Puccinia graminis

(Wheat Stem Rust)

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Background Information

Common Names:
Stem rust, Black rust

Scientific Name:
Puccinia graminis Pers.; Pers. f. sp. *tritici* Eriks. E. Henn

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

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

Introduction

Wheat stem rust, caused by the fungus *Puccinia graminis*, is considered the most damaging disease of wheat (Roelfs et al. 1992). Stem rust infection (Figure 1) can result in severe yield losses by weakening wheat stems and interfering with nutrient transport, causing plants to lodge and grain to shrivel. Stem rust is primarily a warm weather disease, though it can be a problem in temperate climates during the warmer months. Yield losses of fifty percent or more are possible in a region (Leonard 2001), although losses are generally more muted over broader scales (Pardey et al. 2013).

Due to the expense and limited efficacy of fungicides, most efforts to combat *P. graminis* have historically been focused on breeding plants that are resistant to the contemporary pathotypes of *P. graminis*. From the mid-1960s until recently, this strategy has led to marked reductions in the impact of stem rust on wheat yields in many countries worldwide (Pardey et al. 2013). The apparent success of wheat breeders led to cut-backs in their funding. In 1999, a new virulent race of stem rust was identified from wheat fields in Uganda (popularly known as Ug99), for which there is presently little resistance in the world's wheat crop (Pretorius et al. 2000). Ug99 is now spreading out of eastern Africa, posing an increasing threat to the world's wheat production (Singh et al. 2011) (Figure 2).

Figure 1. Wheat stem rust.
(Photograph from CIMMYT)

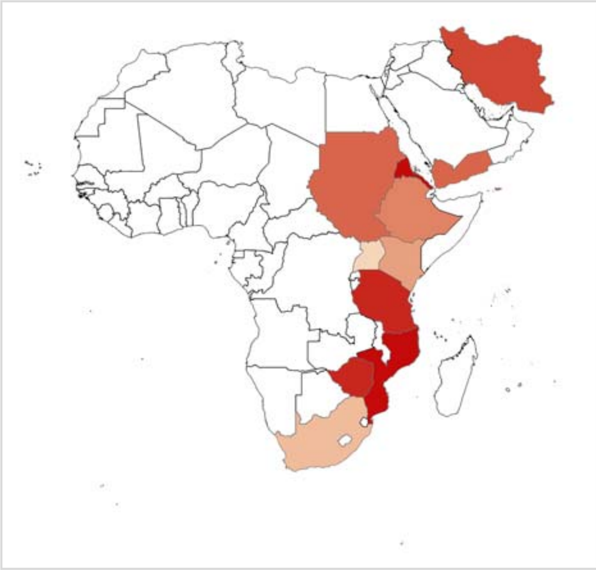

Figure 2. Current status and distribution of the Ug99 group of *P. graminis*, reproduced based on CIMMYT (2013).

Suggested citation: Beddow, J.B., Sutherst, R.W., Kriticos, D.J., Duveiller, E., and Chai, Y. (2015). *Puccinia graminis*. HarvestChoice Pest Geography. St. Paul, MN: InSTePP-HarvestChoice.

