Puccinia triticina

(Wheat Leaf Rust)

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Background Information

Common Names:
Wheat Leaf Rust, Brown Rust

Scientific Name:
Puccinia triticina

Taxonomy:
Kingdom: Fungi; Phylum: Basidiomycota; Class: Pucciniomycetes; Order: Pucciniales; Family: Pucciniaceae

Crop Hosts:
Wheat (*Triticum* sp.), barley (*Hordeum vulgare*), rye (*Secale cereale*), triticale (X Triticosecale)

Figure 1. Wheat leaf rust infection.
Source: USDA-ARS Cereal rust image gallery
http://www.ars.usda.gov/SP2UserFiles/ad_hoc/36400500Cerealrusts/wrl_gnhse4.jpg

Introduction

Among the cereal rust diseases, wheat leaf rust, caused by *Puccinia triticina*, occurs most commonly and has the widest distribution (Kolmer et al. 2009). Leaf rust primarily infects the leaf blades, causing red-orange pustules to erupt from the leaves. These pustules contain thousands of urediniospores that can disperse to infect other plants. Yield losses in excess of 50 percent can result if infection occurs early in the crop's lifecycle (Huerta-Espino et al. 2011). The frequency and wide geographic distribution of leaf rust infections lead some (e.g., Huerta-Espino et al. 2011; Samborski 1985) to conclude that leaf rust is responsible for more crop damage worldwide than the other wheat rusts.

Known Distribution

Wheat leaf rust is distributed in all wheat-growing regions of the world (Fig. 2). Leaf rust occurred nearly every year in the United States (Fig. 3), Canada and Mexico, causing serious losses in wheat production (Huerta-Espino et al. 2011; Roelfs 1989; Singh et al. 2004a). In South America, wheat leaf rust causes major yield losses in Argentina, Bolivia, Brazil, Chile, Paraguay, and Uruguay (German et al. 2004). In East and South Asia, high risk regions for wheat leaf rust include China, India, Pakistan, Bangladesh, and Nepal, while in Central Asia most (more than 90 percent) of the wheat crop is planted in areas prone to the disease (Singh et al. 2004b). In Russia, leaf rust results in yield losses for both winter and spring wheat (Huerta-Espino et al. 2011). In North Africa, leaf rust causes severe yield losses in Egypt and Tunisia (Huerta-Espino et al. 2011). In South Africa, leaf rust epidemics frequently occur on the spring wheat in Western Cape, winter wheat in Orange Free State and irrigated wheat in other provinces (Pretorius et al., 1987). Though leaf rust is considered a disease of concern in South Africa, fungicide application, host resistance and a "non-conducive" environment have limited levels of infection (Huerta-Espino et al. 2011; Terefe et al. 2009). In Australia, leaf rust is widely dispersed, occurring in all wheat growing regions (Murray and Brennan 2009).

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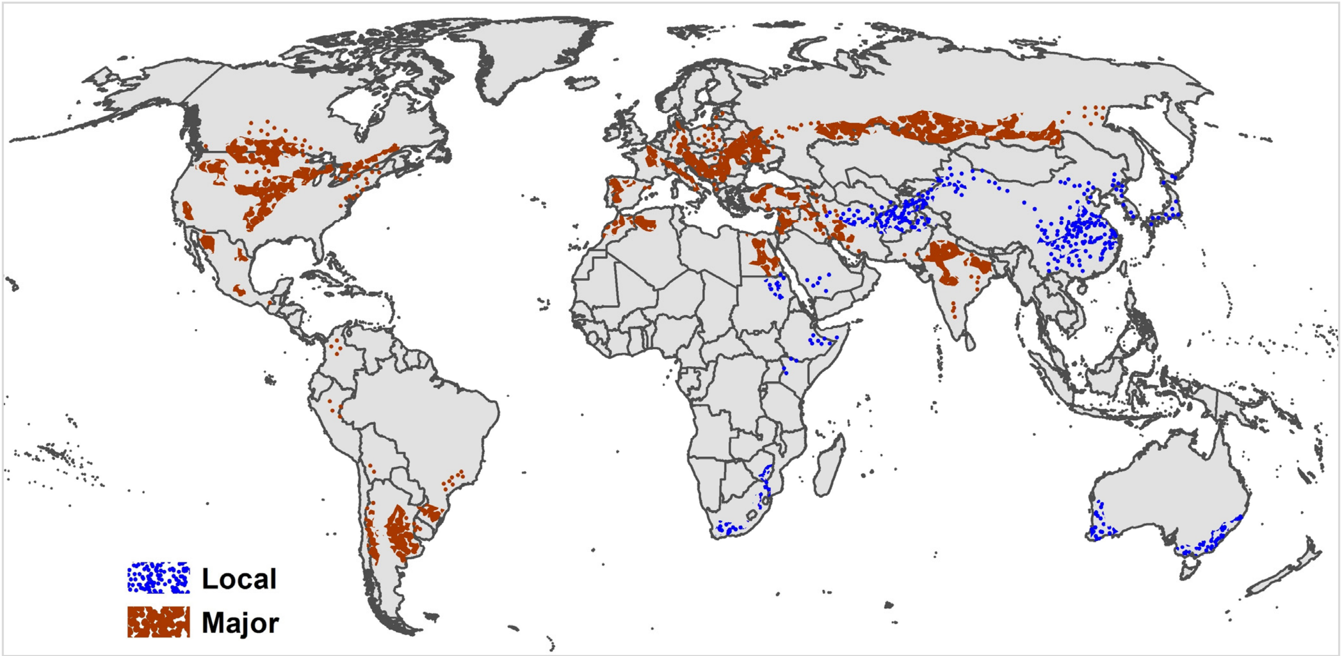

