Puccinia striiformis

(Wheat Stripe Rust)

Yuan Chai[1], Darren J. Kriticos[1,2], Jason M. Beddow[1,2], Etienne Duveiller[3], Will Cuddy[4], Tania Yonow[1,2], and Robert W. Sutherst[5]

[1] HarvestChoice, InSTePP, University of Minnesota, St. Paul, MN, USA
[2] CSIRO, Biosecurity and Agriculture Flagships, Canberra, Australia
[3] CIMMYT, Global Wheat Program, El Batán, Mexico
[4] New South Wales Dept. of Primary Industries, Menangle, NSW, Australia
[5] University of Queensland, Brisbane, QLD, Australia (deceased)

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: Pucciniastraceae

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

Figure 1. Wheat Strip Rust Infection.
Source: USDA-ARS Cereal rust image gallery
http://www.ars.usda.gov/SP2UserFiles/ad_hoc/36400500Cerealrusts/stripe_rust.jpg

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 is 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, stripe rust 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'* native range in Eurasia. An alternative explanation for the invasion lag is that during the early phase of the invasion the rust spores 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, Paki-

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

stan 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 south-eastern 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), taking another thirty years for it to be reported in South Africa. It is now widespread throughout South Africa and the areas of northern Africa where the climate is Mediterranean, and the high elevation areas of eastern Africa experiencing a warm temperate climate (rusttracker.cimmyt.org).

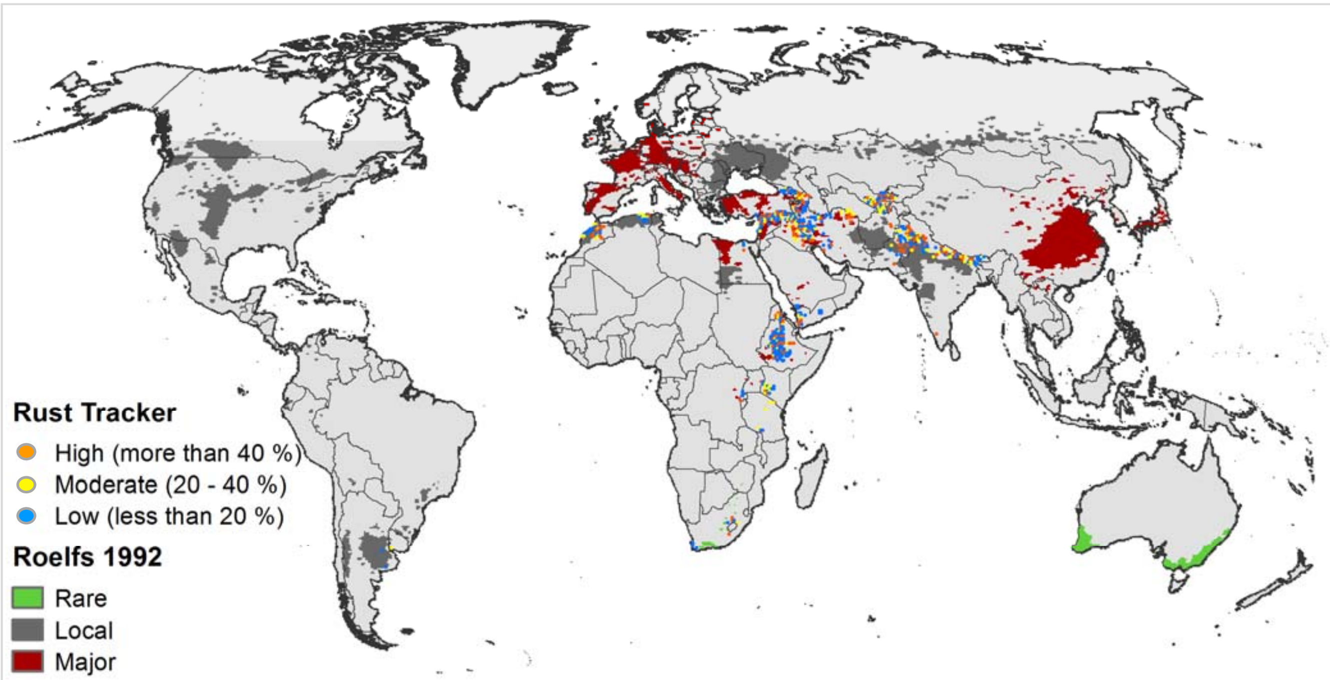

Figure 2. Wheat areas of the world where stripe rust has been a problem (reproduced based on Roelfs et al. 1992 and rusttracker.cimmyt.org).