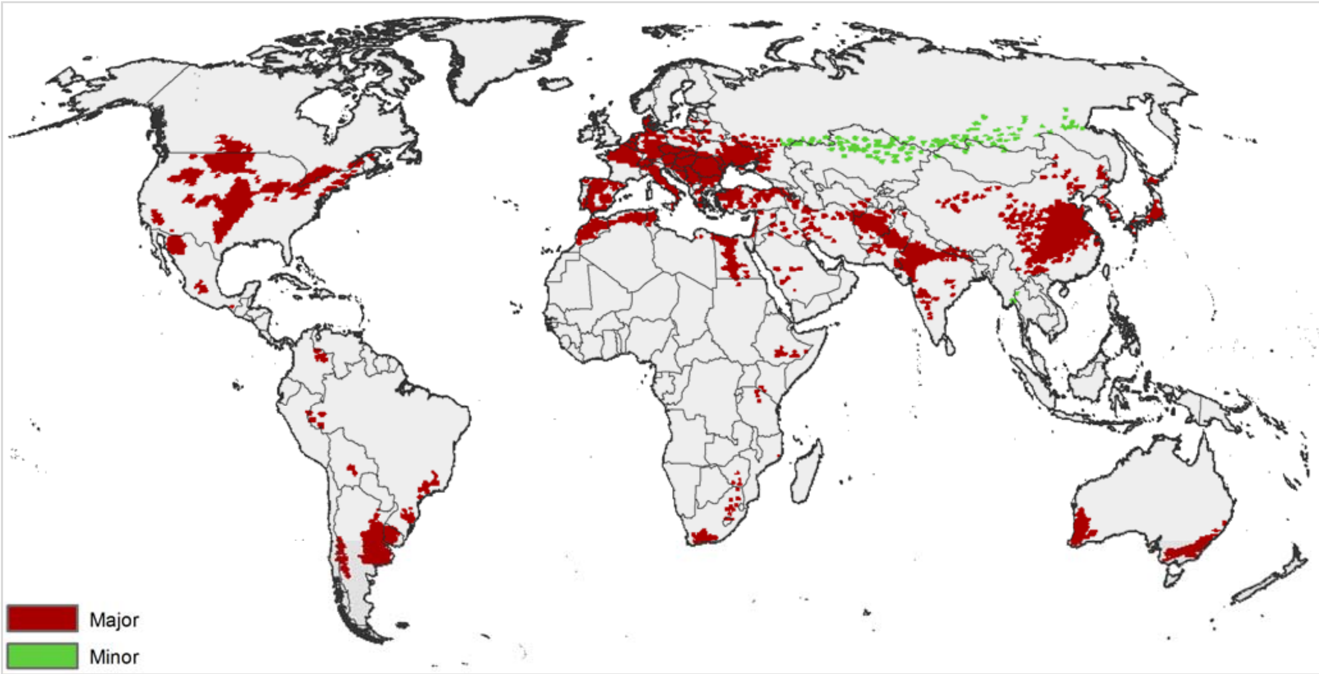

Figure 3. Wheat Stem Rust global occurrences (Adapted from Roelfs et al. 1992)

Known Distribution

Wheat stem rust is known to occur throughout most of the wheat-growing areas of the world (Figure 3) and presently occurs on every continent except Antarctica.

Description and Biology

Puccinia graminis has a complex life cycle with five distinct spore stages on two distinct host species (Figure 4). On the gramineous hosts, stem rust develops brick-red pustules containing masses of rust-coloured urediniospores that form chiefly on the stems and leaf sheaths (Leonard and Szabo 2005). This asexual (uredinial) stage can undergo repeated reproductive cycles every 14-20 days under favourable (warm, moist) conditions. Stem rust needs an alternate host (common barberry: *Berberis vulgaris*) to complete its sexual stage.

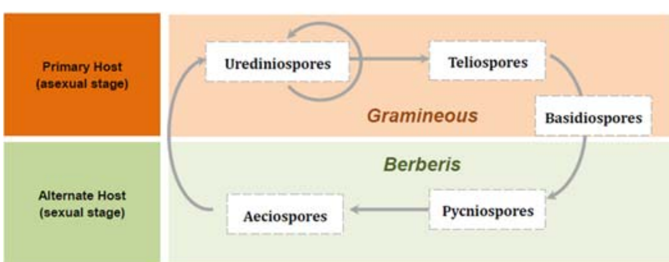

Figure 4. Wheat stem rust life cycle

Wheat stem rust is a highly mobile disease, with spores spreading rapidly over large distances by wind (Stakman 1957) or on travelers' clothing (Singh et al. 2008). With long-distance wind dispersal, populations of *P. graminis* could overwinter in locations with a mild winter but infect distant wheat crops grown in temperate climates during the short summer season (Leonard and Szabo 2005). In the United States, for example, because of the barberry eradication program during the early 20th century, stem rust overwinters as urediniospores on winter wheat in the southern Great Plains, moves northward by wind to infect winter wheat in the central Great Plains and eventually spring-sown cereals in the northern Great Plains (Leonard and Szabo 2005). In southern Africa, wheat stem rust diseases can be found at any time due to overlapping crop cycles and favourable climates, thus southern Africa is considered to be a single epidemiological zone (Roelfs and Bushnell 1985).