Figure 2. Wheat areas of the world where leaf rust has historically been a problem (reproduced based on Roelfs et al. 1992).

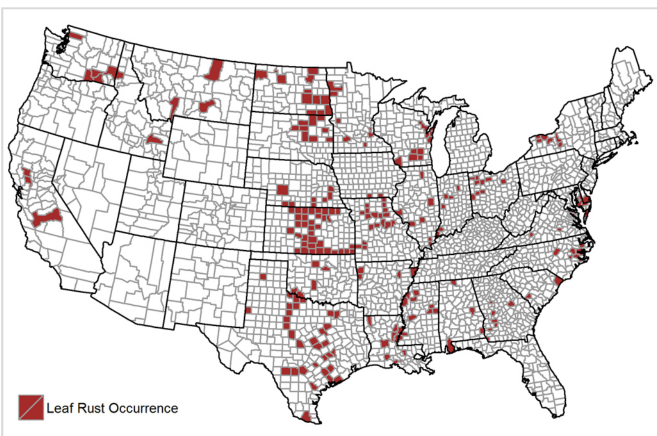

Figure 3. Wheat leaf rust observations in the U.S. by county, 2007-2012 (based on USDA-ARS Cereal Rust Situation Reports and Cereal Rust Bulletins).

Description and Biology

Puccinia triticina has a complex lifecycle, with five spore stages (Fig. 4). The primary hosts include wheat, triticale, and some grasses; the alternate hosts (sexual stage) include several species of *Thalictrum*, *Anchusa*, *Clematis* and *Isopyrum fumarioides*. *Puccina triticina* produces urediniospores on wheat hosts, and this asexual stage can cycle indefinitely when conditions are favorable. Uredinial infections develop teliospores as the host plant reaches later stages of its lifecycle. These teliospores enable oversummering in areas that would otherwise be too hot and dry (e.g., Mediterranean climates). Volunteer wheat provides a reservoir for inoculum in areas such as the U.S. southern plains, providing inoculum for winter wheat planted in the fall. Leaf rust can overwinter as mycelial or uredinial infections on winter wheat in certain areas with a suitable temperature profile. Overwintering mycelium or uredinia can provide the source of inoculum for subsequent infections. Under favorable conditions, urediniospores are disseminated regionally by wind, and deposited by rain.

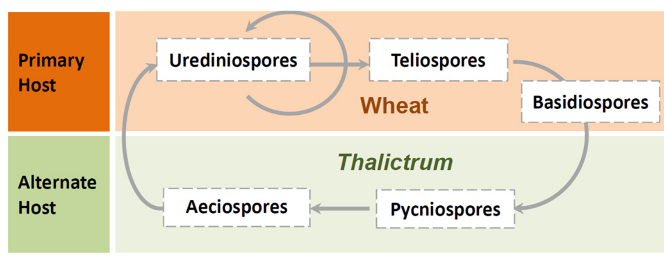

Figure 4. Wheat leaf rust life cycle (reproduced based on USDA-ARS cereal rust image gallery http://www.ars.usda.gov/SP2UserFiles/ad_hoc/36400500Cerealrusts/prt-cycl.jpg).

