



AN OVERVIEW STUDY ON THE INTERACTION BETWEEN CLIMATE CHANGES AND THE OCCURRENCE OF MYCOTOXINS

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Abstract. Climate change may have an effect on the occurrence of food safety risks at different paths of the food chain, from elementary production through to eating. There are multiple pathways through which climate related factors may influence on food safety including: changes in temperature and precipitation patterns, increased consequently of extreme weather conditions, and changes in contaminants transport pathways among others. Climate change may also affect economic portion related to food systems such as agriculture, animal production, global trade and human behavior which all effect on food safety. Available data recommended that slightly CO₂ concentrations and interactions with temperature and water activity may encourage growth of some mycotoxigenic species, especially below water stress. The available information on interacting conditions of water / temperature effects on optimum conditions for growth and mycotoxin production has been used to expect the impactation that +3 and +5 °C raises under water forbidden would have on growth /mycotoxin production by mycotoxigenic species. The era will prepare many challenges for toxicology scientists. This paper reviews the potential impacts of climate changes in food contamination and food safety and submitting adaptation strategies and research priorities to item food safety implications of climate change. The paper concludes that there is a need for international cooperation to better understand the changing food safety situation and emerging risks associated with climate change.

Keywords: Climate change; Mycotoxins contamination; Predictive methods; Fungi; temperature and water activity.

Introduction

Food safety has become a very vital point in the worldwide and the potential effects of climate change on yields and quality of food crops, including mycotoxins, is now receiving scientific attention, especially from a risk analysis perspective. Many staple crops (cereals, nuts and fruits) can be colonized and infected by fungi from the genera *Aspergillus*, *Fusarium* and *Penicillium* which can contaminate the edible parts with toxic secondary metabolites: mycotoxins. Mycotoxins are secondary metabolites produced by fungi, including *Penicillium*, *Aspergillus*, *Fusarium* and *Alternaria* [1]. These mycotoxins always contaminate foodstuffs and cereals, and they have become one of the larger concerns in human health. They can produce nephrotoxic, hepatotoxic, carcinogenic, mutagenic, teratogenic and immunosuppressive effects. Aflatoxin (AFB), ochratoxin (OTA), zearalenone (ZEA), deoxynivalenol (DON), fumonisin B1 (FB1) and T2 toxin are the main contaminants that have been researched extensively [2]. Climate change is expected to have a profound effect on our landscape worldwide. For some areas, climatic models have projected a marked decrease in summer precipitation and increases in temperature, which would result in concomitant drought stress series. The environment in which crops will be grown in the next 10–20 years may change markedly with atmospheric carbon dioxide concentrations expected to rise at the rate of $1.5 \text{ mol. year}^{-1}$. Because of this increase and that of other greenhouse gases, the global temperature is expected to rise at the rate of $0.03^{\circ}\text{C year}^{-1}$.

The present short review attempts to summarize attention about a specific in relationships between kinds of mycotoxin and climate changes and world prediction to prevent the prevalence of mycotoxin in field crops.

1. Climate Change, Mycotoxigenic Fungi and Effective on Food Security

Reducing contamination by mycotoxigenic fungi is important to food security wherever existing mycotoxigenic fungi could become extinct, mutated or attenuated [1]. Some fundamental styles are: (a) crops planted in novel regions can have few mycotoxigenic fungi; (b) is a progression to higher temperature mycotoxigenic fungi (e.g., *A. flavus*) in presently temperate regions; (c) In some regions wherever crops will no longer grow, and so, no mycotoxin drawback; finely (d) temperatures in 41°C and higher than wherever aflatoxigenic fungi are out of adaption by heat resistant and thermophilic fungi [2]. The production of mycotoxins by fungi in wide range of food crops is another necessary issue which contains a severe effect on food security. It's been noticeable that 25% of the globe food crops are tormented by mycotoxins [3]. Production of these compounds, for instance, on crops, is extremely vulnerable to environmental factors [e.g. temperature (Table 1) and available moisture (Table 2)]. However, the three most significant generation of mycotoxigenic fungi are *Aspergillus*, *Fusarium*, and *Penicillium*, producing the subsequent classes of mycotoxins: aflatoxin (*Aspergillus*), ochratoxin (*Aspergillus* and *Penicillium*), trichothecenes and fumonisins (*Fusarium*). Mycotoxin contamination of the food chain may be a food safety risk globally, resulting in human side effects as a result of it will cause mycotoxicosis, leading to acute or chronic disease symptoms (Fig.1) [4]. The mycotoxin hazard is often exacerbated by food insecurity because mycotoxin-contaminated food is consumed instead of discarded and malnutrition enhances the status to lower mycotoxin levels also the attack of toxigenic fungi on crops and products has the potential of making great risk [5]. Additionally, climate change is