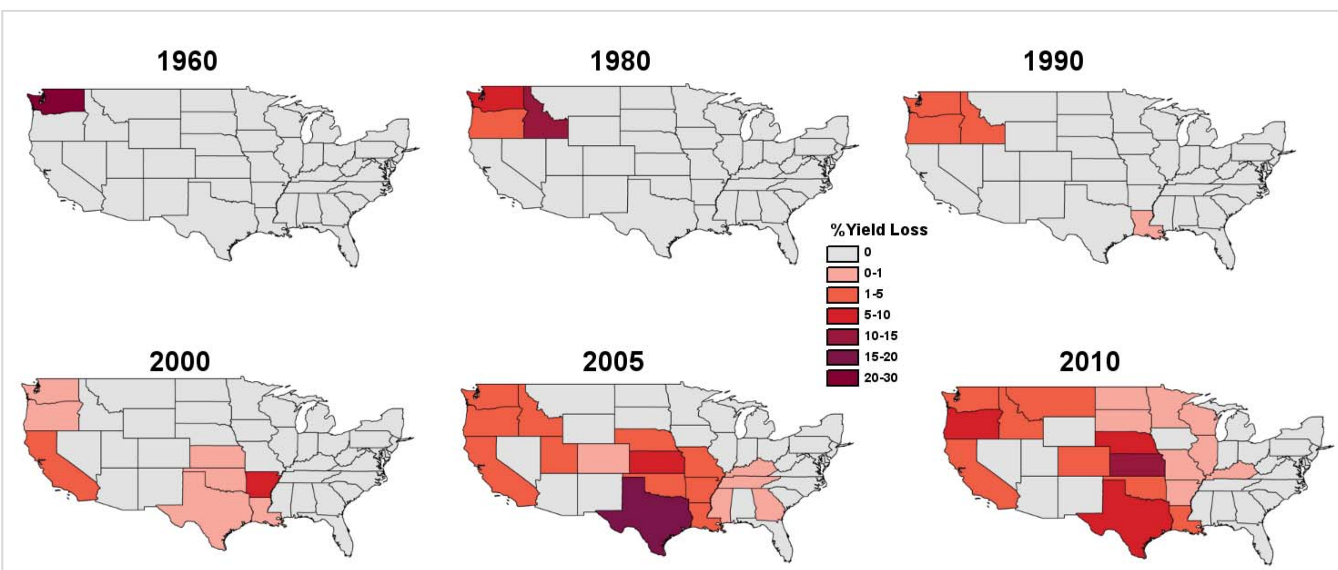

Figure 3. Wheat stripe rust losses in the United States (selected years 1960-2010, produced by authors based on USDA CDL small grain rust losses data from http://www.ars.usda.gov/main/docs.htm?docid=10123).

Description and Biology

Puccinia striiformis has a complex lifecycle, requiring both a primary host and an alternate host for completion (Figure 4). The asexual (uredinial) 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).

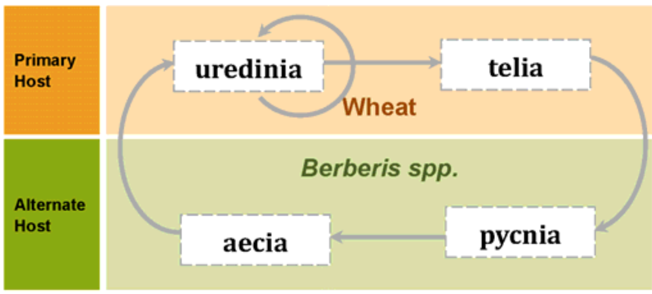

Figure 4. Wheat stripe rust life cycle (reproduced based on Jin et al. 2010)

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 unlikely as stripe rust spores are sensitive to UV radiation (Roelfs et al. 1992).

