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Opinion Article

The rise and rise of emerging infectious fungi challenges food security and ecosystem health

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ABSTRACT

This article highlights some of the more notable persistent fungal diseases of our times. It draws attention to the emergence of new fungal pathotypes infecting food staple crops, due largely to modern agricultural practices, and to nascent fungal diseases decimating frog populations worldwide and killing hibernating bats in Northern USA. We invoke use of the basic disease triangle concept to highlight the "missing" data, with regards to pathogen and host biology and to the various environmental parameters which may dictate disease spread. Given these data "voids" we comment on the implementation of policy. We conclude with a series of recommendations for improved disease surveillance and reporting, the need for greater public awareness of these issues and a call for greater funding for fungal research. In so doing, we have exploited *Magnaporthe oryzae* and *Batrachochytrium dendrobatidis* as exemplar emerging infectious fungi. Our aim is to highlight the impact of emerging and emergent fungi on food security and, more broadly, ecosystem health.

1. Introduction

The global, social, economic and, indeed, potential impact of fungi is huge. Thus far, it has been estimated that we have identified only about 0.2–6 % of fungi predicted as extant in our biosphere (Hibbett *et al.*, 2011). Of these, a select few are highly exploited, as edible mushrooms and in food production, or as producers of industrial enzymes and pharmaceuticals. Less obviously, fungi are intrinsic to recycling organic matter and promoting plant growth. For example, the arbuscular mycorrhizal glomeromycete fungal symbionts are present in 90 % of land plants (Maillet *et al.*, 2011; Parniske, 2008) and are fundamental to plant health. Conversely, pathogenic fungi challenge food security by decimating our harvests, causing widespread malnutrition and starvation (Royal Society Report, 2009; Pennisi, 2010; Skamnioti and Gurr, 2009), they threaten extinction of wildlife, such as species of amphibians (Fisher *et al.*, 2009) and bats (Blehert *et al.*, 2009) whilst human pathogenic fungi cause debilitating disease or acute or fatal infections, particularly in immunocompromised patients (Butler *et al.*, 2009).

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2. The complement of fungi and one oomycete under discussion

We review, albeit briefly, our state of knowledge with regards to three specific diseases of three significant staple food crops, notably rice blast, wheat stem rust and late blight of potato, the so-called "green pathogens". These are, respectively the Ascomycete *Magnaporthe oryzae* (*Mo*, Wilson and Talbot, 2009); Basidiomycete *Puccinia graminis* (*Pg*, Leonard and Szabo, 2005) and Oomycete *Phytophthora infestans* (*Pi*, Fry, 2008; Haas *et al.*, 2009). To this "cauldron of curses" we add the Ascomycete *Geomyces destructans* (*Gd*) (Gargas *et al.*, 2009; Frick *et al.*, 2010), causing white nose syndrome of hibernating bats in USA and the Chytridiomycete *Batrachochytrium dendrobatidis* (*Bd*) causing amphibian chytridiomycosis and affecting over 450 amphibian species (Longcore *et al.*, 1999; Fisher *et al.*, 2009; Kilpatrick *et al.*, 2010), the so-called "red pathogens" (Table 1).

Table 1 – Emerging or persistent fungal (oomycete) diseases, and their respective threat levels. These threat levels are assessed by the disease impact of recent emergence of new virulent races in the green pathogens, as, for example, with *P. infestans* US-8 and Blue 13 (Fry (2008) and Haas *et al.*, 2009); *P. graminis* (Leonard and Szabo, 2005). Early accounts of the green pathogens exist, disease being identifiable by the host symptoms described, as, for example, in during the 1845 Irish potato famine (Haas *et al.*, 2009); with *M. oryzae*, first described in 17th century as "rice fever" (Skamnioti and Gurr, 2009); *P. graminis*, identified from descriptions made in 690 BC (Leonard and Szabo (2005)). New races are, as yet, unknown in the red pathogens. The dates of emergence of the red pathogens are recorded in Table 1, with, for example, *G. destructans* first documented in a photograph taken near Albany New York (Blehert *et al.*, 2009) and *B. dendrobatidis* described in 1998 (Fisher *et al.*, 2009) but recognised later in a *Xenopus laevis* museum specimen preserved in 1938. It is not known, at this stage, as to whether these red pathogens have caused earlier epidemics (designated as ?)

	Emerging?	Persistent but with epidemics?	Threat Level posed by new races
P.infestans	No	Yes (1845 onwards)	High, new races (US-8, Blue 13)
M. oryzae	No	Yes (17thC)	High
P.graminis	No	Yes (690 BC)	High (Ug 99)
G.destructans	Yes (2006)	?	High New races?
B.dendrobatidis	Yes (1998)	? (1938)	High New races?

3. Can we quantify the disease burden inflicted by these microbes?

"Armed and dangerous" – fungi which threaten food security

With regards to wheat, rice and potatoes – these staple crops rank respectively first, second and eighth in terms of the area of global agricultural harvested (millions of hectares) but with potatoes moving up to fourth position due to its production (millions of tonnes) (FAO, 2008). We highlight the disease burden on potatoes for the very particular reason that this crop remains relatively stable in terms of world price fluctuation as there is little international trade in this commodity, due to transport problems. This is in sharp contrast to the fluctuating prices of wheat and rice as evidenced by the huge rise in price of these crops in 2008 and to a lesser extent in 2010, caused partly by climate fluctuations, rampant price speculation and competition for grain for food and fuel (web@foodsecurity.ac.uk). So, what is the cost of disease in terms of loss of crops? Oerke (2006) records that pests and pathogens cause global losses of around 27 % for wheat, 37 % for rice and 40 % for potatoes – this is despite the use of current crop protection practices. Of the various pests and pathogens it is the fungi (and the oomycete *P. infestans*) which cause the most significant losses.

"Active and deadly" – fungi which challenge wild species

While pathogens are not normally recognised as posing a threat of extinction to their hosts owing to density-dependent limitations on the transmission of infection (Anderson, 1979), two phyla of fungi have driven wildlife species extinct and a third threatens future populations. Both the chytrid *Bd* (Crawford *et al.*, 2010) and microsporidian fungi in the genus *Steinhausia* (Cunningham and Daszak, 1998) have been recognised as the aetiological agents that have eradicated their host species; for the former this may number hundreds of species. Concomitantly, the rapidly emerging infection of bats, white nose syndrome (WNS) caused by *G. destructans* is predicted to have a similarly severe impact on affected species (Frick *et al.*, 2010) and the "fungal-like" oomycetes are now known to be widely destructive in vertebrate and invertebrate species; for instance crayfish plague caused by *Aphanomyces astaci* (Alderman *et al.*, 1999). There is now a growing body of evidence that fungi may outrank better-recognised classes of pathogen (bacterial and viral) in the destructive impact that they have on wildlife species while leaving us questioning what underlies this emergent phenomenon.

4. Are these diseases emerging or persistent?

The criteria used to describe emerging infectious diseases (EIDs) are well-defined in human, livestock and wildlife disease but have been used rarely to describe plant disease. There is with one particular exception, that is by Anderson *et al.* (2004), who undertook the first (and only) meta-analysis of EIDs in crops and wild plants. We have exploited their EID descriptors of an increase in disease incidence due to changed geography and/or host range; altered virulence or