scheme to negatively have an effect on food production as local temperature will increase by 2°C or higher than late 20th century levels, however some individual locations can have positive influence. A method primarily based models and regional statistical analysis showed negative impacts of temperature higher than 30–34 °C on crop yields depending on the crop and region [6]. Supported statistical crop models and climate projections for 2030 from 20 general deliberation models, the assembly of wheat in South Asia, rice in Southeast Asia, and maize in Southern Africa can suffer negative effect within the absence of adaptation [7]. Also, climate change may prevent the progress towards food security. Climate change will have a variety of direct and indirect effects on all four dimensions of food security: food availability, access, utilization, and stability [1, 3]. In other hands, the direct influences of global climate change on food availability can occur during of the food chain however are greatest for agriculture considering its climate sensitivity and important key in food provide. Indirect impacts of climate change on nutrition, health, and poverty are more complicated and extremely differentiated. The effect of global climate change on food systems are expected to be widespread, complex, geographically and temporally variable, and greatly influenced by economic conditions [8].

The totally effect of climate change on food safety and security is considered more complex and likely greater than the projected effect on agricultural outputs [6]. Increased hazard of drought-related water and food shortage causing malnutrition is schemes for Asia whereas diminished food production and food quality are projected for Central America [6]. Therefore, increased temperature and altered precipitation without carbon dioxide effects can contribute to raise international food costs by 2050 from 10–80%. Again, any negative impact of global climate change on world crop yields is expected to lead to will increase in world food prices and the proportion of population that is food insecure. Global climate change will alter stages and rates of pathogen development and modify host resistance and host-pathogen interactions [6, 9], and the two most important factors influencing on mycotoxigenic fungi are water availability or humidity and temperature [10]. Moreover, there is limited information on the influencing of upraised carbon dioxide on mycotoxigenic fungi especially in the field. Early in vitro studies have shown that mycotoxigenic fungi can bear concentrations of carbon dioxide which are significantly high from the concentration expected under climate change circulations [1]. Furthermore, fungal species growth and mycotoxin production react with other factors such as humidity, temperature, and nutrients [11]. Depending on the experimental of Samapundo and co- worker [12], findings 10% of CO₂ totally inhibited fumonisin B1 production by *Fusarium verticillioides*, but 40% of CO₂ is necessary to blocked fumonisin B1 production of *F. proliferatum* at 0.984 water activity (aw). Besides, modified atmosphere containing 20% carbon dioxide mostly prevented mold growth, while 20-60 % carbon dioxide significantly minimized mycotoxin production by *Fusarium*, *Aspergillus*, and *Penicillium* spp. [13]. The expected higher temperatures in the next decades will probably affect the spread of different mycotoxigenic fungal species and their growth, epidemiology, and mycotoxin production. *F. graminearum* favors the warm climate of southern Europe [14]. This reposition is possibly due to the higher optimum temperature range of *F. graminearum*. Temperature influences the fungal growth and aflatoxin production of *Aspergillus flavus* in maize [2, 11].

In some studies of current mycotoxigenic fungi and standard mycotoxins consider predominantly the impact of temperature and aw and some include carbon dioxide

levels [4]. However, there's no data on what will occur if these fungi cannot grow due to climate change [15]. Indeed, it is reported that temperatures reached 55.7 °C in Pakistan [4], which is inhibitory to the growth of *A. flavus*. On the other hand, heat waves or extreme temperature also can be detrimental to aflatoxin production. Furthermore, a study showed that aflatoxin production was optimum at 28-30 °C however production stopped at 37 °C because aflatoxin biogenesis was turned off [9]. Temperature, humidity, and relative humidity are the foremost necessary environmental condition factors affecting *Fusarium* blight development and deoxynivalenol (DON) accumulation [8, 13].