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 infection stage for yield losses is the early milk stage (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 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 *Tritocosecale*). *Berberis* species were recently discovered to be suitable hosts (Jin at 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) describes the relative climatic suitability of areas for year-round persistence of the pathogen (i.e., establishment); the Annual Growth Index (GI_A) indicates the relative climatic suitability for population growth (i.e., infection/outbreak). The CLIMEX parameters (Table 1) were fitted based on the biology of stripe rust pathogen and its known distributions in the USA, the Middle-East, India and Pakistan, taking into account the spatial distribution of irrigated and non-irrigated wheat production. The distribution elsewhere was used to validate the goodness of fit of the model. 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).

Table 1. CLIMEX Parameter Values for *Puccinia striiformis*

Stage	Description	Value
Moisture		
SM0	lower soil moisture threshold	0.2
SM1	lower optimum soil moisture	0.7
SM2	upper optimum soil moisture	1.5
SM3	upper soil moisture threshold	2.5
Temperature		
DV0	lower threshold	3 °C
DV1	lower optimum temperature	12 °C
DV2	upper optimum temperature	16 °C
DV3	upper threshold	30 °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	30 °C
THHS	stress accumulation rate	0.01 week^{-1}
Dry Stress		
SMDS	soil moisture dry stress threshold	0.2
HDS	stress accumulation rate	-0.005 week^{-1}
Hot-Wet Stress		
TTHW	Hot-Wet Threshold Temperature	30 °C
MTHW	Hot-Wet Threshold	0.3
PHW	Hot-Wet Stress rate	0.005 week^{-1}
Threshold Heat Sum		
PDD	number of degree days above DV0 needed to complete one generation	200 °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 -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 at 3 °C and 30 °C, respectively. The optimum temperatures concur with the report of Ellison and Murray (1992) where infection rates are positively correlated with mean temperature for the range of 12.9 °C to 16.2 °C. 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 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 d 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.

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

Stage	Temperature (°C)			Light	Free water
	Minimum	Optimum	Maximum		
Germination	0	9-13	23	Low	Essential
Germling	-	10-15	-	Low	Essential
Appressorium	-	-	(not formed)	-	Essential
Penetration	2	8-13	23	Low	Essential
Growth	3	12-15	20	High	None
Sporulation	5	12-15	20	High	None

Source: Roelfs, A.P., Singh, R.P. and Saari, E.E. Rust diseases of wheat: Concepts and methods of disease management. CIMMYT: Mexico, 1992. p.3.

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.

Heat stress was added to limit the potential distribution of stripe rust in India where the growing season appears too hot for stripe rust development (A. Joshi, pers. comm.). Whilst relatively high temperatures (and dry conditions) have been reported to favor dormant survival (Chen 2005), *P. striiformis* apparently cannot persist where temperatures exceed 30 °C for some time. Warm wet conditions reduce spore viability in *P. striiformis* (Chen 2005), and Hot-Wet Stress appears to limit the range of *P. striiformis* into the tropics. This may reflect biotic stress due to hemi-parasitism, but is more likely due to inclement conditions for wheat under warm humid conditions. The temperature threshold of 30 °C is at the upper limit of growth. The soil moisture limit (MTHW) is just above the lower limit for growth of this species. The Hot-Wet Stress accumulation rate (PHW 0.005 week-1) indicates the need for prolonged warm wet conditions to preclude persistence of *P. striiformis*. This set of parameters precludes *P. striiformis* from persisting in the coastal south-eastern USA.