Host Crops and Other Plants

The primary hosts for *Puccinia graminis* include wheat, barley, and triticale and the alternate host is barberry.

Potential Distribution

The CLIMEX Compare Locations model (Sutherst 1985; Sutherst et. al 2007) distinguishes between the climatic suitability for population growth during favourable seasons, represented by a weekly and an annual Growth Index, and an overall index of suitability for year-round persistence, the Ecoclimatic Index. Both indices are scaled between 0 and 100, where a value of 100 represents an optimal climate, experienced year round. The general methodology used to fit the model, along with an accessible guide to the interpretation of CLIMEX models is provided by Beddow et al. (2010).

Defining the potential range of *P. graminis* is complicated by seasonal dispersal patterns, the presence of its alternate host, and irrigation practices. The potential distribution of wheat stem rust was estimated under historical climate conditions using the CliMond 1975H climatology (Kriticos et al. 2012). At each geographical location (in this case a ten arc minute, geo-referenced grid cell), an annual Growth Index (GI_A) quantifies the potential for population growth during the favourable season, and the Ecoclimatic Index (EI) quantifies the overall potential for year-round population persistence, discounting the GI_A with the stresses accumulated during the unfavourable seasons.

Under a rainfed agricultural scenario (no irrigation), the model stresses were fitted to the known distribution of the wheat stem rust in the southern United States where *P. graminis* populations overwinter (Peterson 2001). Parameters were fitted so that all known suitable locations were modelled as being favourable (Table 1 and Figure 3). Cold Stress parameters were adjusted to limit the northern extent of the persistent range in Texas, Louisiana and Alabama. The Dry Stress threshold was set at 0.1, to accord with the permanent wilting point. The Dry Stress accumulation rate was then adjusted to limit the western extent of *P. graminis* in xeric locations such as New Mexico, though the Soil Moisture Index was also limiting in this environment. In the south east of the United States, Hot-Wet Stress parameters were adjusted to limit the potential range of *P. graminis* to known suitable locations. The underlying ecophysiological basis for this climatic stress is unknown, although it is likely to be associated with some form of biotic stress affecting the wheat host or competitive exclusion of the rust.

The Temperature Index and the Soil Moisture Index multiplied together give the Growth Index. The Temperature Index parameters were set in consideration of the observed minimum temperature for infection reported by Tolenaar (1985), and the upper maximum temperature for growth reported by Kramer and Eversmeyer (1992), after accounting for the averaging effect involved in calculating long-term climatic averages. The optimum temperature range was derived from Rowell (1984), Tolenaar (1985) and Kramer and Eversmeyer (1992). The Soil Moisture Index parameters were fitted to match observed patterns of abundance of *P. graminis* epidemics in the United States. The lower soil moisture limit (SM0) was set to 0.3, limiting the suitability in the mid-west of the United States under rainfed wheat cultivation. This value is well above permanent wilting point, and its high value suggests that the lower limit for population growth may be associated with conditions for spore germination and infection, or that *P. graminis* may require stem turgor for growth. The lower and upper optimal soil moisture index values span a relatively wide range around field capacity, reflecting the observed patterns of abundance in the United States. The upper soil moisture limit for growth was set to 2.5, reflecting conditions that are too wet for wheat persistence.

The CLIMEX EI map (Figure 5) indicates locations where stem rust population could potentially persist year-round. To identify regions that would be climatically suitable for *P. graminis* epidemics during the favourable season, two separate CLIMEX GI map scenarios were run: rainfed scenario (Figure 6) and irrigated scenario (Figure 7). The irrigated scenario assumed that 2.5 mm per day of top-up irrigation was applied during the winter months. The results of each scenario were calculated globally for all land areas on a ten arc minute climatic grid.