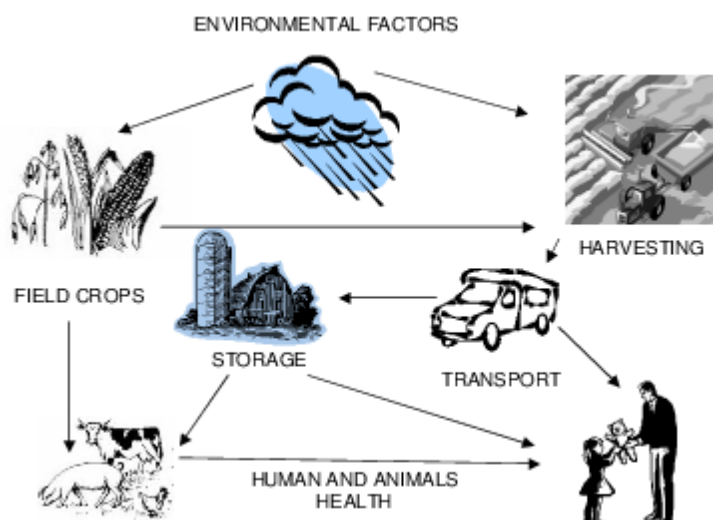


Fig. 1 Factors affecting mycotoxin occurrence in the food chain (Simion et al, 2011)

Table 1. Optimal temperature for mycotoxin production and growth (Sanchis & Magan, 2004).

Fungus species	Mycotoxins Alternuene, alternariol, Alternariol monomethyl ether	Tenuazonic acid	Aflatoxin	Fumonisin	Deoxynivalenol	Ochratoxin A	Growth
<i>Alternaria alternate</i>	25						23
<i>A. tenuissima</i>		20					
<i>Aspergillus flavus</i>			33				35
<i>Fusarium verticillioides</i> , <i>F. proliferatum</i>				15-30			30
<i>F. graminearum</i>					30		20-22
<i>F. culmorum</i>					26		20-25
<i>As. ochraceus</i>						25-30	30
<i>Penicillium verrucosum</i>						25	26

Table 2. Moisture limits for growth of *Aspergillus spp.* and *Penicillium spp.* on seeds of plant species (CAST, 2003).

Plant	Moisture content of grain (%)		
	<i>A. ochraceus</i>	<i>A. flavus</i>	<i>Penicillium spp.</i>
Starch cereal grains	15.5-16.0	17.0-18.0	16.5-20.0
Soybeans	14.5-15.0	17.0-17.5	17.0-20.0
Sunflower, safflower, peanuts and copra	9.0-9.5	10.0-10.5	10.0-15.0

2. Mycotoxigenic fungi and mycotoxins

Climate enjoin contamination could be a worthy mantra for crop producers. Drought years might take most of crop value within the case of aflatoxin problems. Mycotoxin contamination may be divided into that occurring (a) within the developing crop and (b) when maturation that corresponds around to pre- and post-harvest, respectively. Separating the contamination method allows improved assessment of the impact of varied climatic events on contamination [16]. The phases might embrace insect damage in the field or poor post-harvest handling. However, weather influences the two phases of contamination otherwise. Climate

change can impact on infection of crops by toxigenic fungi, the expansion of those fungi and also the production of mycotoxins. Mycotoxins are vital present substances created by toxigenic fungi that usually grow on variety of crops which cause adverse health outcomes once consumed by humans and animals. Similarity, mycotoxins have plagued humanity since the beginning of organized crop production [17] and possibly before. Once studied as a problem arising throughout the storage of commodities, it's currently clear that nearly all, if not all of mycotoxin problems originate in the standing crop as a results of the interaction between the crop plant, the mycotoxin-producing fungus and bio-physical factors.