In the absence of growth response experiments, the Moisture Index parameters were set to biologically reasonable values. The lower limit for population growth, SM0 was set to 0.2; well above permanent wilting point, reflecting the need for active host plant turgor and growth to support growth of the fungus. In accordance with the high SM0 value, The lower and upper range for optimal growth (SM1 and SM2) were set relatively high at 0.7 and 1.5 respectively. The upper limit for optimal growth (SM3) was set to 2.5 to preclude growth under very high soil moisture conditions.

The Dry Stress Threshold (SMDS) of 0.2 is equal to the lower limit for growth (SM0). The Dry Stress Accumulation Rate (HDS) of -0.005 is a relatively slow accumulation rate. These parameters preclude *P. striiformis* from persisting in the xeric regions in the USA and India from which it has not been observed, except where irrigation is practiced during the growing season.

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). Our model also indicates suitable climates for stripe rust persistence along the eastern states from Georgia to Pennsylvania, which has also been reported as potentially both oversummering and overwintering regions along the Appalachian Mountains (Sharma-Poudyal et al. 2013).

In its native range in the Middle East the *P. striiformis* 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 how climatically suitable areas would be for stripe rust development if infection were to occur, typically via wind-dispersed inoculum (Figure 6). In the United States, the CLIMEX GI_A map agrees with the known distribution of stripe rust epidemics in south central states and the central plains. The CLIMEX GI_A map shows 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

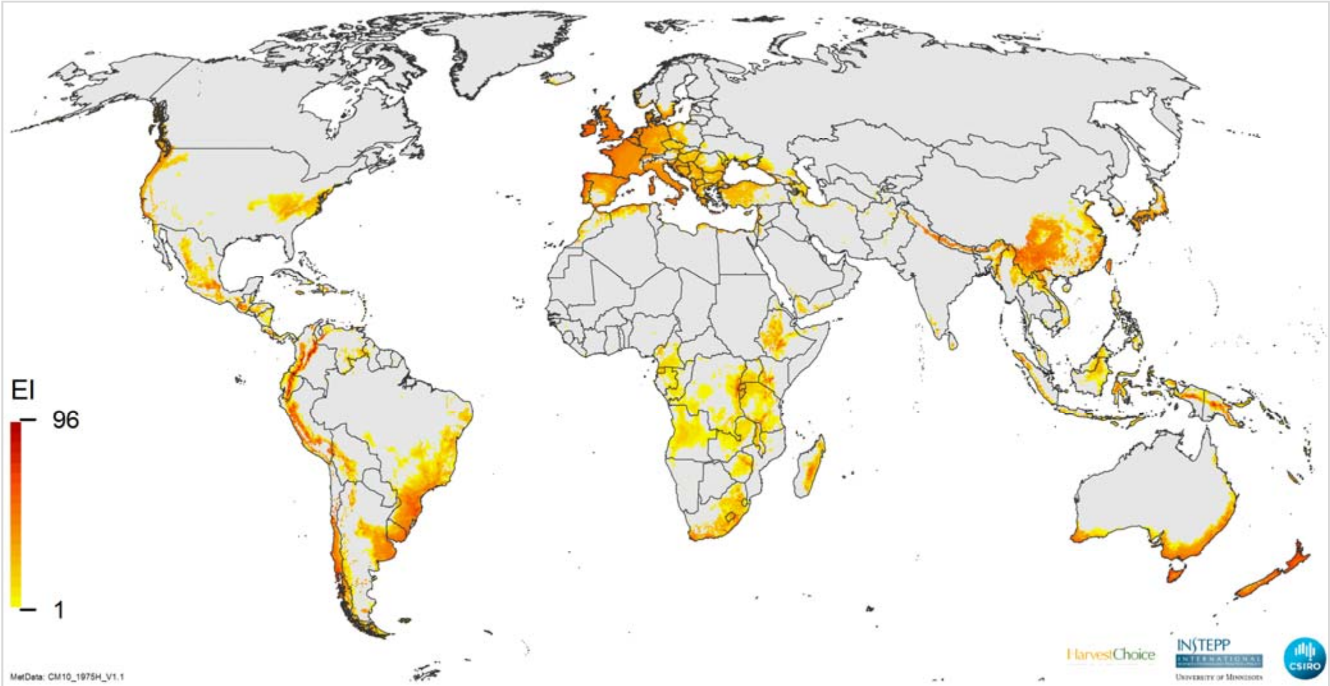

Figure 5. Modelled global climate suitability (EI) for *Puccinia striiformis*, as a composite of natural rainfall and irrigation based on the irrigation areas identified in Spatial Production Allocation Model (SPAM 2005).