Host Crops and Other Plants

The *Puccinia triticina* is a fungal disease of wheat (*Triticum* sp.), barley (*Hordeum vulgare*), rye (*Secale cereale*), goatgrasses (*Aegilops* sp.) and triticale (X Triticosecale). Secondary hosts include dusty meadow rue (*Thalictrum speciosissimum*), *Anchusa*, *Clematis* and *Isopyrum fumaroides*.

Potential Distribution

CLIMEX is a flexible modelling and mapping tool to describe a species' potential geographical distribution based on suitability to climate. CLIMEX has been used for modelling the climatic niche of numerous pests and plant pathogens. The CLIMEX model for *P. triticina* was fitted using the Compare Locations (1 species) model (Sutherst et al. 2007) using the CliMond 1975H historical climate dataset (Kriticos et al. 2012). In CLIMEX, the stress functions limit the potential range of the modelled taxa, and the temperature and moisture growth indices drive the climate suitability within the geographical range. The stress functions are therefore generally fitted to the known distribution of the organism, with reference to experimental data and phenology where applicable and available. The reported distribution of *P. triticina* (Fig. 2) is strongly influenced by land use in terms of host availability (wheat cropping) and irrigation. The reported range also includes a large area of ephemeral habitat, where, due to the mobility of its spores, *P. triticina* infects crops during clement seasons. The map of known occurrences therefore includes areas where it cannot persist year round because the climate is too cold (e.g., Canada), or where it is too dry (e.g., Egypt). There may be areas where *P. triticina* is being excluded by competition with other foliar pathogens such as *Pyrenophora tritici-repentis* (Al-Naimi et al. 2005). The reported distribution may also be affected by mis- or under-reporting of *P. triticina* occurrences. Considering how these various factors affect the reported distribution of *P. triticina*, it is necessary to employ a complicated logic when comparing different scenarios and sets of modelled state variables in CLIMEX to the known distribution. 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 (GI_A) indicates relative climatic suitability for growth (i.e., infection/ outbreak).

The CLIMEX parameters (Table 1) were fitted based on the biology of leaf rust pathogen and adjusted according to its known distribution, using a natural rainfall scenario. Subsequently, an irrigation scenario (2.5 mm day^{-1} applied as top-up) was run and the results compared with xeric areas where cropping is conducted under irrigated conditions. A composite climate suitability map was created by (1) combining the natural rainfall and irrigation scenario results using the data from Siebert et al. (2005), (2) by including both the EI (annual persistence) and GI_A (seasonal growth) values, and (3) by only considering the modelled range that falls within the wheat-growing regions of the world. 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).

To estimate the climatic niche for leaf rust, distribution data from Australia, Brazil, Pakistan and the United States were used to fit the parameters. In the U.S., leaf rust can survive winter in the southern states and is disseminated by wind-blown urediniospores spreading throughout the wheat growing areas of the Great Plains. Two CLIMEX indices, the Ecoclimatic Index (EI) and the Annual Growth Index (GI_A), need to be considered in order to differentiate the regions where wheat leaf rust can persist year round (EI>0) and regions where infections only occur during favourable seasons (GI_A>0).

Table 1. CLIMEX Parameter Values for *Puccina triticina*

Parameter	Description	Value
Moisture		
SM0	lower soil moisture threshold	0.18
SM1	lower optimum soil moisture	0.7
SM2	upper optimum soil moisture	1.0
SM3	upper soil moisture threshold	1.5
Temperature		
DV0	lower temperature threshold	10 °C
DV1	lower optimum temperature	15 °C
DV2	upper optimum temperature	25 °C
DV3	upper temperature threshold	32 °C
Cold Stress		
DTCS	cold stress degree-days threshold	10 °C
DHCS	cold stress degree-days accumulation rate	-0.0005 week^{-1}
Heat Stress		
TTHS	heat stress temperature threshold	33 °C
THHS	temperature threshold stress accumulation rate	0.01 week^{-1}
Dry Stress		
SMDS	soil moisture dry stress threshold	0.18
HDS	dry stress accumulation rate	-0.02 week^{-1}
Wet Stress		
SMWS	soil moisture wet stress threshold	1.5
HWS	wet stress accumulation rate	0.015 week^{-1}
Threshold Heat Sum		
PDD	number of degree-days above DV0 needed to complete one generation threshold	150 °C days*
Irrigation Scenario		
	2.5 mm day^{-1} as top-up throughout the year	

*The Annual Threshold Heat Sum (PDD) was calculated using the minimum survival temperature of 10 °C, the optimal temperature 25 °C and a period of 10 days for one generation: (25 °C-10 °C) ×10days = 150 degree days.