- 1) **Aflatoxin:** One of the foremost toxic and carcinogenic threats in the human food provides could be a natural chemical referred to as "aflatoxin" that's created by a fungus called *Aspergillus*. This opportunist plant pathogen has the capability to grow on a large vary of foods and feeds (corn, peanuts, cotton seed, etc.). Rain, at or close to harvest, means unacceptable concentrations of aflatoxin in several crops in heat regions [19]. However, a good deal of variation has been determined. Semi-arid to arid and drought conditions in tropical countries are related to contamination: changes in climate could lead to acute aflatoxicosis and deaths from the consumption of poor crops that occur even in modern times [16]. Fortuitously, changes in climate could cause variation in aflatoxin risk that's a minimum of certain. Finally, the compositions of fungal communities established during the first phase greatly influence the second phase (e.g. storage) and influences of delayed harvest on contamination are most severe once crops are tormented by rain just before, or during harvest [19]. Some samples of the conditions effecting enhanced aflatoxins are as follows. Delayed harvest, late irrigation, rain and dew during heat periods were related to raise aflatoxin. Aflatoxin will increase were bigger on crops receiving over 50 mm of rain throughout boll gap [19]. Changing weather patterns will influence irrigation requirements, crop rotations, optimum crop timing, and contamination of many crops together with cottonseed. This may result from crop development occurring during heat and water deficit stress [20]. The amount of aflatoxigenic fungi related to crops and soils varies with climate. These fungi contend poorly under cool conditions and also the quantity of *A. flavus* in such areas (Minimum 20°C) is low compared to warmer regions (Minimum 25°C) wherever aflatoxin producers are common throughout air, soils, and crops [21]. Hence, a change in temperature towards these higher temperatures can tend to extend aflatoxin concentrations. Crops mature in warm climates have larger probability of infection by aflatoxin producers and in some regions, infection solely occurs once temperatures rise in association with drought [18, 21]. Aflatoxin creating by fungi is native to tropical, warm, arid, and semi-arid regions, changes in climate lead to large alterations in the amount of aflatoxin producing fungi [21, 22]. Moreover, the two major morphotypes of *A. flavus* (S and L strains) are characterized by culture characteristics. On average, S strains manufacture much larger quantities of aflatoxins, thus climatic factors influencing S strain incidence additionally affect average aflatoxin- producing ability [17]. Variation in S strain incidence over landscapes is related to climatic variations, as are annual cycles in the composition of aerial *A. flavus* communities [22]. Significantly, as climate warms and weather patterns become additional erratic, aflatoxin contamination could more prohibit the area over which crops productively may be grown [16].

- 2) ***Fusarium* toxins:** Species of the genera *Fusarium* are main response on the occurrence of many toxins in wares including *trichothecenes* (e.g. Deoxynivalenol and T 2-toxin), *fumonisin*, *fusarin C*, *moniliformin* and *zearalenone* [23]. The major important species in this relation are *Fusarium verticillioides*, *F. proliferatum* (portion Liseola); *F. sporotrichioides*, *F. poae* (portion Sporotrichiella *F. graminearum*, *F. culmorum*, *F. crookwellense* (portion discolor). These fungi are mostly best thought of as very close corporate with plants via important ways of their natural history carried in soil. Maize is grown from tropical to hot regions and throughout its range *F. verticillioides* is usually found as an endophyte. Also, families of the discolor group are found and *F. graminearum*, considered to be the more pathogens plant, head to predominate in the warmer temperate regions (periods of daytime temperatures of 25-28 °C) with *F. culmorum* more familiar in cold temperate regions. In wheat, Strains of *F. graminearum* produce either deoxynivalenol (DON) or nivalenol (NIV) and zearalenone (ZER) while *F. culmorum* produces only DON and ZER [23]. There are noticed that a kinds of warm European summers has seen the occurrence of the formerly predominant species, *F. culmorum*, fall to be replaced by *F. graminearum* [23]. Moreover, maize impacted by *F. verticillioides* was involved in many human and animal diseases in 20th century. Esophageal cancer of humans was attributed with eating of maize pollute with *F. verticillioides* in a region of South Africa [24]. The fumonisins are classifies in A, B, C, and P types, and FB1 is the most common and most toxic fumonisin. The members of the FB series have been most intensively surveys because of their toxicity and potential carcinogenicity. The raised levels of FB1 toxin found in moldy maize and maize-based food and animal feed [24]. Many research assort have studied the phytotoxicity of FB1. The fumonisins are grouped in A, B, C, and P series, and FB1 is the most commonly and more toxic fumonisin. In study by Doko and co-worker [25] conducted fumonisin counterparts in 26 maize genotypes grown in three European and two African countries, and found a positive correlation between high FAO maturity class of the genotype and fumonisin contamination [25]. The evidence of *F. verticillioides* and *F. proliferatum* is low in the maize growing countries of central and northern Europe [26]. Van Asselt et al. proposed research from mycotoxin observation in silage maize from the Netherlands, Belgium, Germany, and France during the period 2003–2007 [26]. High fumonisin concentrations were found in 2003 and 2007, detecting of suitable conditions for infection by *F. verticillioides* and *F. proliferatum* in Western Europe in two of five recent years. The mean fumonisin contents of positive samples were 1.55 µg g⁻¹ in 2003 and 0.84 µg g⁻¹ in 2007, showing that west European maize crops may contain fumonisin above the EU maximum level of 2.0 µg g⁻¹ [26, 27]. Coakley et al. finding that the influence of climate change may rely on the global location. The averages of pathogen reproductive may change and the physiology of host-plant interaction may be altered. The impaction of climate change on plant disease may be less important than changes in land-use patterns, transgenic technologies, and availability of chemical pesticides [28].
- 3) ***Ochratoxin A:*** Ochratoxins are tiny series of chemically related toxic fungal metabolites (mycotoxins) created by certain molds of the genera *Aspergillus* and *Penicillium* growing on a large range of raw food commodities (**Fig. 2**).

