Institution: University of East Anglia		
Unit of Assessment: 6 - Agriculture, Food and Veterinary Sciences		
Title of case study: Improving global crop disease diagnosis to reduce economic loss and improve food security		
Period when the underpinning research was undertaken: 2012 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof. Sophien Kamoun FRS returned to UoA5	Group Leader and Professor, The Sainsbury Laboratory	2007 - present
Period when the claimed impact occurred: January 2016 – December 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Kamoun's research resulted in novel genomics-based tools *Field Pathogenomics* (sequencing technology), and *OpenWheatBlast* (a web platform) that enabled the rapid and accurate diagnosis of a specific strain of devastating wheat blast, originating from wheat imported from South America. *Field Pathogenomics* has subsequently diagnosed further crop disease outbreaks. The impact of this research was:

1) Immediate changes to farming practice in affected areas in Bangladesh preventing most severe crop losses and minimising the consequent humanitarian and societal disaster;
2) Rapidly improved biosecurity measures that included capacity building in Bangladesh and more globally (Australia, Ethiopia, Europe, India and the UK) to alleviate yield and associated economic losses, by preventing the further spread of emerging crop diseases, such as wheat blast.

2. Underpinning research

Research focused on the rapid diagnosis and subsequent control of plant diseases, and the development and implementation of open science approaches to counteract emerging disease threats.

Plant diseases are an ever-present danger to ensuring global food security. New crop diseases are increasing in their spread and severity, and climate change and globalisation enable viruses, bacteria and fungal pathogens to move rapidly across the world. Diseases that affect staple cereal crops – such as wheat and rice – are particularly concerning, because these crops provide about 20% of dietary calories for humankind. Plant diseases are also difficult to diagnose accurately and are very hard to control. The developing world relies on well-resourced plant breeding programmes to develop disease-resistant varieties, and application of large amounts of fungicides. Yet, even with these interventions crop losses due to disease remain around 30% per annum. In low-income countries, crop disease can be truly devastating, threatening livelihoods and causing food insecurity. These concerns are so significant that the United Nations declared 2020 the 'International Year of Plant Health'.

The **Kamoun** laboratory developed a novel diagnostic approach; *Field Pathogenomics*. By carrying out transcriptome sequencing directly from diseased plant tissue, diseases could be diagnosed accurately, and very rapidly. *Field Pathogenomics* therefore enables rapid molecular genetic evaluation of previously resistant wheat varieties, that may have been overcome by new virulent pathogen strains. This method does not require microbial culturing and purification, speeding up the diagnostic procedure - *Field Pathogenomics* can be completed in six weeks from field collection to posting an analysis report, compared to traditional approaches that take two-three months [**R1**]. The Kamoun laboratory made the *Field Pathogenomics* toolkit openly available.

In 2016, the wheat crop in Bangladesh failed dramatically due to a completely new disease to Asia, and farmers resorted to burning their crops to limit its spread. Wheat is the second largest food crop in Bangladesh after rice, having grown from ~0.1 million tonnes (t) in the 1970s to 1.4 million tonnes production in 2015. The diseases devastated 15,000 hectares of wheat (~16% of cultivated area) in 8 districts, with yield losses of up to 100%. Kamoun worked with local collaborators and led an international team to rapidly collect diseased samples from the field, applying *Field Pathogenomics* to identify the disease-causing agent. This research identified that the disease was caused by a single genotype (clone) closely related to the South American population of the wheat blast pathogen *Magnaporthe oryzae*, and that the pathogen was most likely introduced to Bangladesh from South America via infected wheat shipments [**R2**]. A distinctive and vital research step was Kamoun initiating the start-up, development and early adoption of the OpenWheatBlast web platform. Vital sequencing data and information donated from more than 30 scientists from across the globe (including the UK, France, Bangladesh, Australia and Brazil) was released immediately via this platform, the first example of an open science response to a plant health emergency [**R2, R3**]. Kamoun's experience of identifying the Blast pathogen, and the use of *Field Pathogenomics* and Open Science significantly contributed to the Global Surveillance System (GSS) concept published in Science. These tools are corner stones for an early response systems outlined in this seminal publication [**R4**].

3. References to the research

UEA authors are in bold.

