Image: Adobe Stock

Cereal killers

Who they are and how they impact our lives

Franziska Fischer – ff283@cam.ac.uk

Slides retrospectively annotated in blue for archiving the presentation.

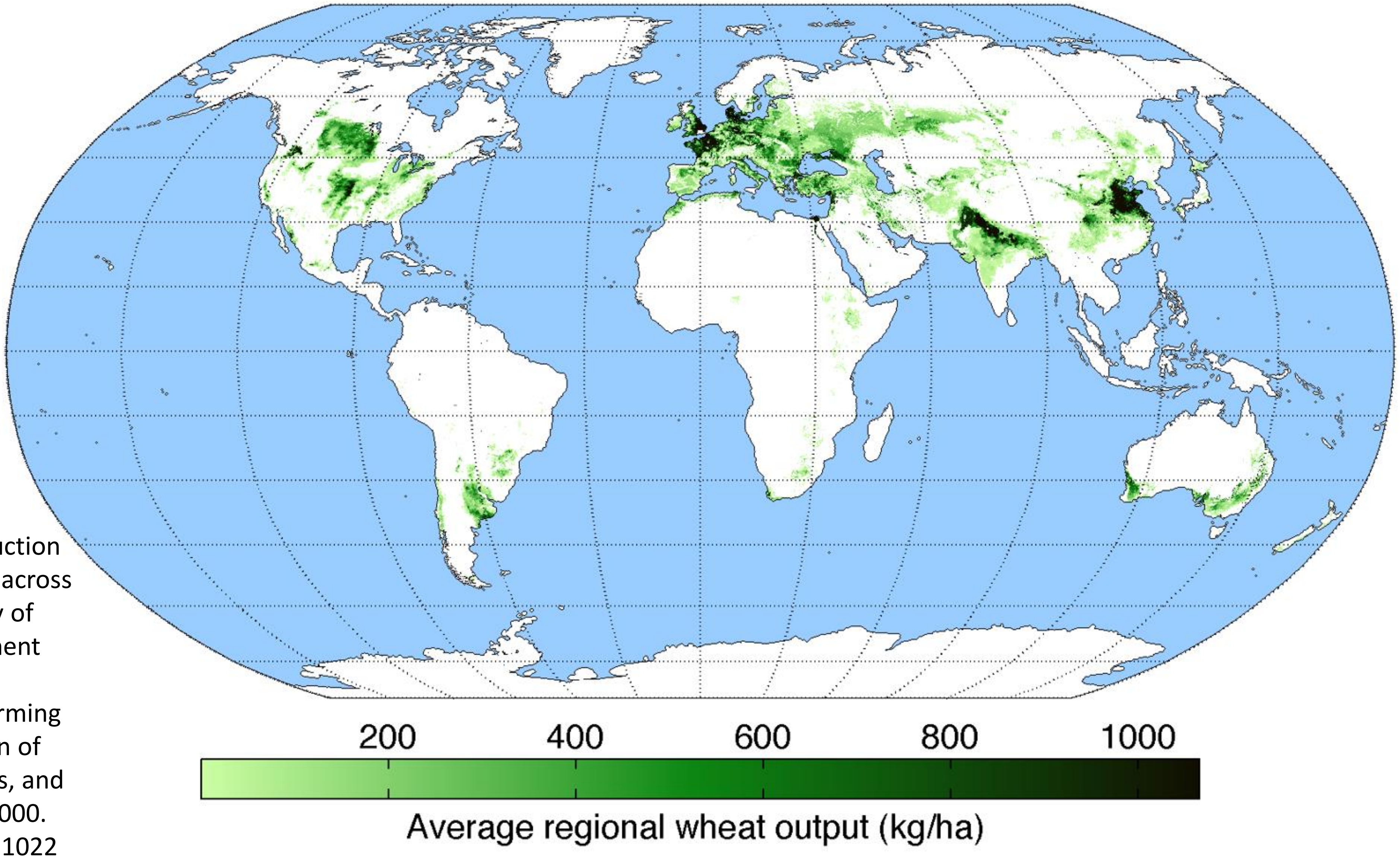
- Wheat as the world’s staple crop.
- Wheat pathogens, especially Fusarium Head Blight.
- The quest for FHB resistance.
- Personal interdisciplinary questions arising from the project.

Today’s topics

A map of worldwide wheat production

By AndrewMT published on https://en.wikipedia.org/

Wheat is among the top 5 crops in quantity produced and the most widely grown staple crop. The other subject of today's research project, Fusarium Head Blight, is similarly distributed.

