Open science to tackle a cereal killer on the run

Sophien Kamoun[1], Nicholas J. Talbot[1], M. Tofazzal Islam[2]

[1]The Sainsbury Laboratory, University of East Anglia, Norwich Research Park, Norwich, NR4 7UH, United Kingdom; [2]Department of Biotechnology, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh.

Outbreaks of emerging plant diseases and insect pests are increasing at an alarming rate threatening the food security needs of a booming world population. The role of plant pathologists in addressing these threats to plant health is critical. This report elaborates our personal experience with the appearance in Bangladesh of a destructive new fungal disease wheat blast. Here we recap our experience and stress the importance of open science platforms and crowdsourced community responses in tackling emerging plant diseases. Benefits of the open science approach include recruitment of multidisciplinary experts, application of cutting-edge methods and timely replication of data analyses to increase the robustness of the findings.

When we think of the densely populated south Asian country of Bangladesh, we don't think of wheat. Yet the wheat crop has grown to become the second largest food crop in the country, after rice, helping Bangladeshi farmers feed their 160 million countrymen. Over the years, wheat production has grown from 0.5 to 1.4 million tons in 2015. Domestic consumption had also risen to ~6 million tons per annum with wheat being an important ingredient of Bengali cuisine. To meet the gap, Bangladesh has imported wheat in large amounts—and still does—but in this instance, this is where the problems began.

The wheat crop in Bangladesh was generally viewed as relatively disease free. Many of the usual wheat diseases familiar to farmers elsewhere in the world, such as Septoria leaf blotch and rust diseases, were seldom reported. Many wheat farmers managed to grow a healthy crop with little need to spray fungicides. But in February 2016, the crop failed. Dramatically. An untimely rainfall followed by a sudden outbreak of a new fungal disease devastated 15,000 hectares of wheat in 8 districts with yield loss of up to 100% (Islam et al. 2016). Some farmers lost the entire crop and thus skipped harvesting. Others were forced to burn their sterile fields to avoid further spread of the pathogen. Unusually hot and humid climatic conditions due to untimely rain fall further exacerbated the epidemic (Islam et al. 2019).

As news of this destructive outbreak spread out, we spontaneously volunteered to apply the latest genomics technology to identify the precise nature and origin of the culprit. Thanks in large part to the Facebook Messenger app, MTI and SK coordinated the rapid collection of diseased samples and transcriptome sequencing directly from diseased plant tissue. This approach, known as field pathogenomics, enables swift genetic diagnostic of a pathogen population without time consuming culturing and purification of the fungus (Hubbard et al. 2015). We elected to publicly release the sequence data of our samples through an open science web platform that we called OpenWheatBlast. NJT and other plant pathologists

volunteered unpublished genome sequence data of the wheat blast pathogen to add to our data and the single genome sequence that was publicly available prior to OpenWheatBlast. Two population geneticists, Daniel Croll and Pierre Gladieux, independently volunteered to analyze the data. Both of their conclusions were unequivocal. The Bangladeshi strain of the wheat blast fungus is closely related to the South American population of the wheat blast pathogen *Magnaporthe oryzae* (Syn. *Pyricularia oryzae*). Based on phylogenomic analyses of these independent groups and our laboratory tests, we drew the logical conclusion that the pathogen was introduced to Bangladesh from South America (Islam et al. 2016). This scenario is not that surprising. About half a year before the outbreak, a scandal broke out in Bangladesh following investigative reporting by local science journalists, notably Iftekhar Mahmud, on imported wheat from Brazil that was described as "rotten and infected with fungi" (Islam and Mahmud, 2015). Given that wheat blast is a seed transmitted disease, it remains plausible that infected wheat shipments from 2015 somehow made it to agricultural fields a few months later.

