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Climate change and mycotoxigenic fungi: impacts on mycotoxin production

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There is interest in the impacts that climate change (CC) factors will have on the infection of staple food commodities by fungal diseases pre-harvest and by spoilage fungi post-harvest and the possible contamination with mycotoxins. It is essential to examine the effect of three-way interactions between elevated CO_2 (350 ppm versus 650–1200 ppm), temperature increases (+2–+5 °C) and drought stress on growth/mycotoxin production by key spoilage fungi in staple food commodities. This paper examines the available evidence on possible impacts on infection of key food commodities by mycotoxigenic fungi and whether mycotoxin contamination will increase or decrease due to CC scenarios. Examples are chosen from aflatoxin and fumonisin contamination of maize and trichothecene producing diseases of wheat. Acclimatization issues and regional effects are considered. The key questions which remain unanswered and the impacts on food security are discussed.

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Introduction

To supply the growing world-wide population with staple foodstuffs such as temperate/tropical cereals and rice requires intensive inputs of fertilisers/pesticides/fungicides/herbicides to obtain the necessary yields. There have been questions about the capacity to provide such additional requirements in the coming 25–50 years [1•]. These have to be produced in the context of the impacts that climate change (CC) scenarios may have on the changes in global weather patterns which could have a profound impact on the production and delivery of enough food [2–4]. CC is expected to have a significant effect on our landscape worldwide and the way we interact with it. For some areas, CC models have projected a marked decrease in summer precipitation and increases in CO_2 (×2–3 existing concentrations) and temperature, which would result in concomitant drought stress episodes.

The European Food Safety Authority (EFSA) has examined the potential impact of CC in Europe and has suggested that effects will be (a) regional and (b) detrimental or advantageous depending on geographical region [1•]. This suggests that in northern Europe the effects may be positive, while the Mediterranean basin may be a hot spot where many effects will be negative, with extreme changes in rainfall/drought, elevated temperatures and elevated CO_2 impacting on food production. Effects of CC on cereals will be significant and detrimental as ripening in southern and central Europe will occur much earlier than at present. This will influence pests and diseases with decreasing yields and increasing mycotoxin contamination. Indeed it has been suggested that CC may be responsible for a 1/3 of the global yield variability in key staple commodities on a global basis [5]. This will have profound impacts on food security in different continents.

On the basis of present available data, atmospheric concentrations of CO_2 are expected to double or triple (from 350–400 to 800–1200 ppb) in the next 25–50 years. This will result in a global temperature rise of between 2 and 5 °C depending on levels of industrial activity. Thus different regions in Europe mentioned previously will be impacted by the increases in temperature of 2–4 °C coupled with elevated CO_2 (650–1200 ppm) and drought episodes having a profound impacts on pests and diseases and ultimately yields [6••,7••]. Similar impacts have been described in other areas of the world, especially parts of Asia, and Central and South America which are important producers of wheat, maize and soya beans for food and feed uses on a global basis [8].

Interactions between elevated CO_2, temperature and drought stress need to be considered together to examine impacts on mycotoxigenic fungi and mycotoxin contamination. The environmental changes occurring now are slowly but steadily shaping the relationship between plant growth and the associated fungal diseases and pest populations. Recent predictions suggest that on a global scale, pests and diseases are migrating to the poles at the rate of 3–5 km/year and the diversity of pest populations will also significantly change and have profound economic impacts on staple food production systems [6••,7••,9••]. While these studies did not focus on mycotoxigenic fungal pathogens, this suggests significant potential impacts on mycotoxin contamination of staple foods/crops. A recent study of wheat diseases and CC suggests that the physiology of wheat is modified when comparing exposure to 390 ppm and 780 ppm CO_2, in terms of leaf physiology and stomatal production on adaxial and abaxial surfaces [10••]. Acclimatization of wheat and *Septoria tritici* blotch (STB) disease and *Fusarium* Head Blight (FHB) resulted in increased severity to these diseases. The effect of elevated CO_2 was more pronounced for FHB than STB. This study did not examine effects on type B trichothecenes (e.g. deoxynivalenol) which would have been interesting. Increases in pest reproduction rates would increase damage to ripening crops (during anthesis in wheat; silking in maize) and facilitate more infection by mycotoxigenic fungi and potential contamination with mycotoxins. However, few studies have examined the impact of these three-way interactions on growth and mycotoxin production by *Aspergillus*, *Penicillium* and *Fusarium* species.