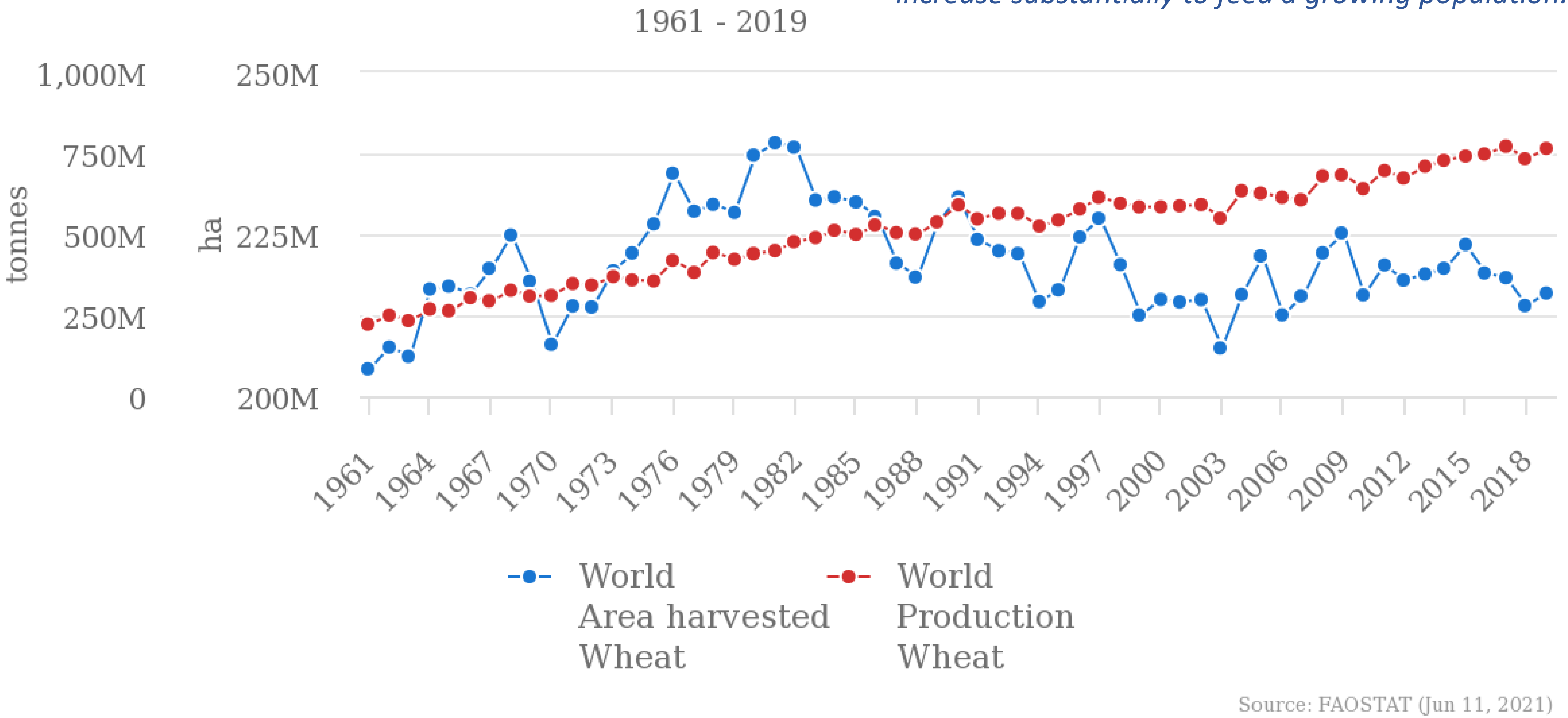


Cited description:
Map of wheat production (average percentage of land used for its production times average yield in each grid cell) across the world compiled by the University of Minnesota Institute on the Environment with data from: Monfreda, C., N. Ramankutty, and J.A. Foley. 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biogeochemical Cycles 22: GB1022

World wheat production

Chart downloaded from http://www.fao.org/faostat/

Wheat production has been linearly increasing on a global scale. In areas of high production per area, for instance the UK, yields however are stagnating, the 'yield plateau'. This is concerning, as crop production needs to increase substantially to feed a growing population.



Wheat yield lost to pathogens

An estimated 20% of the wheat yield are lost to pathogens on average. Losses vary by region from about 10% to 28%.