The Soil Moisture Index parameters were initially fitted to the observed distribution of *P. triticina* in the United States. The lower soil moisture threshold (SM0) was subsequently set to 0.18 to reflect distribution data in the Sindh in southeast Pakistan and to better fit the available data on the distribution of the disease in southwestern Australia. The lower (SM1) and upper (SM2) optimum soil moisture parameters were set as 0.7 and 1 respectively, where 1 is field capacity. The upper threshold for growth (SM3) was set at 1.5, reflecting the conditions too wet for the growth of wheat and leaf rust.

The Temperature Index parameters were informed by the environmental conditions required for wheat leaf rust (Table 2). According to the controlled environment studies on leaf rust, the optimum temperature for spore germination, appresorium formation and penetration is 15 °C, with the optimal temperature range 15 - 20 °C for substomatal vesicle development (Clifford 1981). Eversmeyer et al. (1980) showed that the optimum tempera-

Table 2. Temperature and moisture requirements for *P. triticina* (from Roelfs et al. 1992)

	Temperature °C			Light	Free Water
	Minimum	Optimum	Maximum		
Germination	2	20	30	Low	Essential
Germling	5	15-20	30	Low	Essential
Appressorium		15-20		None	Essential
Penetration	10	20	30	No Effect	Essential
Growth	2	25	35	High	None
Sporulation	10	25	35	High	None

ture for the latent period is 15 - 26 °C. According to Roelfs (1989), a temperature range of 15 - 25 °C is optimal for all stages of leaf rust infection, including spore germination, penetration, growth and sporulation. Thus, the lower (DV1) and upper (DV2) optimal temperature limits were set to 15 °C and 25 °C respectively. This optimal temperature range is greater than usually found for many organisms, but may be a feature that is common to some plant pathogens (e.g., Kriticos et al. 2013), where pathogen growth rates are driven by photosynthate, which may be relatively abundant across a wide range of temperatures. The lower temperature limit for development (DV0) was set to 10 °C and the upper limit (DV3) was set to 32 °C, according to the experiments by Eversmeyer et al. (1980) and Tollenaar (1985), where at 10 °C leaf rust cultures fail to reach the sporulation stage and above 32 °C there was no spore germination.

A degree-day cold stress mechanism was fitted to the cold limits of the over-wintering regions for leaf rust in the United States identified by Roelfs (1989). The threshold of 10 degree days above DV0 (10 °C) and stress accumulation rate of -0.0005 week^{-1} matched the reported limits closely. Under this mechanism, the species needs to experience a minimum of 10 degree-days above 10 °C each week, otherwise cold stress accumulates. This cold stress mechanism is related to the balance of anabolic and catabolic processes, reflecting the need for the organism to grow at a minimum rate in order to offset basal respiration processes. In the case of field infections by fungal phytopathogens, this probably reflects the need for the plant to generate sufficient photosynthate to be co-opted by the fungus.

The threshold for heat stress was set at 33 °C, just above the maximum temperature for spore germination (32.2 °C) (Eversmeyer et al. 1980; Tollenaar 1985). The rate of heat stress accumulation was set at 0.01 week^{-1} to match the known distribution of leaf rust in the United States.

Based on the distribution of leaf rust in the United States, the threshold for Dry Stress was set at 0.18 and the rate of stress accumulation was set at -0.02 week^{-1}. Wet Stress was set to make parts of the Pacific north-west of the United States unsuitable for *P. triticina*, with a threshold soil moisture level (SMWS) of 1.5 and an accumulation rate (HWS) of 0.015 week^{-1}. The heat sum necessary to complete a generation was used to limit the area in which *P. triticina* can complete a single generation. The fitted value of 150 degree days above the base temperature for development (10 °C) accorded with the approximate northernmost record noted by Roelfs et al. (1992) in Canada.

