Mycotoxin risks under a climate change scenario in Europe

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Abstract

As determined by the Intergovernmental Panel on Climate Change, warming of the climate system is unequivocal and has been associated with rising sea levels, diminished amounts of ice and snow and increasing oceanic and atmospheric temperatures. Such climate changes have a significant impact on stages and rates of toxigenic fungi development and can modify host-resistance and host-pathogen interactions, influencing deeply also the conditions for mycotoxin production that vary for each individual pathogen. Moreover, the new combinations mycotoxins/host plants/geographical areas are arising to the attention of the scientific community and require new diagnostic tools and deeper knowledge of both biology and genetics of toxigenic fungi. In this review, it is underlined that an extension of the aflatoxin contamination risk in maize in South and Central-Europe is highly likely in the next 30 years, due to favorable climatic conditions to the growth of *Aspergillus flavus*. Moreover, the mycotoxigenic *Fusarium* species profile on wheat in Europe is in continuous change in Northern, Central and Southern-Europe with, in particular, a worrisome growing contamination of *F. graminearum* in the Central and Northern Europe.

Keywords: Food safety, *Aspergillus flavus*, aflatoxin B_1, *Fusarium graminearum*, deoxynivalenol

1. Introduction

Among the emerging issues in food safety, the increase of plant diseases associated to the occurrence of toxigenic fungal species and their secondary metabolites is of major importance. These fungi can synthesize hundreds of different secondary metabolites, including mycotoxins, low molecular weight toxic compounds, that pose a serious risk to human and animal health worldwide. Cereals are often the most severely affected crops, and because they are a staple food for a large portion of humanity, mycotoxins are the most prevalent food-related health risk in field crops. Worldwide scientific and economic focus on mycotoxins also results from the significant economic losses associated with their negative impact on human health, animal productivity, and international trade (Windel, 2000; Wu, 2015).

The mycotoxins of greatest concern to food and feed safety are produced by several fungal genera of filamentous fungi, among which, primarily, *Aspergillus*, *Fusarium* and *Penicillium,* that include several species producing the mos timportant ones worldwide: aflatoxins, fumonisins, ochratoxins, trichothecenes, and zearalenone (Marasas, Gelderblom, Shephard, & Vismer, 2008).. These fungi colonize a large variety of crop species and can adapt to a wide range of environmental conditions. Knowledge of environmental factors which affect the ability of fungi to grow, survive, and interact with plants is important in order to better understand the variation in the population structures of mycotoxigenic fungi, their interactions with crop plants, and their ability to produce mycotoxins. Because climate can profoundly affect growth, distribution, and mycotoxin production in fungi, climate change has the potential to increase the risks that mycotoxigenic fungi pose to food and feed safety (Medina, Gonzalez-Jartin, & Sainz, 2017). The appearance of new mycotoxin-commodity combinations is of further concern and provides evidence for the emergence of new fungal genotypes with higher levels of aggressiveness and altered mycotoxin production.

2. Climate change and the risk of aflatoxin and *Aspergillus* contamination in Europe

Aflatoxins (AFs) are potent carcinogens which include four major structural analogues: AFB1, AFB2, AFG1, andAFG2. The International Agency for Research on Cancer (IARC) has classified AFB1 as a Group 1 carcinogens, i.e. carcinogenic to humans (IARC, 1993). In addition to hepatocellular carcinoma, aflatoxins are associated with occasional outbreaks of acute aflatoxicoses which lead to death shortly after exposure (Azziz-Baumgartner, Lindblade, & Gieseker, 2005). Aflatoxins are produced in diverse agricultural products by several species of *Aspergillus*, but the two species of greatest concern are *A. flavus* and *A. parasiticus* (Marasas, Gelderblom, Shephard, & Vismer, 2008). Aflatoxin outbreaks are most severe in tropical and subtropical areas around the world, with temperate regions, such as the United States Midwest, also subject to aflatoxin contamination. Until 2004, the European perspective regarding aflatoxin contamination was confined only to imported foods. Several surveys conducted to detect AFs in feed samples in Europe led to only a small percentage of materials contaminated, with AFB1 concentrations above the regulatory limit (European Food Safety Authority, 2004). However, a big survey conducted by the European Food Safety Authority (EFSA) established the emerging issue of potential aflatoxin contamination of corn, almonds, and pistachios grown in areas of southern Europe due to the subtropical climate which had occurred in the recent years (European Food Safety Authority, 2007). A shift in traditional occurrence areas for aflatoxins is therefore to be expected due to the increasing average temperatures. In this respect, the Mediterranean zones have been identified as a climate change hotspot where extreme changes in temperature, CO_2 levels, and rainfall patterns are predicted. Regarding aflatoxins, their contamination events are more prevalent during times of high heat and drought, which may stress the host plant and thereby facilitate *A. flavus* infection (Marasas, Gelderblom, Shephard, & Vismer, 2008).