The image to the right seeks to illustrate what a yield loss of 20% means in practice. Given the scale of wheat production, even a small improvement would make a big difference. In line with previous literature, Savary et al. also report that Fusarium Head Blight (alias scab) is among the most damaging wheat diseases.

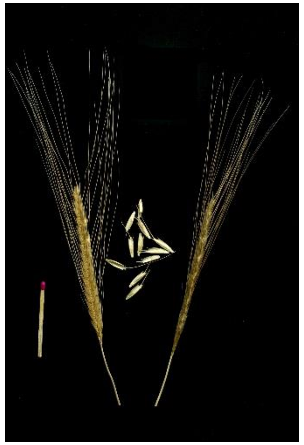
Savary *et al.* (2019) The global burden of pathogens and pests on major food crops, Nature Ecology & Evolution, 3, pp 430-439, https://doi.org/10.1038/s41559-018-0793-y

Image of grains: Adobe Stock

Wheat evolution

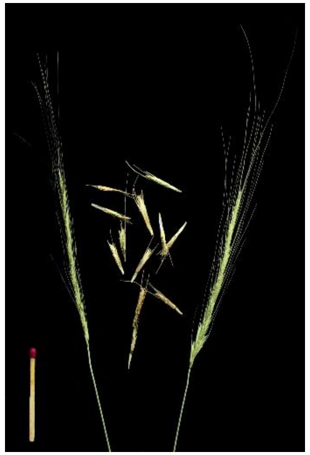
A rough sketch summarising ongoing research.

T. urartu is the most likely AA ancestor according to more recent research



Wild Einkorn
T. boeoticum
AA

X



A. speltoides
BB

The exact origin of the BB genome is under debate.

→

Wild Emmer
T. dicoccoides
AABB

X

Goats grass
A. tauschii
DD

Goats grass contributed for example to disease resistance and bread making quality.

→

Bread wheat is an allohexaploid with a very large genome of about 17 gigabases. This makes wheat genetics challenging – including research into disease resistance. While its origins are still not fully understood, the bread wheat genome has now been sequenced.

Bread wheat
T. aestivum
AABBDD

Images: Honegger, J. (2008) Virtual Cereal Cultivar Garden, Institute for Plant Sciences, ETH Zurich, http://www.sortengarten.ethz.ch/

Fusarium Head Blight

FHB is also known as scab in North America. It is caused by a group of fungal pathogens, primarily F. graminearum and F. culmorum.

Affected ears photographed in the field (healthy ear at the top left for comparison). Note the bleaching (usually first upwards, then downwards of the infection site) and the salmon pink spores that may become visible.

Spikelets photographed under a microscope: top healthy, bottom infected. Left during growth stages, right just before harvest. In the infected spikelets at the bottom, note the shrivelled kernels, pinkish-white mycelium, and in the later stage the secondary infection visible as black spots.

Harvested grain. Top two healthy, bottom two infected. There are limits on acceptable mycotoxin levels for sale. The main toxin, deoxynivalenol, is also toxic to humans, animals, and microorganisms.

Fig. 91.—Upper part of an infected ear of wheat invaded by *Fusisporium culmorum*, W.Sm. Natural size.

