**Combining a disease model with a crop phenology model to assess and map pest risk: Karnal bunt disease (*Tilletia indica*) of wheat in Europe**

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**ABSTRACT**

In order for plant pests to establish in a new area, the presence and distribution of food or host plants is critical. For some pathogens not only spatial but also temporal synchrony is required for survival since infection can occur only during specific host growth stages and climatic conditions. We used bread and durum wheat phenology models to predict the timing of the vulnerable developmental stages of wheat to infection by *Tilletia indica*, the causal agent of Karnal bunt, in Europe. Climatic data during these stages were then used to calculate an index of disease risk. The results were interpolated over the European landscape and mapped; summaries of the risks for each country were calculated. The arable areas of western and central Europe, particularly in France, were found to be most suitable for bread and feed wheat infection. The northern Italian plain and the important Italian pasta regions of Tuscany and Marche were most suitable for durum wheat infection.

## INTRODUCTION

The successful establishment of invertebrate pests and pathogens of plants in new areas is critically dependent on the availability of the host plant species needed for their survival, development and multiplication. International standards on pest risk analysis (PRA) (FAO, 2003) require the assessor to consider whether hosts are present and are sufficiently abundant and widespread in the area at risk to allow the pest to complete its life cycle. However, they ignore the fact that some pests can only utilise host plants if their life cycles are synchronised and environmental conditions are suitable when such synchrony occurs. Although the requirements for pest-host synchrony are frequently exploited in pest control and may play an important role when predicting the impacts of climate change (Dewar & Watt, 1992), their role in alien pest establishment has received little attention. We investigated this aspect of PRA by modelling the extent to which *Tilletia indica*, a fungal pathogen of wheat and the causal agent of Karnal bunt disease, would find conditions in Europe suitable for infection and development when its principal host is at susceptible growth stages. Maps summarising our predictions for Europe at low spatial resolution are reported here. Further analyses and high resolution predictions for England, Wales, Denmark and three provinces of Italy are given by Baker *et al*. (2004, unpublished).

## METHODS

For Karnal bunt of wheat to develop, conditions must be suitable for teliospores of *T. indica* to germinate to produce sporidia between the flag leaf emergence and anthesis stages of the growing wheat plant and for these spores to infect the developing ear (Nagarajan *et al*., 1997; Murray, 2004). Two wheat phenology models, AFRCWHEAT (Weir *et al*., 1984; Porter, 1993) and the IATA wheat development model (Miglietta, 1991), were applied to simulate these vulnerable growth stages for three cultivar maturity classes and three winter sowing dates of *Triticum aestivum* (bread and feed wheats) and *T. durum* (durum wheat). Bread wheat in this paper refers to both bread and feed wheat varieties of *T. aestivum*.

Since wheat development is predicted through the interaction of time, temperature, photoperiod and vernalisation, an extensive European meteorological dataset was required. Daily synoptic 1995-2002 European meteorological data from the US National Climate Data Center (NCDC, 2004), supplemented by data from the German National Weather Service, were downloaded and checked for consistency. Annual station data with more than three consecutive missing days were removed. A seven day running mean was used to estimate missing data for three consecutive days or less. To select stations relevant to wheat growing areas, we used Geographical Information System (GIS) software (ArcView 3.2, ESRI. Inc) to filter the weather station locations based on arable grid cells in PELCOM, a 1 km resolution European land cover map (Mücher, 2000). The maximum elevation for arable land in each country was estimated by combining PELCOM with GTOPO30 (GTOPO30, 2004), a global digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometre). We deleted all stations located 200 metres higher than the maximum elevation for arable land in each country. A 100 km buffer was then created around each remaining weather station and all stations more than 100 km from a PELCOM arable grid cell were also removed from the data set.

Running the wheat phenology models with the meteorological data enabled the timing of vulnerable wheat growth stages to be predicted throughout Europe for 1995-2002. To determine whether conditions were suitable for *T. indica* infection and disease development, the Humid Thermal Index (HTI), a climatic index originally used to forecast Karnal bunt in the Punjab, India, (Jhorar *et al*., 1992), was calculated for this vulnerable period. This index has been used in support of a PRA for the UK (Sansford, 1998). When the HTI, defined as the ratio of the average afternoon relative humidity to the average daily maximum temperature is between 2.2 and 3.3, conditions are favourable for infection and disease development. Below 2.2, it is too dry or too warm and above 3.3, too humid or too cold.