The wheat blast epidemic is emblematic of a rise in emerging plant diseases (Fisher et al. 2012; Inoue et al., 2017; Savary et al. 2019). As the world is becoming more and more interconnected and global trade spreads, plant pathogens are increasingly invading new continents. Climate change and the propensity of these pathogens to jump from one host to another only exacerbate this problem. When emergencies such as the wheat blast outbreak take place, we would expect scientists to immediately release the data and recruit experts. Sometimes this does happen. But we were taken aback by a rather hostile response from some quarters of the community to our rallying cry for international experts to volunteer their time, funds and resources to help Bangladesh address the emergency. Fortunately, the agriculture minister of Bangladesh, Matia Chowdhury, was extremely supportive. After listening to MTI the day after the launch of OpenWheatBlast, she was full of pride and praise for the team's umprompted engagement and call to arms. Nonetheless, this progressive attitude towards open science remains somewhat exceptional among decision makers and scientists alike. Traditional plant pathologists work at a pace that is often set by their desire to publish papers and stake claims to priority in discovery. Research groups hold on to data, are careful to withhold findings until they can submit a manuscript, and are not necessarily forthcoming in sharing strains and host varieties. What the wheat blast outbreak has shown is that this situation cannot stand. When a crisis is underway, it needs a swift, coordinated response. If researchers studying Ebola or Zika virus acted in such an unforthcoming manner they would be jailed—and rightly so. The response to outbreaks of human diseases are immediate and exemplified by open data, public information, and a scientifically-informed, coordinated response. This is clearly what is required for wheat blast and other emerging crop diseases that threaten food security. It is for this reason that the International Society for Plant Pathology (ISPP) has recently proposed a code of ethics, which our experience suggests is urgently needed (Anonymous, 2018).

Three years after the 2016 outbreak—just a few days before we wrote this article—we visited wheat fields in Meherpur near the Bangladesh-Indian border. This region is now viewed as a hot spot of wheat blast and legitimate concerns that the pathogen would spread over to India and elsewhere remain (Islam et al. 2019). Meherpur looks different now than it did prior to the 2016 outbreak. Where widespread wheat cultivation took place, there are now many fields of tobacco. The tobacco companies moved in quickly after the wheat blast outbreak,

promising farmers guaranteed prices and up-front cash incentives. So where a food crop was once sown, there is now a drug crop. Another consequence of blast disease, with the stench of tobacco curing houses in the air and racks of drying leaves, through which children play. A sorry sight.

Although no outbreak of the magnitude of the 2016 epidemic has taken place yet, the disease has spread to 8 more neighboring districts within a couple of years. It is clear that the pathogen is now well established in Bangladesh (Islam et al. 2019). Wheat blast symptoms are widespread and, in some cases, devastating. It was a powerful and emotional experience for us to stand in the infested fields of Meherpur and hold an empty grainless wheat spike. One of the farmers we visited lost his first sowing in early February 2019 and resorted to harvesting the wheat as fodder long before it set grain. His second sowing at first sight seemed healthy but, despite regular fungicide spraying, signs of wheat blast were evident. As we left Meherpur, a wet weather front that lasted few days was settling in and we could only brace ourselves for an even more dramatic outbreak.

The cultivation of wheat has considerably decreased in the blast affected districts of Bangladesh to about half of 2016 levels. Nearby in India, West Bengal has declared a 3-year "wheat holiday" following reports of wheat blast in 2017 (Islam et al. 2019) and the noticeable switch to tobacco cultivation is particularly perverse in a country so vulnerable to food insecurity. But all is not bad. The finding that the pathogen is of the same genetic stock as South American populations meant that the knowledge gathered in Brazil about forecasting, fungicide treatments, and varietal choices can be immediately applied in Asia. Bangladeshi wheat breeders working with the International Maize and Wheat Improvement Center (CIMMYT) have trialed and released a new wheat variety BARIgom 33, which promises to mitigate the impact of the disease. Other sources of wheat blast resistance, such as the gene *Rmg8*, appear to be effective against a Bangladeshi strain of the fungus (Jensen et al. 2019). Our own approach is to harness the newly developed CRISPR gene editing technology to breed resistant wheat plants. Already, in collaboration with Emma Wallington at the National Institute of Agricultural Botany, our team has generated the first CRISPR bioedited wheat lines and we have initiated disease resistance tests. In parallel, we continue to monitor the evolution of the pathogen. Given that the Bangladesh population appears to be clonal, we need a high-resolution genome map to precisely define any genetic changes. The near-complete genome sequences of four Bangladeshi isolates from 2016 and 2017 that we recently publicly released are a first step in this direction (Win et al. 2019). Throughout these efforts, we pledge to continue to openly share data, analyses and bioresources without restriction and prior to formal publication in journal articles.