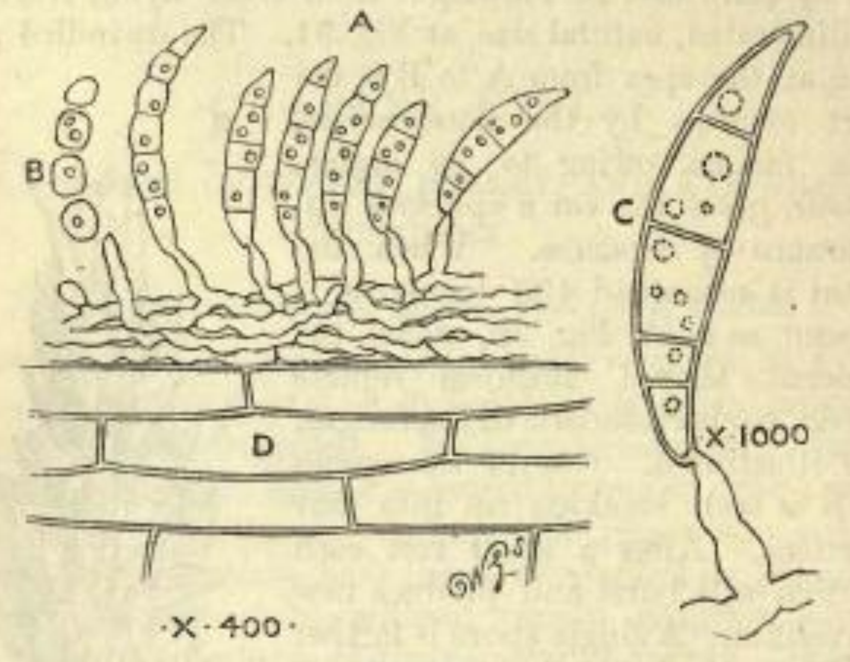


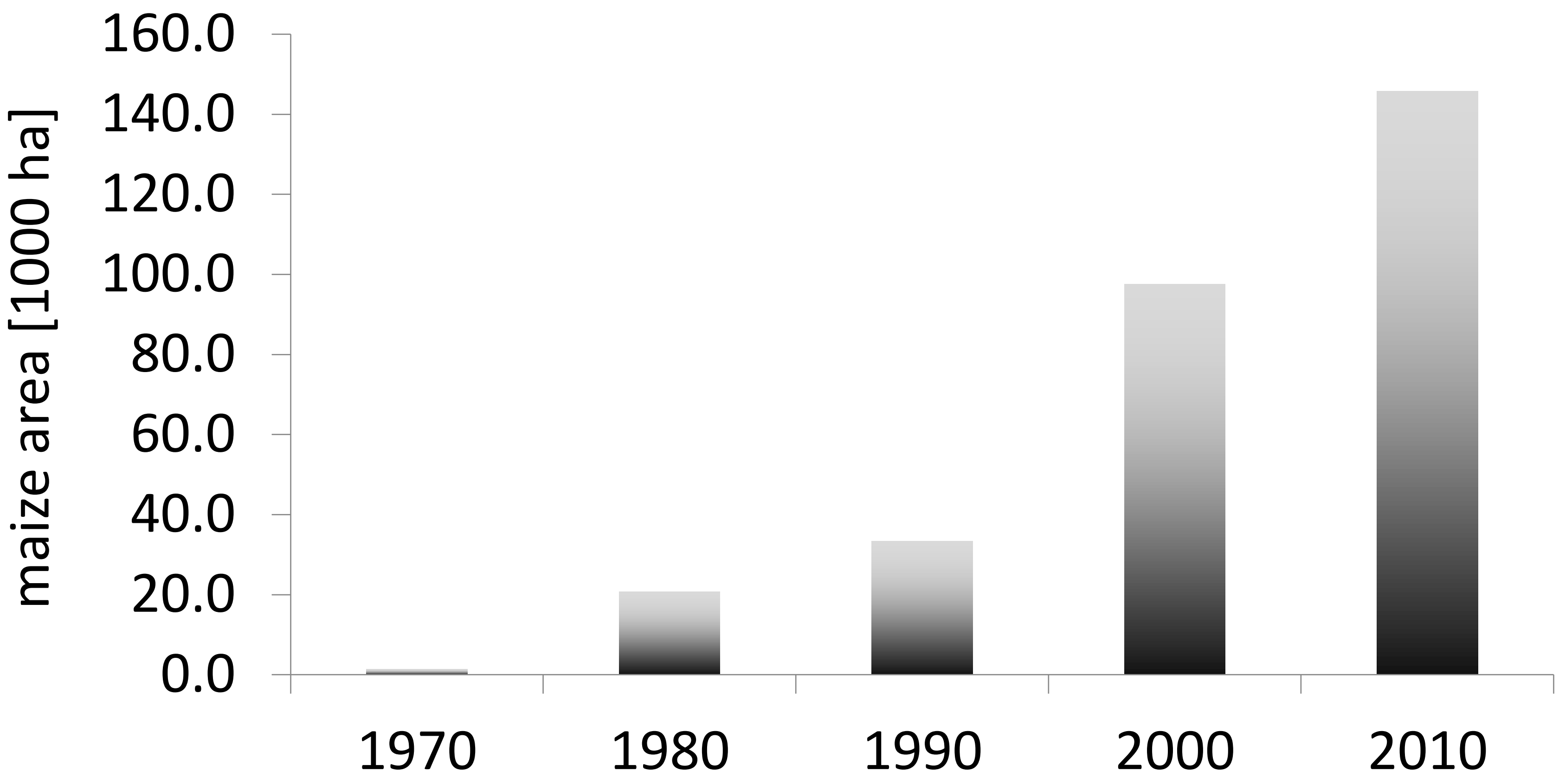
Fig. 92.
Fusisporium culmorum, W.Sm. Enlarged 400 diameters.
Spore enlarged 1000 diameters.

