence data have value in guiding the development of stripe rust resistant wheat and the deployment of other strategies to mitigate the crop losses attributable to stripe rust.

Figure 6. Modelled global potential occurrences (GI) for \textit{Puccinia striiformis}, as a composite of natural rainfall and irrigation based on the irrigation areas identified in Spatial Production Allocation Model (SPAM 2000).

Figure 7. CLIMEX GI_{A} Map with natural rainfall.
References


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