In the last 15 years several hot and dry seasons led to severe *A. flavus* infections of maize in several countries in Europe, including Italy, Romania, Serbia and Spain. As a result of the very dry conditions in those years, *A. flavus* became a significant problem as a dominant pathogen in maize (Battilani, Toscano, Van der Fels-Klerx, Moretti, Camardo Leggieri, M., et al., 2016). Battilani, Toscano, Van der Fels-Klerx, Moretti, Camardo Leggieri, M., et al. (2016) investigated the possibility of the emergence of aflatoxin B1 in cereals in the EU due to climate change. Based on the predictive model developed for *A. flavus* growth and AFB1 production linked to crop phenology data, the risk of aflatoxin contamination was assessed to have a chance of increasing in maize in the future, due to the climate change trend. In the +2 °C climate change scenario there is a clear increase in aflatoxin risk in areas such as central and southern Spain, the south of Italy, Greece, northern and southeastern Portugal, Bulgaria, Albania, Cyprus, and European Turkey as compared to the actual current temperature. In addition to the high aflatoxin risk in these southern European countries, low and medium aflatoxin risk at harvest in the four main maize producing countries (Romania, France, Hungary, and northeast Italy) was predicted. It will be therefore more important across Europe each year to: (1) improve harmonization of surveillance and monitoring of aflatoxins; (2) improve databases on the geographical distribution and prevention methods for aflatoxins; (3) develop models for the prediction of aflatoxin contamination in the new bio-geographical agricultural scenarios.

3. Fusarium head blight (FHB) of cereals: impact of climate change on the *Fusarium* species profile and deoxynivalenol contamination.

The fungal genus *Fusarium* consists of over 90 described species and likely many additional as yet undescribed but phylogenetically distinct species (Leslie & Summerell, 2006). Many of these species are plant pathogens and produce a range of mycotoxins, the most agriculturally important being trichothecenes on wheat and fumonisins on maize (Desjardins, 2006). They can be toxic also to plants and contribute to the pathogenesis of *Fusarium* on some crops (Desjardins, 2006). The trichothecenes of greatest concern are T-2 and HT-2 toxins, and deoxynivalenol (DON), nivalenol (NIV), and their acetyl-derivatives (Desjardins, 2006).

Fusarium Head Blight (FHB), caused by a complex of *Fusarium* species, is one of the most important fungal diseases associated with wheat and several other minor cereals. The effects of

FHB are related to yield and quality reduction of the infected kernels, due to the accumulation in the raw grain and in the processed wheat products of mycotoxins, especially DON, produced mainly by *F. graminearum* and *F. culmorum* (Desjardins, 2006). Levels of *Fusarium* mycotoxins in wheat kernels are positively correlated to FHB disease incidence and severity, as reported by several authors (Wenda-Piesik, Lemanczyk, Twaruzek, et al. 2017; Nielsen, Jensen, Nielsen et al., 2011; van der Fels-Klerx, de Rijk, Booij, et al., 2012).