Worthington G. Smith accurately linked the pathogen which he called Fusisporium culmorum, and the symptoms it causes, in his 1884 book "Diseases of field and garden crops. Chiefly such as are caused by fungi." He commented that the pathogen was newly recognised at the time. He sketched a wheat ear provided by Charles B. Plowright from Norfolk and noted the typical premature bleaching, mycelium colour ranging from cream to yellow and pink, and the crescent-shaped and septate orange (now also described as salmon-pink) asexual spores (the causal pathogens' sexual stage was identified later). While contemporaries seem to have contested that he was first to describe the disease in this fashion, his description is certainly among the earliest.
Unfortunately, we have since failed to make the same progress in combating this disease as in comparable wheat diseases: there still aren't any fully resistant wheat varieties, resistance remains poorly understood, and other countermeasures remain challenging. According to unpublished work, FHB resistance in UK elite wheat varieties even decreased for a time and over the past few decades has stagnated – in noticeable contrast to other major fungal pathogens in the UK.

FHB risk factors

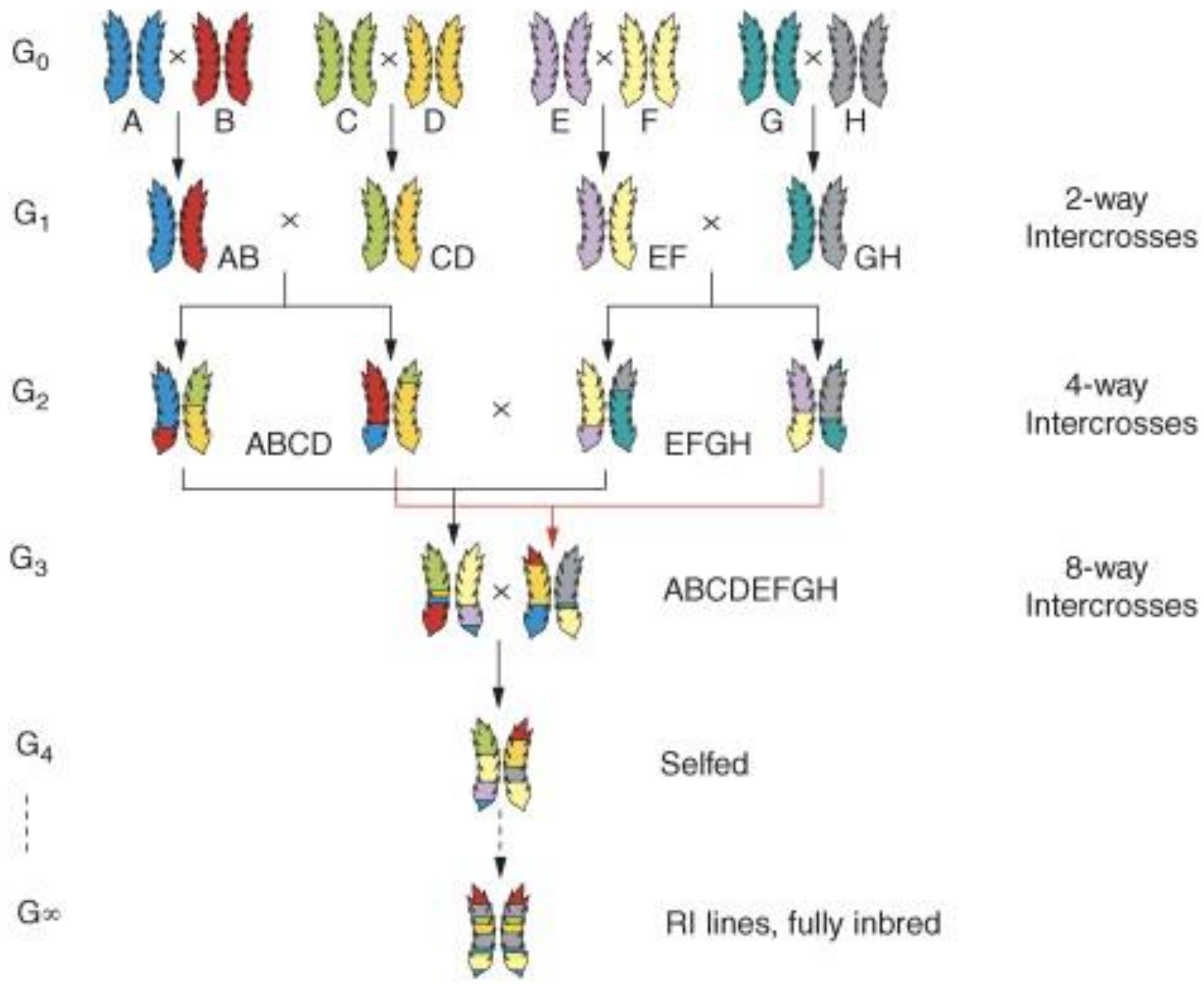
- Increasing no-till cropping.
- Concerns over fungicides.
- Climate change.
- Maize-wheat rotations.