Table 1. CLIMEX Parameter Values for *Puccina graminis*

Parameter	Description	Value
Moisture		
SM0	lower soil moisture threshold	0.3
SM1	lower optimum soil moisture	0.6
SM2	upper optimum soil moisture	1.5
SM3	upper soil moisture threshold	2.5
Temperature		
DV0	lower temperature threshold	4 °C
DV1	lower optimum temperature	17 °C
DV2	upper optimum temperature	25 °C
DV3	upper temperature threshold	32 °C
Cold Stress		
TTCS	cold stress temperature threshold	4 °C
THCS	temperature threshold stress accumulation rate	-0.01 $week^{-1}$
Heat Stress		
TTHS	heat stress temperature threshold	34 °C
THHS	temperature threshold stress accumulation rate	0.005 $week^{-1}$
Dry Stress		
SMDS	soil moisture dry stress threshold	0.1
HDS	stress accumulation rate	-0.005 $week^{-1}$
Hot-Wet Stress		
TTHW	Hot-Wet temperature threshold	30°C
MTHW	Hot-Wet moisture threshold	0.35
PHW	Hot-Wet stress accumulation rate	0.03 $week^{-1}$
Irrigation Scenario		
	2.5 mm day^{-1} as top-up during winter season	

The fit of the model in the United States and India was subject to close scrutiny by a panel of experts, who agreed that the CLIMEX model accorded with their understanding of the spatial and temporal patterns of wheat stem rust. To effectively develop and deploy resistant wheat varieties against stem rust, our CLIMEX model can serve as a powerful tool to help scientists and policy makers to control this widespread, highly mobile disease.