R1 'Field pathogenomics reveals the emergence of a diverse wheat yellow rust population'.
Hubbard. A, Lewis. C, **Yoshida. K**, Ramirez-Gonzalez.R, Vallavieille-Pope.C, Thomas. J, **Kamoun. S**, Bayles.R, **Uauy. C**, **Saunders. D**
Genome Biology, **2015,** vol.16, no. 23, DOI: 10.1186/s13059-015-0590-8

R2 'Emergence of wheat blast in Bangladesh was caused by a South American lineage of Magnaporthe oryzae'.
Islam, M.T., Croll, D., Gladieux. P, **Kellner, R**., **Win, J**. […] **Kamoun, S**.
BMC Biology, **2016**, vol. 14, no. 84, DOI: 10.1186/s12915-016-0309-7

R3 'Plant health emergencies demand open science: Tackling a cereal killer on the run'.
Kamoun S, Talbot NJ, Islam MT
PLoS Biology, **2019**, vol. 17, no.6. DOI: 10.1371/journal.pbio.3000302

R4 'A global surveillance system for crop diseases'.
Carvajal-Yepes, M., Cardwell, K., Nelson, A., Garrett, K.A., Giovani, B., **Saunders, D.G.O**., **Kamoun, S**., Legg, J.P., Verdier, V., Lessel, J., Neher, R.A., Day, R., Pardey, P., Gullino, M.L., Records, A.R., Bextine, B., Leach, J.E., Staiger, S., Tohme, J.
Science, **2019**. 364:1237-1239. DOI: 10.1126/science.aaw1572

Funding:
Project: *Development of novel blast resistant wheat varieties for Bangladesh by genome editing.*
Co-I: **Kamoun, S**. Funder: BBSRC-GCRF. Grant value: GBP603,518 (GBP420,600 to UEA).
Dates: May 2017 – Aug 2018. https://gtr.ukri.org/projects?ref=BB%2FP023339%2F1

Project: *Retooling plant immunity for resistance to blast fungi.*
PI: **Kamoun, S.** Funder: ERC-ADG - Advanced Grant.
Grant value: EUR2,491,893 (EUR1,874,187 to UEA). Dates: Sep 2017 – Aug 2022.
https://cordis.europa.eu/project/id/743165

4. Details of the impact

The invention of *Field Pathogenomics* crop disease diagnostic methodology and the establishment of an open-source platform; 'OpenWheatBlast' by Kamoun at UEA [**R1** & **R2**] has transformed plant pathogen diagnosis by providing tools that enable a quick response time to tackle crop disease disasters. This is especially important in low-income countries where growing populations and global warming threaten food security. The International Maize and Wheat Improvement Center (CIMMYT) is responsible for maintaining the health of crops that are responsible for 20%

of global calories. The Director of the Global Wheat Program, CIMMYT states that "*The collaboration between CIMMYT and Prof. Kamoun will continue to be vital as global wheat production faces rapidly changing trans-boundary disease threats. The work to date is a blueprint for how we need to respond to crop disease outbreaks in future*" [**S1**]. Kamoun's work has achieved impact at multiple levels, including reducing the economic impact on Bangladeshi farmers [**S2**]. The Agriculture Minister of Bangladesh states "*The impact of this work has therefore been very considerable in Bangladesh. The open and transparent way in which the data was shared and scientists from Bangladesh were trained was also commendable. Professor Tofazzal Islam* [The Director of the Institute of Biotechnology and Genetic Engineering, IBGE] *has been an important leader in combatting wheat blast disease and his ongoing collaboration with Professor Kamoun … has had an important and enduring impact on wheat production in this region*" [**S3**]. In addition, Kamoun's research has informed international strategies to avoid and combat plant disease disasters [**S6, S7, S8**] (described in detail below).

1) Changes to farming practice in Bangladesh, reducing economic loss.
The wheat blast outbreak diagnosed by Kamoun threatened the livelihoods of ~3 million farmers and affected 15,000 hectares of wheat in 2016. It was a direct threat to food security for the 160 million population of Bangladesh, a low-income country, with a highly distributed, resource-poor farming community. The impact of Kamoun's identification of the precise strain and origin of this pathogen, and open sharing of this information via OpenWheatBlast is recognised by The Minister of Agriculture of Bangladesh who stated that '*Knowing this information meant that we were able to draw an effective disease control strategy for Bangladesh to try and limit the spread of the disease*" [**S3**]. The strategy taken included:

a.) Effective pesticides: The Director of IBGE, Bangladesh reported that: *'Identifying the pathotype of the diseases…allowed effective, specific fungicides that had been used in South America to be provided as management options for farmers… The* [Bangladeshi] *government suggested farmers change from their usual pesticides and to use specific pesticides, Nativo (Trifloxystrobin and Tebuconazole) for controlling the wheat blast outbreak. This helped to restrict the negative financial and societal impacts of the pathogen by significantly lowering wheat yield loss*' [**S4**].