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 this GI_A map (Figure 7), soil moisture is a limiting factor. However, there is a substantial amount of irrigated wheat production in Pakistan. Once we allow for 2.5 mm per day of top-up irrigation throughout the year (Figure 6), the mapped GI_A accords 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 *P. striiformis* include all regions in which wheat is grown under conditions with high soil moisture

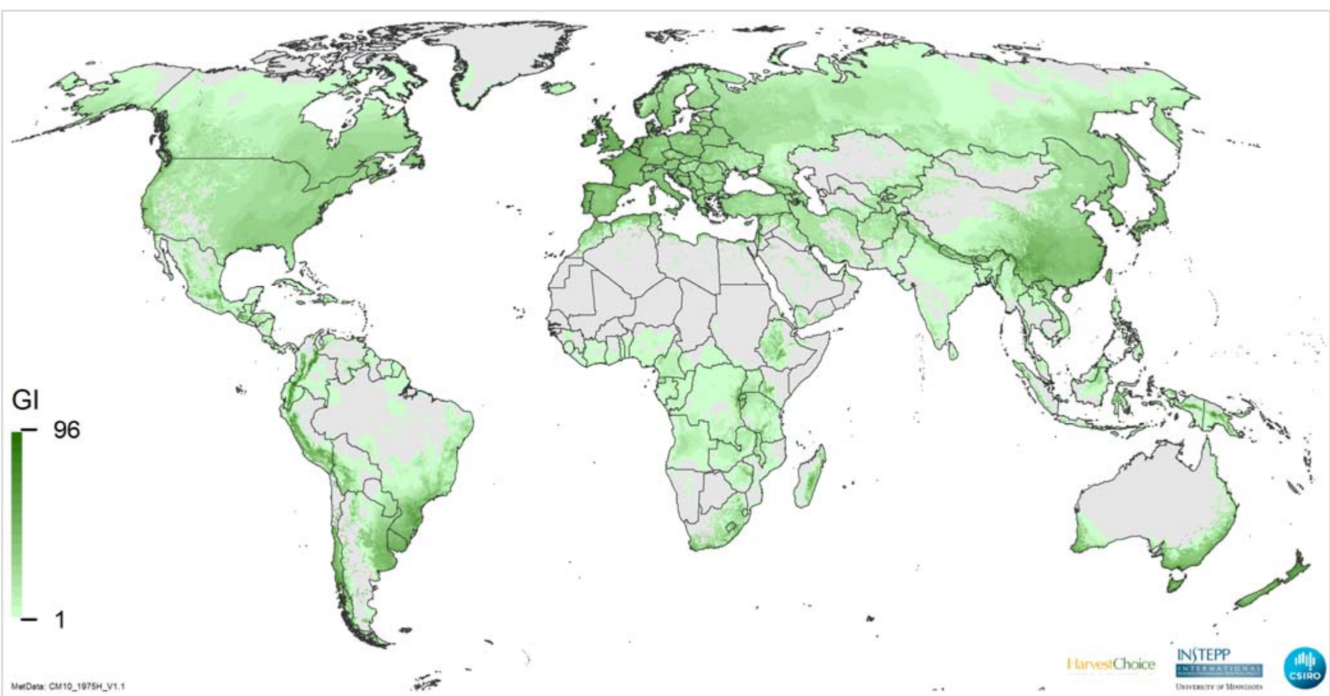

Figure 6. Modelled global potential occurrences (GI) for *Puccinia striiformis*, as a composite of natural rainfall and irrigation based on the irrigation areas identified in Spatial Production Allocation Model (SPAM 2005).