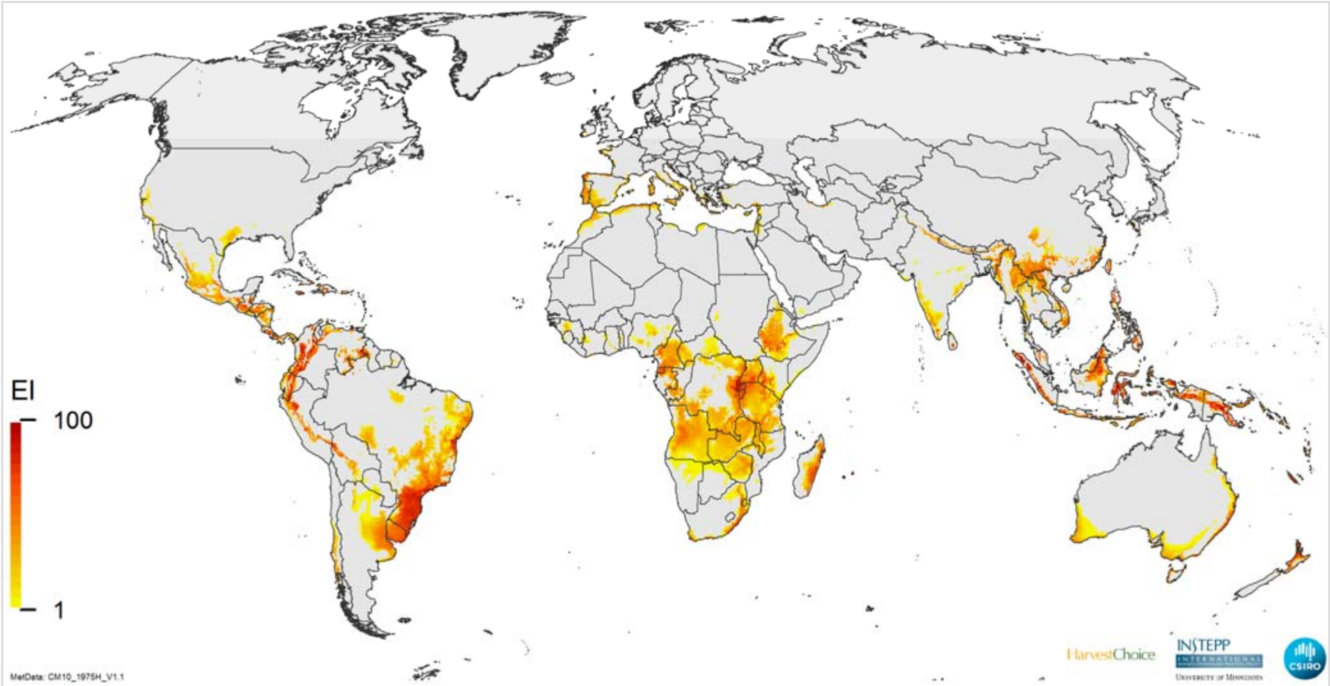

Figure 5. Modelled global climate suitability (EI) for *Puccinia graminis* with only natural rainfall.

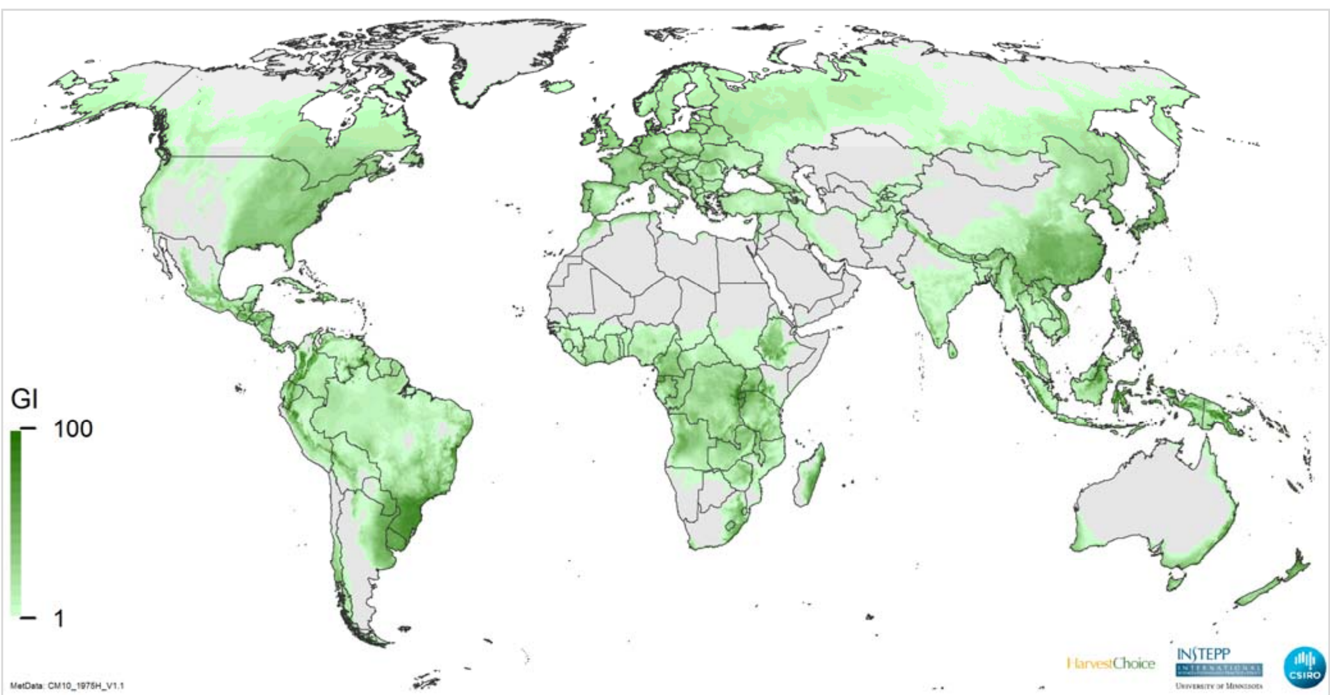

Figure 6. Modelled global climate suitability (GI) for *Puccinia graminis* with only natural rainfall.