Although agricultural practices play a key role in the prevalence of FHB pathogens, the predominance of *F. graminearum* or *F. culmorum* is determined, to a greater extent, by climatic factors, particularly temperature and moisture (Xu, Nicholson, Thomsett, Simpson, Cooke, et al., 2008), and can therefore dramatically change in different geographical areas. In particular, Europe, which is characterized by a wide range of climatic conditions from the southern (Mediterranean countries) to central and northern regions, shows dramatic differences in the species composition associated with FHB (Logrieco & Moretti, 2008). The species differ in their climatic distribution and in the optimum climatic conditions they require (Xu, Nicholson, Thomsett, Simpson, Cooke, et al., 2008). While *F. graminearum* is the main DON producer in central and southern Europe, in Nordic areas, *F. culmorum* has been reported as dominant, being common on cereal roots, stem base, and heads in all Scandinavian countries, including Finland (Logrieco & Moretti, 2008). However, a decline in the presence of *F. culmorum* and an increase in *F. graminearum* have been reported in the last decade in some areas of central and northern Europe (Nielsen LK, Jensen JD, & Nielsen GC, 2011). In the cooler, maritime climate of Britain and the Netherlands, the most common species involved in FHB in cereal grains was *F. culmorum*. However, at the beginning of 2000, *F. graminearum* became the most abundant *Fusarium* species on wheat in the Netherlands; a significant change in the situation had occurred compared with the early 1990s when *F. culmorum* was the dominating species in wheat (Logrieco, & Moretti, 2008). The same was observed in the UK, where *F. graminearum* has increased on wheat, while the previously common *F. culmorum* has become less important (Edwards, 2009). Morever, also in the cooler temperate climates of Europe areas such as Germany, where *F. culmorum* used to be the prevalent species, *F. graminearum* has become the dominant species in the last decade, because the higher temperatures favor its dominance in the FHB complex (Miedaner, Cumagun, & Chakraborty, 2008). Also, a significant increase in the frequency of *F. graminearum* was observed during the last decade in all regions of Poland, including the northern areas, as reported by Stępień & Chełkowski (2008). In general, FHB incidence is low or absent in the most southern regions of Italy and Spain; however, in the more northern regions of Italy, Spain, and Portugal, southern France, and the whole Balkan Peninsula, *F. graminearum* is reported to occur frequently on cereals at maturity, together with DON (Logrieco, & Moretti, 2008).

Several reports have tried to comprehend the possible shifting of *Fusarium* species involved in FHB in different geographic areas according to future environmental scenarios. The North European climate is predicted to become milder and more humid towards 2050 (Parikka, Hakala, & Tiilikkala, 2010). The subsequent climate change effects will therefore lead to a slight shift in composition of *Fusarium* flora in cereal grains, that would benefit *F. graminearum* (Parikka, Hakala, & Tiilikkala, 2010). On the other hand, Madgwick, West, & White (2011) studied the impact of climate change on wheat anthesis date concluding that FHB epidemics will be more severe, especially in southern England, because of an increase of *F. gramineraum* and the associated DON. A further study from the Netherlands evaluated the climate change effects projected by 2040. The study, revealed that the enhancing of wheat flowering and full maturation by 1-2 weeks in most of north western Europe could result in an increase of DON contamination, up to a factor of three, with an estimation of a mean DON concentration in the future scenario exceeding the EC limit of 1250 μg kg^{-1} for the presence of DON in unprocessed wheat in the whole area (van der Fels-Klerx, van Asselt, Madsen, & Olesen 2013). As comparison, is interesting to notice that a relevant study in China, carried out by Zhang, Halder, & White (2014), investigated the impacts on FHB on wheat in Central China, due to climate change, for the period 2020–2050. The study conclusions were that climate changes will increase the risk of serious FHB epidemics on winter wheat in central China by the middle of this century, with dramatic implications for food security due mainly to the high level of DON accumulation in the kernels.

In general, the information obtained from all investigations on the impacts of climate change on FHB should allow the definition of strategies for both governments and industry for reduction of the risk related to the more favorable conditions for FHB and mycotoxin contamination of grains. New wheat cultivars with higher tolerance and more effective fungicide treatments to control *Fusarium* species which cause FHB should be considered. Since both strategies could require many years to become effective, it is important to begin adapting to the impacts of climate change on crop disease soon. Such strategies for adaptation to impacts of climate change on FHB will contribute to sustainable wheat production and improved food safety and security.

4. Conclusions

The impact of climate change on *Aspergillus* infection of crops and FHB disease could result in a dramatic increase of both phenomena worldwide, with higher food safety risks for human and animals due to high levels of AFs and DON contamination in the end products. Moreover, the deep profile modifications of toxigenic *Fusarium* species occurring on kernels at maturity in different geographical areas of the world will cause the development of new mycotoxin risks in specific regions, due to the changed ability of given *Fusarium* species to colonize new environments. This will require a deeper knowledge of toxigenic *Fusarium* species genetic variability for a better understanding of the genetic mechanisms used for mycotoxin production, in order to have suitable strategic solutions for disease management.

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