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.

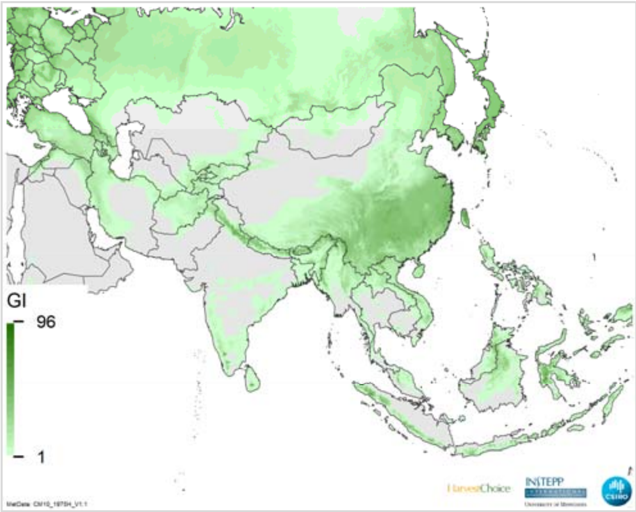

Figure 7. CLIMEX GI_A Map for Eurasia with only natural rainfall

References

Afzal, S.N., Haque, M., Ahmedani, M., Bashir, S., and Rattu, A. (2007). Assessment of yield losses caused by *Puccinia striiformis* triggering stripe rust in the most common wheat varieties. *Pakistan Journal of Botany* 39: 2127-2134.

Angus, A. (1965). Annotated list of plant pests and diseases in Zambia. Parts 1–7 and supplements. Mount Makulu Research Station, Chilanga, Zambia.

Beddow, J.M., Kriticos, D.J., Pardey, P.G., and Sutherst, R.W. (2010). Potential global pest distributions using CLIMEX: HarvestChoice Applications. HarvestChoice: St. Paul, MN.

Chen, X. (2005). Epidemiology and control of stripe rust [*Puccinia striiformis* f. sp. *tritici*] on wheat. *Canadian Journal of Plant Pathology* 27: 314-337.

Coakley, S.M., McDaniel, L.R., and Line, R.F. (1988). Quantifying how climatic factors affect variation in plant disease severity: a general method using a new way to analyze meteorological data. *Climatic Change* 12: 57-75.

Dennis, J.I. (1987). Effect of high temperatures on survival and development of *Puccinia striiformis* on wheat. *Transactions of the British Mycological Society* 88: 91-96.

Ellison, P.J. and Murray, G.M. (1992). Epidemiology of *Puccinia striiformis f. sp. tritici* on wheat in southern New South Wales. *Australian Journal of Agricultural Research* 43(1): 29-41.

Georgievskaja, N.A. (1966). Quelques lois sur le developpement de la rouille Jaune du blé. [Some laws on the development of Wheat Yellow Rust]. Trudy Vsesoyuznyi nauchno-issledovatel'skii Instut Zabtsh Rost Leningrad [Leningrad National Research Institute] 26: 55-63.

Germán, S., Barcellos, A., Chaves, M., Kohli, M., Campos, P., and de Viedma, L. (2007). The situation of common wheat rusts in the southern cone of America and perspectives for control. *Crop and Pasture Science* 58(6): 620-630.

Jin, Y., Szabo, L.J., and Carson, M. (2010). Century-old mystery of *Puccinia striiformis* life history solved with the identification of *Berberis* as an alternate host. *Phytopathology* 100: 432-435.

Kriticos, D.J., Webber, B.L., Leriche, A., Ota, N., Macadam, I., Bathols, J., and Scott, J.K. (2012). CliMond: global high-resolution historical and future scenario climate surfaces for bioclimatic modelling. *Methods in Ecology and Evolution* 3(1): 53-64.

Milus, E.A., Kristensen, K., and Hovmøller, M.S. (2009). Evidence for increased aggressiveness in a recent widespread strain of *Puccinia striiformis* f. sp. *tritici* causing stripe rust of wheat. *Phytopathology* 99(1): 89-94.