Some Ochratoxins are potent toxins and their presence in food is undesirable. In addition, *Ochratoxin A* (OTA) contaminates an excellent kind of foodstuffs, like grapes, coffee, cocoa, and baby food. It is of nice concern for human health. International organizations worldwide such as WHO and FAO have continuously tried to determine the tolerable dose of OTA. However, as a result of inconsistent evaluation standards, the limit of the OTA dose is completely different. In 1991, the Nordic Expert Group on Food Safety proposed the tolerable daily intake (TDI) at 5 ng/kg, bw/day. In 2006, the European Food Authority set the provisional tolerable weekly intake (PTWI) at 120 ng/kg, bw/week. Nowadays, Surveys in Europe have used a similar trend to investigate the regions in Europe which may be hot spots for *Aspergillus carbonarius* contamination of wine grapes and the European regions that at more risky for contamination with OTA [29]. Furthermore, this study immersed geostatistics to analyze the weather patterns over a period of three years (2001-2003). From the results of authors were shows that the highest contamination with black aspergilli was just before to harvest. At this phase the Special variability was considerably associated with latitude and longitude, showing a positive west–east and north–south regression. Predictive maps showed that the best incidence in Europe of *A. carbonarius* was possible to be in Greece, southern France and southern Italy since parts of Greece are thought of to be a hot spot for OTA in red wine this might have implications for survival, growth and raised contamination with this mycotoxin below modified climatic conditions. Apparently, the thermo-wetness maps for the three years showed an identical trend to that for isolation of the mycotoxigenic fungi and so correlate well with OTA contamination of wines in these regions, particularly red wine. However, ecological information on *A. carbonarius* has recommended that conditions that favor growth and resulting high incidence are totally different from those which are optimum for OTA production. Thus, OTA production happens in the range 0.92-0.99 aw with most accumulation at 0.95-0.99 aw depending on isolates [30, 31]. Optimum temperature for OTA production is at 20°C, followed by 15°C and markedly lowers at 30-37 °C. In distinction, maximum growth happens at near 30°C.