Figure 5 reports the modelled Growth Index (GI) for *Puccinia triticina*, which shows areas suitable for seasonal development of the disease within the global extent of wheat production reported by You et al. (2015). Higher values of GI indicate areas with climates more favorable to development of the disease. These potential occurrence estimates were modelled using a composite of natural rainfall and irrigation based on the irrigated areas reported by Siebert et al. (2005). Overall, the CLIMEX model for wheat leaf rust occurrence accords with the known distribution of this disease and provides a tool suitable for assessing climate suitability and potential yield losses caused by wheat leaf rust. In the United States, the CLIMEX composite risk map (Fig. 5) matches the recent reports from U.S. field and experimental plots observations (Fig. 3), where leaf rust occurs throughout south-eastern states, South Great Plains and North Great Plains (Kolmer et al. 2007). It also agrees with the reports for wheat leaf rust occurrence in other wheat growing regions, including the eastern prairies of Canada, Mexico, Argentina and Uruguay in South America, southern China, Russia, South Africa and Australia. The composite risk model correctly identifies the xeric parts of Egypt, Pakistan and India where wheat is grown under irrigation, and where *P. triticina* has been recorded.

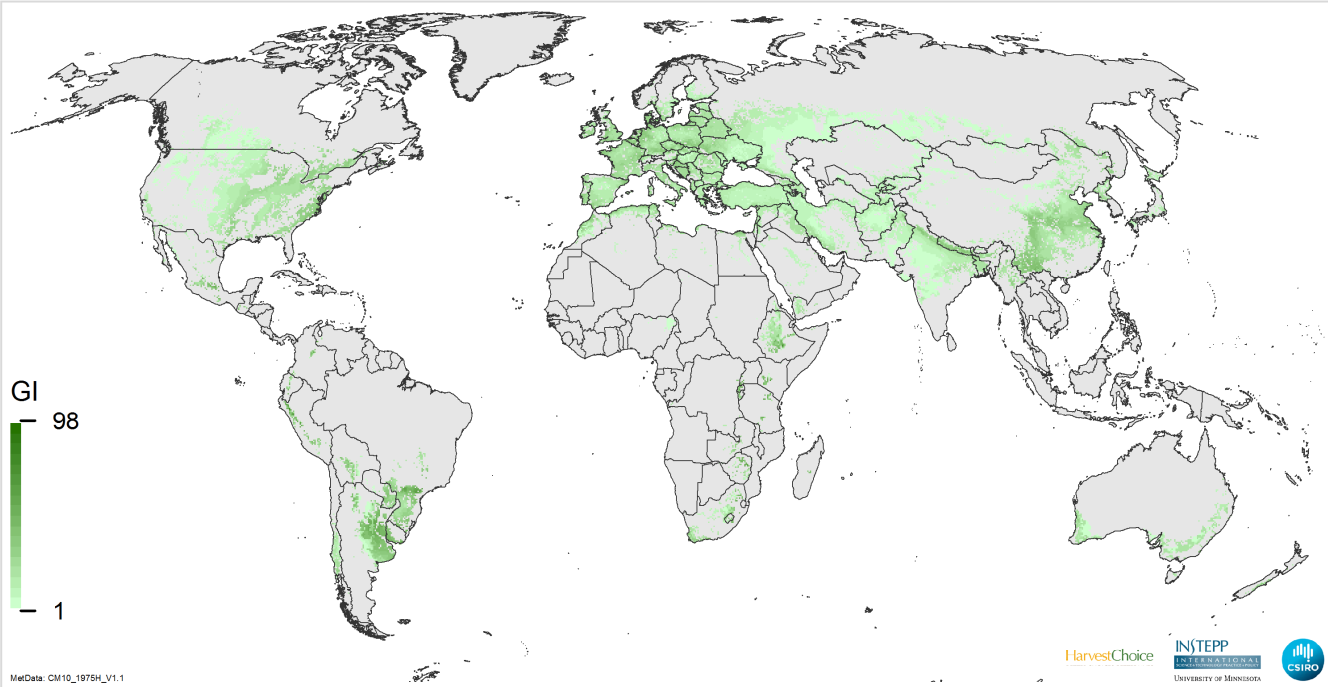

Figure 5. Modelled global climate suitability (GI) for *Puccinia triticina* as a composite of natural rainfall and irrigation based on the irrigation areas identified in Spatial Production Allocation Model (SPAM 2005).

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