So far, FHB epidemics in the UK have been relatively rare: it is only an issue every few years. However, several factors listed to the left may be contributing to an increase in risk.



Area cultivated with maize for stock feeding in England. *Data sourced from DEFRA.*

MAGIC populations



Traditionally, resistance to FHB (like the genetic basis of other interesting phenotypes) has been studied using panels of wheat varieties or bi-parental mapping populations. The multi-parent advanced generation intercross (MAGIC) population based on eight UK elite winter wheat varieties used in this research project provides benefits of both, and also comparatively high resolution, and potential opportunities to follow up on mapped QTLs using residual heterozygosity. The image to the left is a classic illustration of the development process for MAGIC populations. Parent numbers may vary.

Image from Cavanagh, C., Morell, M., Mackay, I., and Powell, W. (2008). From mutations to magic: resources for gene discovery, validation and delivery in crop plants. Curr. Opin. Plant Biol. 11, 215–221. doi: 10.1016/j.pbi.2008.01.002

Field trial methods for wheat and FHB

See below for an illustration of the field trials used to gain phenotypic data. These are typical in research projects, commercial breeding, and testing for variety registration.

Lines from the population are sown in small plots, often bordered by barley (for clear visual distinction) and often irrigated, as shown above.

The flowering time of each plot is recorded, as this is a major factor in Fusarium infection. Usually, as a minimum, height is also recorded.

There are two main methods of inoculation: spraying with spores at the suitable growth stages (top) or natural build-up of spores on maize residue.

The level of symptoms in each plot is observed and recorded, using one or more of several scales. A 1-9 scale of overall infection is a classic.

Field trial locations

Testing the NIAB MAGIC elite winter wheat population for FHB resistance

Field trials for this project took place in various locations throughout Europe, to provide replication and data from different environments.

Map produced with google.com/maps

Preliminary analysis

Data redacted. Please refer to the forthcoming thesis or contact the author.

Image: Adobe Stock

Institutional acknowledgements

Field trials
- NIAB, especially Genetics and Breeding, Plant Pathology, and the field trials team.
- University of Hohenheim, State Plant Breeding Institute, Research Group Wheat.
- Saaten Union, Moosburg Trial Station.
- SECOBRA Recherches.
- Norwegian University of Life Science, Faculty of Biosciences.

Funding
- BBSRC.
- University of Cambridge, Department of Plant Sciences.
- Cambridge Commonwealth, European & International Trust
- Magdalene College.
- Cambridge Philosophical Society.

For individual acknowledgements please see the forthcoming thesis.

Personal interdisciplinary questions

A number of interdisciplinary topics and questions that I'm curious about alongside my research: I'd be delighted to hear from other GFS IRC members.

1) Poor public knowledge and understanding of plant disease. *Can impact for example funding.*
2) Large potential for contributions from fundamental and interdisciplinary applied research:
   - Better understanding of genetics. *E.g. what about epigenetics?*
   - Refinement of research methods. *E.g. QTL analysis (or more accurate alternatives!) and downstream research.*
   - Mechanisation and digitisation of screening methods. *E.g. why am I still standing in the field, estimating overall symptom levels by eye, and recording them with pencil & paper?*
3) The wider view of food security.
   - Required increases in wheat production.
   - Increasing reliance on a small number of food crops, including wheat.

There are some shocking numbers on this for example from FAO, and insightful research for example from CIAT (for interactive illustrations see https://ciat.cgiar.org/the-changing-global-diet/).


Image: Adobe Stock