To display the HTIs predicted for wheat-growing areas away from weather stations, the results were interpolated over the landscape at 0.05° latitude/longitude resolution guided by elevation using ANUSPLIN, a partial thin plate smoothing spline interpolation technique

(Hutchinson, 2001). The interpolated data were then imported into the GIS. Only predictions for PELCOM arable grid cells were generated.

## RESULTS

Sowing data and cultivar maturity class had a minimal impact on the HTI values for winter sown bread and durum wheat (Baker *et al*., 2004). However, Figures 1 and 2 show that latitude and longitude had a considerable influence on both bread and durum wheat risk.

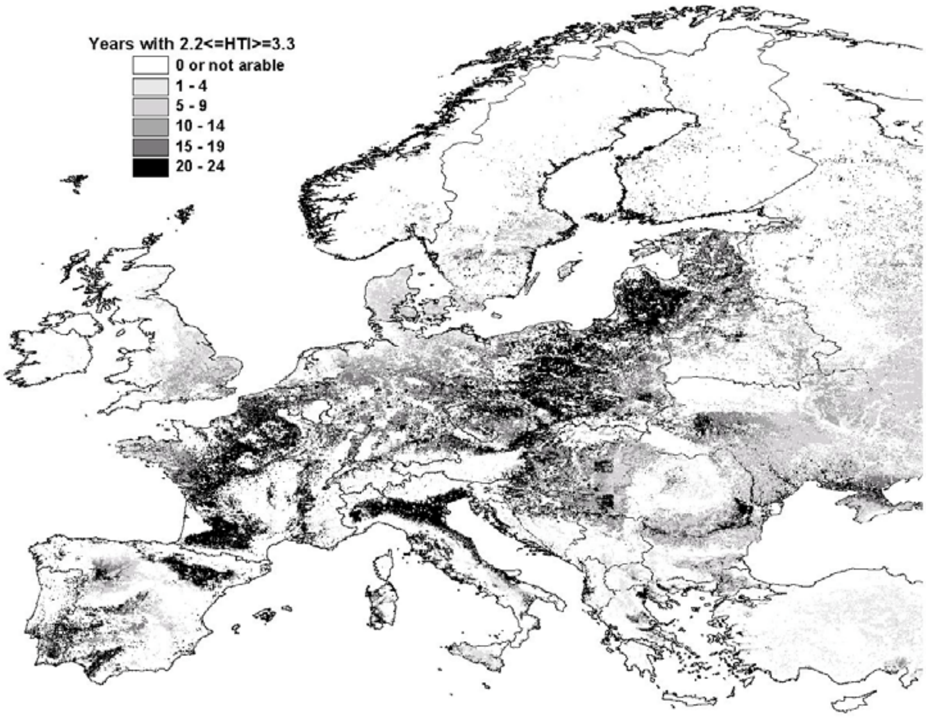


Figure 1. Risk score (out of 24) for each arable grid cell based on the number of years (1995-2002) when bread wheat sown on three dates (Julian dates 274, 305 and 335) has a Humid Thermal Index (HTI) between 2.2 and 3.3 during the growth stages susceptible to *T. indica* infection.

Figure 1 shows that in the major bread wheat growing regions of western and central Europe, particularly France, the HTIs are often within the range suitable for infection when the crop is at vulnerable growth stages. More northerly regions are predicted to have critical HTI values in about one third of the cases. The risk map for durum wheat (Figure 2) shows very high frequencies of critical HTI values for the northern Italian plain and the important pasta growing areas of Marche and Toscana. Southern Italy is at lower risk with high temperatures raising the HTI above its critical range. Durum wheat production in France and Spain is less vulnerable than bread wheat, because durum is generally sown later than winter wheat and the susceptible phenological stages are reached when conditions are drier and warmer.