b.) Reduction in the amount of wheat grown in Bangladesh to minimise the spread of the disease [**S4, S5**]: The Director of IBGE stated that *'…wheat cultivated area in the blast affected districts was reduced by 52% because the* [government] *recommended that farmers stop growing wheat and switch to the cultivation of alternate crops such as boro-rice, maize,* [and] *lentil'* [**S4**].

c.) Implementation of crop rotation practices: '…*the Bangladesh government provided new advice to farmers suggesting that they practice crop rotation… and to cultivate legume or oilseed crops in the wheat blast infected regions for at least three years'* [**S4**]. A local farmer affected by the wheat blast outbreak acknowledged that '*I didn't* [know what caused the disease] *and I burned my entire wheat field.* [From the scientists' research] *now I know the disease name and what causes it.* [I] *got training including farming practice and which fungicide* [is best] *to use… Now, I mostly cultivate rapeseed and onion* [and] *I grow a little amount of wheat'* [**S5**].

d.) Employing resistant wheat strains: The Minister of Agriculture in Bangladesh reported that "*We were also able to draw on knowledge of where this disease had occurred previously in South America and work with the International Maize and Wheat Improvement Centre (CIMMYT). The research work therefore meant that we could attempt to deploy new, resistant wheat varieties…*" [**S3**]. CIMMYT translated the knowledge they had gathered from previous Bolivian field trials with ~4500 wheat varieties, to Bangladesh. A new wheat variety (BARI Gom 33) with resistance to the wheat blast strain in Bangladesh was trialled and subsequently released [**S1, S2, S3**]. Bangladesh's national seed board approved this variety for dissemination in 2017, and by 2017-18, the Bangladesh Wheat Research Council had provided BARI Gom 33 seeds for multiplication, and on-farm demonstration in blast prone districts, established by the Department of Agricultural [**S2**]. CIMMYT's Director of the Global Wheat Program stated that: *'…the impact of Prof. Kamoun's work in Bangladesh has been considerable. It has enabled a rapid response to an emerging crop disease that immediately threatens food security in a low-income country. The fact that resistant wheat lines are already deployed in the region, is because of this rapid international response, catalysed by Prof. Kamoun's leadership and commitment to open science.'* [**S1**]. This resistant wheat line is estimated to provide a 5.1% increase in yield and ex-ante economic benefits of the dissemination and uptake of the newly approved BARI Gom 33, of between USD230,000 – USD1,600,000 (September 2019) [**S2**].

2. Informing international Biosecurity measures to prevent global spread of emerging crop diseases, thereby alleviating yield losses.
The appearance of wheat blast disease in Bangladesh in 2016 was of global concern. As Director of the Global Wheat Program at CIMMYT states: *'It also presents the potential for spread to the largest wheat producing regions in the Indian sub-continent…*[and] *is therefore of enormous concern to global food security'* [**S1**]. Kamoun's research enabled a number of measures to ameliorate this global threat, including the adoption of new biosecurity measures on a global stage. The Director of IBGE who worked with Kamoun states that '*Bangladesh and many countries also stopped the import of wheat from South American Wheat Blast affected countries. Our transcriptomics data, available in OpenWheatBlast Framework Website also enabled us to develop specific primers for detection of this Wheat Blast fungus. More recently, we used this genomics information to develop a rapid diagnostics system based on the CRISPR-Cas12a enzymes. Subsequently, a molecular diagnosis protocol based on our research findings has been used in quarantine and surveillance practices to identify and control this pathogen in wheat that is imported in Bangladesh and grown in the field*' [**S4**].

a.) Wheat Blast response in India: The Head of Wheat Pathology at CIMMYT describes how following Kamoun's identification of the wheat blast pathogen, *'*[t]*o avert further spread of wheat blast beyond Bangladesh, the Indian Council for Agricultural Research (ICAR) has implemented in 2017 a temporary 'wheat holiday' […], documentation of the occurrence of the wheat blast strain in Bangladesh, particularly in the Indian border area, prompted these actions which served as preventive measures to preempt disastrous outbreaks. With colleagues, we demonstrated how alternative crops to wheat can alleviate the economic burden of the wheat blast holiday in West Bengal'* [**S6a**]. CIMMYT scientists calculated the gross return from wheat cultivation in 287,000 hectares across nine districts of West Bengal was USD31,600,000 [**S6b**, p.9]. CIMMYT scientists recommended to the Indian Government that farmers in all border districts should cultivate economically viable legumes such as gram (chickpea), urad (an Indian pulse), rapeseed, mustard, and potatoes, instead of wheat [**S4, S6**]. This decision was estimated to provide the same gross economic return to the region while disease-control strategies were developed [**S4, S6**].