The introduction of wheat blast to Bangladesh is a plant health disaster that has already had both economic and societal consequences for a developing country. We hope that our open source response has helped to rally the community towards the common goal of fighting this formidable foe and limiting the damage it can cause in Bangladesh and other countries in the region. Our approach has also raised awareness of donors and policy makers for increased funding. The success of our project could, however, also serve as an example for dealing with any future plant health emergency. Plant pathologists should be more ready to embrace open science, given the marked increase in new disease outbreaks (Fisher et al. 2012; Savary et al. 2019). We can be fairly confident that any crop disease that is present anywhere in the world,

will spread to other areas where climatic conditions allow. Eventually, globalization will trump phytosanitary inspections, however rigorous they may be. We urgently need to be better prepared and to work pro-actively to breed locally adapted varieties against diseases that are not yet present in countries around the world. Because the lesson of wheat blast is that these diseases are coming.

We hope that the friendships and collegiality that has developed among our OpenWheatBlast network will inspire other scientists to openly share their data and work together to make the world a better place for us and future generations.

Acknowledgments

We thank our team and collaborators for their contributions and ideas. Special thanks are due to Md Shabab Mehebub, BSMRAU, Bangladesh, for assistance in making the video clips.

References

Anonymous. A code of ethics for plant health emergencies. The International Society for Plant Pathology (ISPP) December newsletter 2019 http://www.isppweb.org/newsletters/pdf/48_12.pdf

Fisher M.C.; Henk D.A.; Briggs C.J.; Brownstein J.S.; Madoff L.C.; McCraw S.L.; Gurr S.J. Emerging fungal threats to animal, plant and ecosystem health. *Nature* 2012, 484, 186–94.

Hubbard A.; Lewis C.M.; Yoshida K.; Ramirez-Gonzalez R.; de Vallavieilla-Pope C.; Thomas J.; Kamoun S.; Bayles R.; Uauy C.; Saunders D.G.O. Field pathogenomics reveals the emergence of a diverse wheat yellow rust population. *Genome Biol* 2015, 16, 23.

Inoue Y.; Vy T.T.P.; Yoshida K.; Asano H.; Mitsuoka C.; Asuke S.; Anh V.L.; Cumagun C.J.R.; Chuma I.; Terauchi R.; Kato K.; Mitchell T.; Valent B.; Farman M.; Tosa Y. Evolution of the wheat blast fungus through functional losses in a host specificity determinant. *Science* 2017, 357, 80.

Islam M.T.; Croll D.; Gladieux P.; Soanes D.M.; Persoons A.; Bhattacharjee P.; Hossain M.S.; Gupta D.R.; Rahman M.M.; Mahboob M.G.; Cook N.; Salam M.U.; Surovy M. Z.; Sancho V.B.; Maciel J.L.N.; NhaniJúnior A.; Castroagudín V.L.; de Assis Reges J.T.; Ceresini P.C.; Ravel S.; Kellner R.; Fournier E.; Tharreau D.; Lebrun M.H.; McDonald B.A.; Stitt T.; Swan D.; Talbot N.J.; Saunders D.G.O.; Win J.; Kamoun S. Emergence of wheat blast in Bangladesh was caused by a South American lineage of *Magnaporthe oryzae*. *BMC Biol* 2016, 14, 84.

Islam M.T.; Kim K.H.; Choi J. Wheat blast in Bangladesh: the current situation and future impacts. *Plant Pathol J* 2019, 35, 1-10.

Islam R.; Mahmud I. 2015. Low quality wheat imported from Brazil. *Prothom Alo* https://bit.ly/2VxWCxF

Jensen C.; Tosa Y.; Islam M.T.; Talbot N.J.; Kamoun S.; Saunders D.G.O. *Rmg8* confers resistance to the Bangladeshi lineage of the wheat blast fungus. *Zenodo* 2019 http://doi.org/10.5281/zenodo.2574196

Savary, S., Willocquet, L., Pethybridge, SJ.., Esker, P., McRoberts, N., Nelson, A. The global burden of pathogens and pests on major food crops. *Nat Ecol Evol* 2019 3, 430.

Win J.; Chanclud E.; Reyes-Avila C.S.; Langner T.; Islam T.; Kamoun S. Nanopore sequencing of genomic DNA from *Magnaporthe oryzae* isolates from different hosts. *Zenodo* 2019, http://doi.org/10.5281/zenodo.2564950

Funding

SK and NJT acknowledge funding from the Gatsby Charitable Foundation, European Research Council, the BBSRC, and the Global Challenges Research Fund (BB/P023339/1). MTI acknowledge funding of the Krishi Gobeshona Foundation, Bangladesh (KGF-TF 50-C/17) for funding.

Image 1. Wheat infected with the blast fungus, February 24, 2019, Meherpur, Bangladesh.