Milus E., Seyran, E., and McNew, R. (2006). Aggressiveness of *Puccinia striiformis* f. sp. *tritici* isolates in the south-central United States. *Plant Disease* 90: 847-852.

Murray, G., Ellison, P., Watson, A., and Cullis, B. (1994). The relationship between wheat yield and stripe rust as affected by length of epidemic and temperature at the grain development stage of crop growth. *Plant Pathology* 43: 397-405.

O'Brien, L., Brown, J.S., Young, R.M., and Pascoe, I. (1980). Occurrence and distribution of wheat stripe rust in Victoria and susceptibility of commercial wheat cultivars. *Australasian Plant Pathology* 9: 14.

Rapilly, F. (1979). Yellow rust epidemiology. *Annual Review of Phytopathology* 17: 59-73.

Roelfs, A.P. and Bushnell, W.R. (1985). The Cereal Rusts. Academic Press: Orlando, FL.

Roelfs, A.P., Singh, R.P., and Saari, E.E. (1992). Rust diseases of wheat: concepts and methods of disease management. CIMMYT: Mexico.

Sharma-Poudyal, D., Chen, X. and Rupp, R.A. (2014). Potential oversummering and overwintering regions for the wheat stripe rust pathogen in the contiguous United States. *International journal of biometeorology* 58(5): 987-997.

Solh, M., Nazari, K., Tadess, W., and Wellings C.R. (2012). The growing threat of stripe rust worldwide. *Borlaug Global Rust Initiative 2012 Technical Workshop*, Beijing, China. pp 1-10.

Sutherst, R.W., Maywald, G.F., and Kriticos, D.J. (2007). CLIMEX Version 3: User's Guide. Hearne Scientific Software Pty Ltd.

Tollenaar, H. and Houston, B.R. (1967). A study on the epidemiology of stripe rust, *Puccinia striiformis* West., in California. *Canadian Journal Botany* 45: 291-307.

USDA, Agricultural Research Services, Cereal Disease Laboratory. (2014) "Small grain losses due to rust", St. Paul, Minnesota, (http://www.ars.usda.gov/main/docs.htm?docid=10123, accessed September 2014).

Viljanen-Rollinson, S., and Cromey, M. (2002). Pathways of entry and spread of rust pathogens: implications for New Zealand's biosecurity. *New Zealand Plant Protection* 55: 42-48.

Wellings, C.R. (2007). *Puccinia striiformis* in Australia: a review of the incursion, evolution, and adaptation of stripe rust in the period 1979–2006. *Australian Journal of Agricultural Research* 58: 567–575.

Wellings, C.R. and McIntosh, R.A. (1990). *Puccinia striiformis* f. sp. *tritici* in Australasia: pathogenic changes during the first 10 years. *Plant Pathology* 39: 316–325.

Wellings C.R., Singh, R., Yahyaoui, A., Nazari, K., and McIntosh, R.A. (2009). The development and application of near-isogenic lines for monitoring cereal rust pathogens. *Borlaug Global Rust Initiative 2009 Technical Workshop*, Sonora, Mexico. pp 77-87.

You, L., Wood-Sichra, U., Fritz, S., Guo, Z., See, L. and Koo, J. Spatial Production Allocation Model (SPAM) (2005) Version 1. (International Food Policy Research Institute, Washington, DC, 2014). Available online at http://mapspam.info.

Zeng, S.M. and Luo, Y. (2008). Systems analysis of wheat stripe rust epidemics in China. *European Journal of Plant Pathology* 121: 425-438.

ACKNOWLEDGEMENTS

HarvestChoice would like to acknowledge Noboru Ota for spatial data analysis and the production of all maps. 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.

ABOUT HARVESTCHOICE

HarvestChoice generates knowledge products to help guide strategic investments to improve the well-being of poor people in sub-Saharan Africa through more productive and profitable farming. Learn more at www.harvestchoice.org.