b.) Wheat Blast response in Australia: Wheat is critical component to Australia's economy. It produces 25-30 million tonnes of high-quality grain per annum, and its listed in the top 10 Australian exports (by value). Australia places great emphasis on biosecurity and disease management. The emergence of wheat blast, first in South America, and then Bangladesh prompted questions about the impact wheat blast could have if it arrived in Australia. A national response involved pre-emptive wheat breeding and evaluation of wheat blast resistance in locally adapted wheat germplasm. A Professor in the Research School of Biology at the Australian National University states that *"Field Pathogenomics has provided us with very valuable information on pathogen evolution and movement over growing seasons. …Professor Kamoun's contributions have been significant in enabling Australia to carry out pro-active planning for a potential wheat blast incursion with pre-emptive attempts to breed disease resistance and thereby safeguard wheat production. In addition, the methods developed in his laboratory have been used widely against a wide range of diseases of economic significance in Australia*" [**S7**].

c.) Wheat Blast Response in Zambia: Recently, wheat blast emerged in Zambia – the first report of the disease in Africa. CIMMYT immediately contacted Kamoun and UEA colleagues (November 2020), to characterise the wheat blast pathogen and determine its origin and genetic relatedness [**S1, S6**]. This work demonstrates the impact of *Field Pathogenomics* and OpenWheatBlast initiatives on the wider wheat breeding community, who are turning to Kamoun, for leadership in controlling the spread of this wheat disease.

d.) A New Technology for Wheat Rust surveillance in Ethiopia & Europe: *Field Pathogenomics* has become an integral part of a plant disease surveillance programme called MARPLE diagnostics. A former Postdoctoral Researcher from Kamoun's Laboratory (currently a Project Leader at the John Innes Centre (JIC)) collaborates in a large international partnership including 7 industrial partners to further developing the *Field Pathogenomics* methodology [**S8**].

They study the global spread of wheat yellow rust pathogen strains, generating unprecedented data resolution about the global diversity of this pathogen. They have used many innovative ideas from *Field Pathogenomics* methodologies to create a modified version called Mobile And Real-time PLant disEase (MARPLE) diagnostics, swapping reliance on large, immobile Illumina sequencing technology for a portable nanopore MinION sequencer, ensuring capacity building as MARPLE can be used directly in resource-poor regions such as Ethiopia - the largest wheat producer in sub-Sahara Africa - but a high priority country for yellow rust surveillance. Total loss estimates for yellow rust in Ethiopia is approximately USD250,000,000 [**S8**]. The precise pathogen/s causing these problems was unknown resulting in further losses caused by ineffective use of pesticides. The Principal Investigator states '*training and support for integration of the methodology within the wheat rust early warning system in Ethiopia is underway, however, this is […] on hold due to covid-19'* [**S8**].

The implementation of the *Field Pathogenomics* system in the UK cereal pathogen virulence survey (UKCPVS) has led to changes in the naming system for wheat rust races in the UK that is now much more reflective of the genetic diversity of strains [**S8**]. Training events for researchers leading rust surveillance programs across Europe have occurred and work is underway to integrate the MARPLE diagnostics system into UK cereal pathogen virulence survey.

In summary, Kamoun's research has had a global impact on food security, by changing farming practice and improvements in biosecurity measures to reduce losses of staple crops.

5. Sources to corroborate the impact

S1 Letter from Director, Global Wheat Program, CIMMYT (24.1.21).

S2 Economic benefits of blast-resistant biofortified wheat in Bangladesh: The case of *BARI Gom 33*, Khondoker *et al* (2019), Crop protection 123 45-58.

S3 Letter from the Minister of Agriculture in Bangladesh (8.2.21).

S4 Letter from Professor and Director, Institute of Biotechnology and Genetic Engineering (IBGE), Bangladesh (5.2.21).

S5 Questionnaire responses from farmers in Bangladesh.

S6 (a) Letter from Head-Wheat Pathology, Global Wheat Program, International Maize and Wheat Improvement Center (CIMMYT) (19.1.21); (b) Article from Plos One Journal (2019) - Averting Wheat blast by implementing a 'wheat holiday': In search of alternative crops in West Bengal, India (p.3).

S7 Letter from Professor in the Research School of Biology at the Australian National University (ANU) (2.2.21).

S8 (a) Letter from Group Leader, John Innes Centre and developer of MARPLE diagnostics (2.2.21); (b) Article from BMC Journal (2019) MARPLE, a point-of-care, strain-level disease diagnostics and surveillance tool for complex fungal pathogens (p.3).