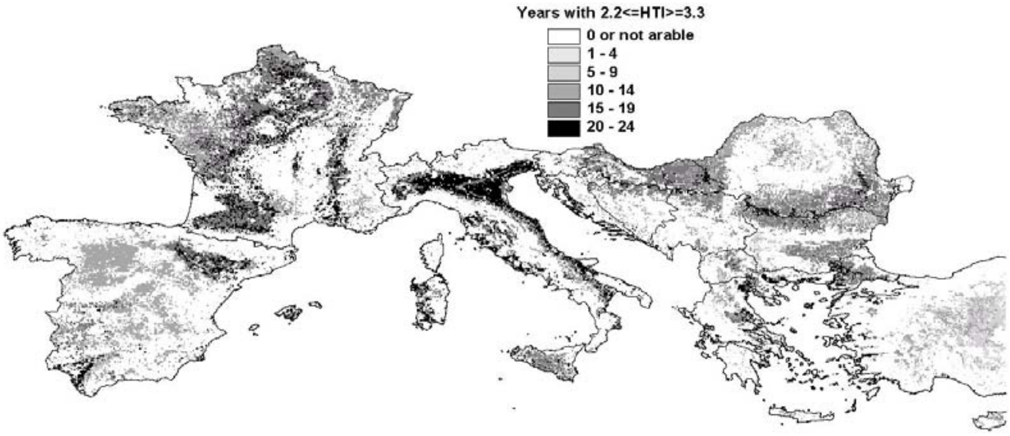


Figure 2. Risk score (out of 24) for each arable grid cell based on the number of years (1995-2002) when durum wheat sown on three dates (Julian dates 294, 314 and 335) has a Humid Thermal Index (HTI) between 2.2 and 3.3 during the growth stages susceptible to *T. indica* infection. Only data for countries with significant durum wheat production are displayed.

In order to provide a risk rating for each country, we calculated the mean score for arable grid cells and the sum of scores for all arable grids (Table 1).

Table 1. Two measures of the risks posed by *T. indica* to bread and durum wheat production in European countries based on: (a) The mean score out of 24 (8 years times 3 sowing dates) for arable grid cells in each country, (b) the sum of scores for all arable grid cells in each country. Only the top five countries for (b) are given in descending order.

| | **Bread Wheat** | | | **Durum Wheat** | |
|---|---|---|---|---|---|
| **Country** | **(a)** | **(b)** | **Country** | **(a)** | **(b)** |
| France | 19.3 ± 0.05 | 230139 | France | 16.4 ± 0.03 | 196452 |
| Poland | 19.1 ± 0.04 | 197291 | Italy | 17.8 ± 0.06 | 101707 |
| Ukraine | 9.9 ± 0.04 | 146992 | Spain | 14.0 ± 0.04 | 97335 |
| Germany | 15.1 ± 0.05 | 145396 | Romania | 13.5 ± 0.05 | 70472 |
| Italy | 17.2 ± 0.10 | 98416 | Turkey | 11.0 ± 0.07 | 42643 |

When both the mean score per arable grid cell and the area of production is taken into consideration, French bread and durum wheat production is under the greatest threat. However, Italian grid cells have a higher mean score per arable grid cell for durum wheat.

## CONCLUSIONS

Assuming the Indian HTI is also appropriate for the range of temperatures and humidities occurring in Europe and ungerminated viable teliospores are present, Figures 1 and 2 indicate that large areas of European wheat production are vulnerable to *T. indica* infection. It has not been possible to determine the extent to which the HTI is valid in countries outside India because widespread crop irrigation in areas where the pathogen has been introduced makes climatic data unrepresentative and comparative within-canopy humidity data are lacking. However, Inman *et al*. (2004) found that teliospores can survive ungerminated for at least three years in European conditions and Baker *et al*. (2004) showed that, while HTIs may not be within the critical 2.2-3.3 range every year, the maximum interval without suitable HTIs exceeds four years in only 21% of the European arable areas.

Additional sources of error were due to the variation in the availability of meteorological data from different countries. Data for Poland, Sweden, several countries in Eastern Europe and Germany for 2001-2002 were very limited and predictions were therefore based on interpolations from weather stations in neighbouring countries. Jarvis *et al*., (1999) highlight the logical inconsistencies which may result when interpolating the results of "at a point" models rather than model inputs. However, we found only occasional instances of development stages occurring in the wrong order and these were in areas where wheat production is known to be low. Although wheat production is widespread in Europe, our use of PELCOM arable areas to represent wheat production will give an over-estimate of the area at risk. Unfortunately, there is no up to date high resolution European-wide wheat production dataset.

The methodology used here to generate European maps for potential *T. indica* teliospore germination and disease development, summarising risk by country, is applicable to other PRAs where climate and hosts are key factors in determining pest distribution and the relationships with and between these factors can be modelled or inferred.

This research has highlighted the critical lack of accurate, consistent, easily accessible high resolution European-wide datasets for climate and crop distribution. The need to develop and enhance PRA procedures not just for individual countries but also for the European Union as a whole to justify phytosanitary measures has increasingly been emphasised. This study shows that unless such datasets can be created, PRAs valid for the whole of Europe will remain very difficult to produce.

## ACKNOWLEDGEMENTS

The EC Fifth Framework provided part-funding for this project (QLK5-1999-01554) and the contribution of all nine partner institutes is acknowledged. The authors' member state governments provided the balance of the financial support. We are very grateful to the German National Meteorological Service (Deutscher Wetterdienst, http://www.dwd.de) for providing weather data.

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