Many of the current predictions and hypotheses towards the real effect of CC on fungal diseases and mycotoxigenic fungi are based on historical or current climatic conditions datasets that predominantly considers interactions between water availability and temperature [1•]. Presently there are very few research studies which have examined the effect of 3-way interactions between these identified environmental factors (temperature, water availability and CO_2) and what changes in terms of the ecophysiology of mycotoxigenic fungi and mycotoxin accumulation might occur [11••,12••,13,14].

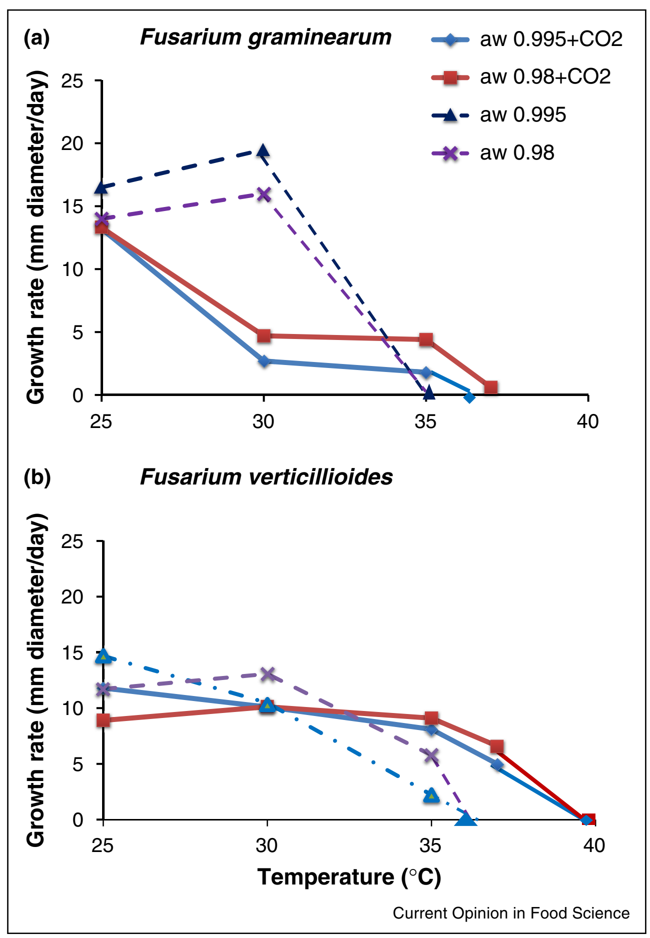
Impact of climate change factors on growth and mycotoxin production

Impact of water activity (a_w) × temperature interactions on growth and mycotoxin production

Over the last three decades we have examined the impact that a_w × temperature factors have on growth and mycotoxin production by a wide range of mycotoxigenic fungi [15–17]. This has included data on the optimum/marginal conditions for growth, mycotoxin production, and the boundary conditions for germination, growth and mycotoxin production *in vitro* and in some cases *in situ* in the key commodities. This has usually shown that the range of a_w × temperature for mycotoxin production is narrower than that for growth. The only exception, to our knowledge, is *Penicillium verrucosum* which grows and produces ochratoxin A under a very similar range of a_w × temperatemperature conditions [18]. However, extreme drought episodes, desertification and fluctuations in wet/dry cycles will have an impact on their life cycles [18].

Magan *et al.* [19] reviewed some of the available ecological data on optimum and marginal interacting conditions of a_w × temperature for growth and mycotoxin production by several mycotoxigenic species which was done by examining effects of drought stress conditions and +3 or +5 °C temperature change. These have now been updated to include more data which has become available [20]. This has shown that mycotoxigenic fungi would normally grow slower and produce, in most cases, similar or lower amounts of mycotoxins. However, in some cases, such as for *Aspergillus flavus*, which is able to grow and produce aflatoxin B_1 (AFB_1) under high temperatures and efficiently colonize maize, groundnuts and tree nuts under drought conditions, the forecasted conditions could be an emerging problem mainly in the Mediterranean and other temperate regions. Studies suggest that there are impacts of CC based on recent surveys in Serbia of maize, where in 2009–2011 seasons no aflatoxin contamination occurred. Prolonged hot and dry weather in 2012 resulted in 69% of samples contaminated with aflatoxins [21]. Similarly, in Hungary, it has also been shown that an increase in aflatoxins may be due to CC conditions [22]. However, there are only a few concrete examples of such incidences where CC factors have been implicated.

Figure 1



Effect of different temperatures × 350 ppm (dotted lines) and 1000 ppm CO_2 (solid lines) at 0.995 and 0.98 water activity (a_w) on growth of **(a)** *F. graminearum* and **(b)** *F. verticillioides* on a milled wheat agar.