- 4) ***Aspergillus and Penicillium***: A number of *Aspergillus* and *Penicillium* species are xerophilic and able to thrive in low moisture in food products that represent environmentally stressed conditions for several alternative fungi and bacteria. This physiological malleability provides these species a vital ecological advantage that permits them to successfully colonize a spread of various food matrices. As a result, many staple crops (cereals, nuts, fruits) may be settled and infected by *Aspergillus*, *Penicillium* and *Fusarium* species which may then contaminate the edible parts with toxic secondary metabolites, the supposed mycotoxins. Although *Fusarium* species are not xerophiles, they can usually colonize crops pre-harvest and turn out mycotoxins when they are below relative water and temperature stress (0.90–0.93 aw; 30°C) for these species. These necessary toxigenic fungi occupy an ambiguous ecological position. It is sure that many, maybe most of the species of those genera are primarily soil fungi however the foremost vital species, from the purpose of view of mycotoxin contamination, seem to be real associates of plants. Of the host of toxic compounds together produced by this group, the three most vital are the aflatoxins (AF), Ochratoxin A (OTA) and patulin. Aflatoxin produced by *Aspergillus flavus*, *A. parasiticus*, *A. nomius* and *A. wentii*, is a genotoxic substance, is also a potent acute toxin, and is

widely distributed however associated particularly with maize, groundnuts, tree nuts, figs, dates and certain oil seeds like cottonseed. Aflatoxin contamination of susceptible crops in some hot dry regions of the American South-West has made it economically infeasible to grow these crops in the region [32]. Therefore, the producing fungi are cosmopolitan from the tropics through the low latitude temperate zone however will occur nearly anywhere in food systems. There does not seem to be one mode of infection of the host plant however high toxin levels tend to be related with some kind of damage or stress of the host. In Maize, attack of the cob by numerous caterpillars, head blight (caused by *Fusarium spp.*) and drought are all reportable to stimulate AF accumulation. In groundnut, infection takes place during flowering however, usually, robust development of the fungus and considerable AF contamination is seen when drought conditions throughout crop development. In pistachio it may be that mechanical delay caused by premature splitting of the hull and navel orange worm attack are necessary contributory factors leading to late infection of the seed however it is clear there is infection of un-split fruit [32, 33]. In cottonseed, a high background contamination is exacerbated by wet weather when bole opening [19]. It has been prompt that a general warming trend can each increase insect pest numbers and their range [33] thus where mycotoxin contamination is increased by insect pest activity one would predict a correlation between warming and contamination. The impact of global climate change on plants tailored to a semi-arid climate, like pistachio, is unclear. There are reports that periods of upper than average temperatures and reduced annual rainfall have already been practiced in Kerman Province in Iran and raised rates of nut deformity and increased levels of aflatoxin contamination has been recorded [34]. Plant stress does not appear to be a very important factor in these cases. Patulin is simply significant in pomaceous fruit and juices and ciders made of them, a fact that reflects the close association of the producing fungus, *Penicillium expansum*, to apples and pears [35]. OTA is related to varied seed crops, including some nuts, and grapes and, consequently, in beverages like wine, beer and coffee.

3. Climate change impacts on mycotoxin production

The life cycle of all microorganisms, as well as mycotoxigenic molds, depends on two main factors: water availability and temperature [36]. These factors act to influence a series of parameters including germination, growth, sporulation, and mycotoxin production. In general, there is a temperature vary within that fungi perform best. Therefore, increasing average temperatures could alter varies at which fungi are ready to compete. As concentrations of methane, carbon dioxide, nitrous oxide, and chlorofluorocarbons in the atmosphere increase, therefore can incidences of environmental warming, higher precipitation, or drought [1]. These extreme climatic conditions can have wide-ranging impacts, depending on world region and mycotoxin systems [37]. Also, many authors have reviewed some aspects of the impact that global climate change might have on plant breeding, plant diseases, and mycotoxins in Europe, Australia, and Africa [1, 5 and 37]. There are some expected effects of temperature increase and water availability on each fungal growth rates and on the assembly of some of the foremost relevant mycotoxins: *Alternaria* toxins, *fumonisin*s, *trichothecenes*, *Ochratoxin A*, *aflatoxin B1*, and patulin. However, these predictions do not take the attainable additional