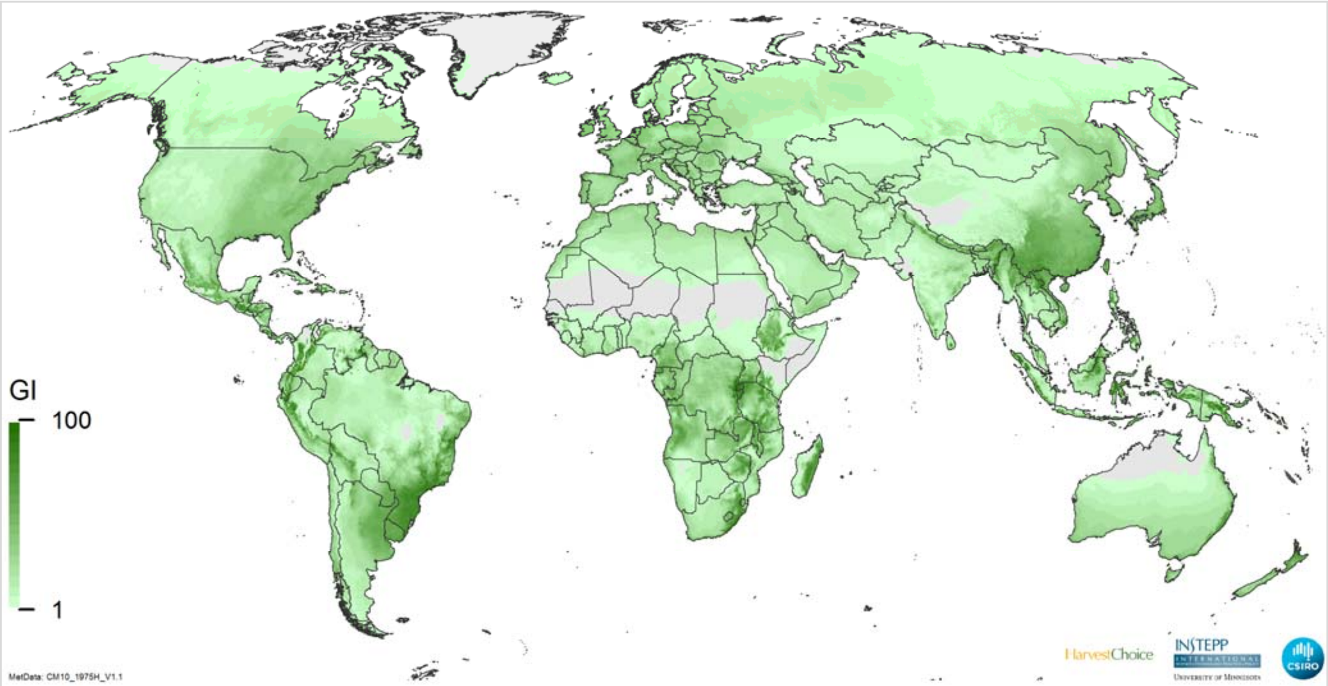

Figure 7. Modelled global climate suitability (GI) for *Puccinia graminis* as a composite of natural rainfall and irrigation based on the irrigation areas identified in Siebert et al. (2005).

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ACKNOWLEDGEMENTS

HarvestChoice would like to acknowledge Noboru Ota for spatial data analysis and the production of all maps and Philip Pardey for his significant help in preparing this brief. This brief was prepared with support from the CGIAR Research Program on Wheat led by CIMMYT (International Maize and Wheat Improvement Center) and ICARDA (International Center for Agricultural Research in the Dry Areas), and the Bill and Melinda Gates Foundation by way of the HarvestChoice project with additional support from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and The International Science and Technology Practice and Policy Center (InSTePP), University of Minnesota.

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