impact of carbon dioxide into account [11]. Typically, high concentrations of mycotoxins in grains rely on the amount of rainy days and days with relative humidity higher than 75%, however there is a decrease in mycotoxin concentrations at temperatures below 12 or above 32 °C [38]. *Aspergillus flavus* and *A. parasiticus*, the most aflatoxin producers, are xerophilic fungi that thrive below higher temperatures and lower rainfall. For example, during the hot and dry episodes in northern Italy in 2003, *A. flavus* was ready to actively colonize the ripening maize, a key crop, by outcompeted a lot of common *Fusarium* species [39]. This led to strange increase in *Afla* B1 contamination in Europe. Fumonisin prevalence is joined to drought stress. Additionally, Dry season maize in South and eastern Africa could contain high levels of this toxin, although the maize seems to be of excellent quality. Fumonsins are diminished in northern temperate zones with cooler climates. High temperatures favor the growth of the fumonisin producer *Fusarium verticillioides*, which means that a warming trend would cause larger domination of the fungus compared to different maize-borne *Fusarium* species [2]. Consequentially, global climate change is predicted to extend the biomass of crops and various host plants will further increase substance production. Water availability is expected to be altered by global climate change, and a few areas can experience drought whereas others experience more precipitation. The consequences of humidity on mycotoxin production in crops are less easy than those for temperature [1, 5]. Patterson et al. have recommended that just as in the situation where global climate change can lead to a rise in total mycotoxins because a lot of crops are produced within a region, conversely there would be a decrease in total mycotoxins because fewer crops are made within a region [37]. High temperatures and drought are expected to minimize water availability and consequently crop productivity in the south of Europe. Daily precipitation is predicted to increase in northern Europe. In southern and south-eastern Europe, such as Portugal, Spain, southern France, Italy, Slovenia, Greece, Malta, Cyprus, Bulgaria, and Romania, a rise of 4-5°C is expected and water availability is predicted to be reduced, particularly in the summer [4].

4. Predicting techniques in climate change

The presence of mycotoxins in food and feedstuffs can be checked by fast and simple methods, employed as rapid screening tools, and with sophisticated analytical methods useful for identification and quantification of the amount of each toxin. A detection method should be sensitive, robust, reproducible, and applicable to a wide range of compounds. Therefore, predicting global climate change is a fuzzy science, presently there are no novel-based overthrows of the effect of global climate change on food safety systems. Predictive models are currently being developed (along with alternative tools like operational oceanographic, meteorological, and remote sensing data) by the marine sector for the prediction of harmful algal blooms [40]. These tools may be utilized by other sectors to predict the probability of global climate change on ecological systems and emerging food hazards, animal and plant health risks. The utilization of mathematical models in microbial ecology is an emerging field, and though not however applied to global climate change, this is a promising new direction for food safety issues [41]. Predictions rely on the standard and amount of obtainable data; therefore, international collaboration is essential to confirm that applicable information is collected and good models are developed. However, the impacts of climate change might manifest themselves slowly and therefore the manifestations

are also complicated and extremely uncertain. Consequently, this makes climate change difficult to manage. Also, the effect of climate change on agricultural systems will be profound, although with variations within each system when the global perspective is considered. However, Miraglia et al. (2009) and Van Asselt et al. (2012) are started to title some of the point issues in relation to mycotoxins. Surprisingly, it is not clear whether disease severity is enhanced or diminished. For example, there are no data on the effects of CO₂ on the development of rice diseases regardless of the energy dependence of the global population on this crop and this stratifies for mycotoxins in rice. Furthermore, the potential use of the geographical emerging mycotoxin identification system model has been tested across Europe to examine the effects of changes in temperature (+2 °C) and rainfall (+3mm) on heading date and cereal productivity areas [26]. A similar approach to that used for DONCAST was developed to predict fumonisin contamination, taking climatic information relevant to the growing period into account. Changes in temperature and the amount of rain post-silking were used to predict the risk of fumonisins in maize and genetically modified maize [26, 43].

5. Mycotoxin legislation and climate change.

Climate change is predicted to raise the evidence and many of pests and diseases in crops, and can have a considerable influence on mycotoxins and their regulation [44]. In 2012, five notifications of aflatoxin M₁ in milk at levels upper the maximum level of 0.05 ppb mandatory by EU legislation. All were referring to an increased spread of aflatoxins in maize for animal feed from southeast Europe [45]. Additionally, the germination season of maize in that area had been observed by a very severe drought, making the crop weakness to infection by *Aspergillus flavus* and *A. parasiticus* and resulting in increased prevalence of aflatoxins [45]. In the EU, hazard of aflatoxin contamination in maize is expected to be raised in some southern European countries, and low to medium in the four main maize producing countries (Romania, France, Hungary, and northeast Italy) in a +2 °C climate change, whilst in a +5 °C scenario, aflatoxin levels are expected to be lower but risks are predicted to be broader and boost towards northern EU countries [46]. In a climate change conditions, a rigid control system will have to be used not only to imported food and feedstuffs but also to national agricultural commodities susceptible to contamination by aflatoxins. In more scientific views from December 2014 on the risks for human and animal health related to the presence of modulated forms of the *Fusarium* toxins *zearalenone*, *nivalenol*, *T-2* and *HT-2* toxins and *fumonisins* [47]. Mycotoxin regulations may have an effect not only on international trade of food and feed product but also on food safety in developing countries in a climate change scenario, as demand for agricultural products is evaluated to increase by about 50% by 2030 as the world population increases [48]. Some approaches used in mycology are not conducive to accurate assessments of disease severity in crops, including mycotoxin problems. The apparently straight-forward task of quantifying fungi is problematic and especially where colony forming units (cfu) are employed. The fungi are isolated using ways which may oust relevant fungi (e.g. endophytic, non sporulating fungi, etc.). When analysing collected fungi for particular mycotoxins it is impossible to state that the fungus does not produce the mycotoxin, only that it was not investigate below the conditions used. The best mycotoxin analytical methods will be required, and the use of PCR in all forms will need to be improved for detecting specific fungi and mycotoxin pathway genes [1, 2 and 48]. There

will be a requirement for much better methods when climate change becomes much more generally accepted as a problem in food production. Mass spectroscopy may have advantages in this regard [1]. Paterson and Lima (2011) recommended an approach identification test for mycotoxigenic fungi which may assist in determining those fungi which are the true producers in commodities. It is proposed that fungi are examined to an easily recognized character and then analysed for the specific mycotoxin of interest, together with undertaking PCR for the metabolic pathway genes of same mycotoxin. Finally, more information is required on how mycotoxins affect competitors within the food and crop systems(34).

Conclusion

This review has focused on the available information which may be spread to fungal generation which is known to produce mycotoxins on some key food products which are relevant to both developing and developed countries. Paterson & Lima (2010) recommend that main hazard in developed countries will be in temperate climates. This is depending on temperatures rising to >30 °C, which would be proposing to aflatoxin production and represent a considerable risk. They also have recommended that in cooler climates mycotoxins such as *patulin* and *ochratoxin A* may become more important as warmer climatic conditions would be conducive to *Penicillium expansum* and *P. verrucosum* inhibition. Climate-change factors will have adapted effect on both growth and relative mycotoxin production. It may be useful to state and very generally; that the biggest hazard in regard to mycotoxins from climate change will be spread in developed countries with temperate climates (e.g. parts of Europe and the United States of America, etc.). The climate of these regions will become warmer revealing temperatures of 33 °C. This may be the case with recent crops, accordingly if recognized aflatoxin plants (e.g. peanuts, maize) are mature increasingly to achieve the new conditions. The fact that these are the most dangerous mycotoxins adds to the increase in risk compared to what may occur in other climatic regions. Hence, from a position where aflatoxins are not a special problem from crops, In other term, aflatoxins may not be of any significantly greater concern than already found in countries with very cold climates (e.g. Norway, Canada, and Russia) where even global warming will not result in temperatures for optimal *A. flavus*, etc. growth. Although if the temperature does not become greatly higher and drought conditions become more frequent, then these may convert aflatoxin contamination, Common *Penicillium*/*Aspergillus* toxins such as *patulin* and *ochratoxin A* may become less important in the currently temperate climates as the temperature range becomes too high for these fungi. However, in already cold climates *patulin* and *Ochratoxin A* may become more problematic as their temperatures become warmer. *Fusarium* toxins at approximately 25°C, however these may not be such a problem where the temperature becomes high. Finely, we believe that weather extremes are clearly affecting fungal profiles, and consequently mycotoxin patterns, on a worldwide scale and global trade makes mycotoxin prediction even more difficult than it currently is an integrated systems approach would be necessary to warrant the accuracy of predictions. The first steps towards preventing the negative effects of these harmful substances are the implementation of good agricultural practices and proper storage conditions.

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