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Luis M. Botana, María J. Sainz (Eds.)

CLIMATE CHANGE AND MYCOTOXINS

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Climate Change and Mycotoxins

Edited by
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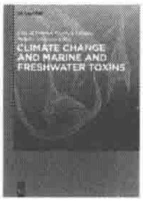

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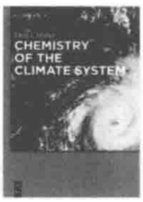

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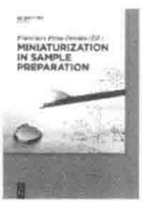

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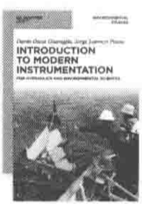

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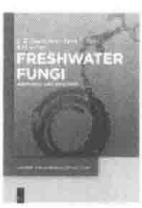

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Preface

Climate change is expected to strongly affect agricultural productivity, food safety, and food security worldwide in the coming decades, due to higher temperatures, changes in water supply and availability, year-to-year climate variability, and extreme weather events. The impact on food and feed crops is expected to manifest not only in changes to plant physiology, yield, and quality, but also in incidence and severity of pests and diseases. Of particular concern are the potential changes in geographical distribution, natural inoculum, activity, and biological fitness of some of those fungal species which cause disease in staple food crops, particularly cereals, or grow saprophytically on stored plant products and produce mycotoxins.

Mycotoxins are secondary metabolites produced by filamentous fungi either pre- or postharvest and which can contaminate agricultural food and feed products and have detrimental effects on human and animal health. Although awareness of the fact that mycotoxins are ubiquitous in food and feed products is not very high, they are deeply ingrained in human culture, as their presence has been associated with deaths and serious feed and food poisoning throughout history. Those from *Claviceps* have even been an inspiration to artists, for example in paintings (e.g. by Peter Brueghel) and sculptures.

Nowadays, more than 100 countries have regulations specifying maximum tolerable levels for the most toxic and/or abundant mycotoxins, mainly in human food. Criteria for limits have not been harmonized worldwide, however. Much of the research on mycotoxins, including recent research on the effects of climate change on mycotoxins, has focused on the *Aspergillus*, *Fusarium*, and *Penicillium* species, as they are the major mycotoxin-producing fungi in field crops and stored products in the world.

When we decided to edit a book on climate change and mycotoxins, we were aware that, although it is relatively easy to identify climate change from the study of climatological records and the development of predictive models, it is not so easy to clearly define a link between climate change and expected mycotoxin risks in the different geographical zones of the world. In this book, the authors wrote outstanding chapters on the subject by reviewing the effects of changes in temperature, water availability, and CO_2 on the biodiversity, plasticity, occurrence, and mycotoxin profile of the most prevalent mycotoxigenic fungi on cereals in different regions, as there is no historical record to compare the amounts of toxins now and a century or more ago. The book provides information on the trends in mycotoxin occurrence in agricultural commodities over the last ten years. Toxins have been discovered by modern science, and therefore their presence, structure, or levels in food have only been known recently. The science of mycotoxins has significantly advanced in recent years as a result of the implementation of sensitive analytical detection technology, such as mass spectrometry, and the availability of the first certified standards; but improved standardized multitoxin detection analysis and further certified reference materials will have to be developed to support current and future mycotoxin regulation for the protection of human and animal health. They will also be essential to track any shift in the mycotoxin levels within the food chain worldwide in a climate change scenario.

This book intends to highlight the importance of the study of climate change impacts on mycotoxigenic fungi and their mycotoxins in food and feed crops in order to guarantee safe and sufficient food and feed in the future. The book is thus suitable for mycologists, mycotoxicologists, pathologists, epidemiologists, toxicologists, physicians, veterinarians, nutritionists, the food and feed industries, legislators, analytical chemists, microbiologists, biologists, or students of these fields.

As always, a book of this kind is unthinkable without the valuable work of the authors of the individual chapters. We wish to thank them, not only for their time, effort, and generosity in contributing their experience and expertise to this book, but also for their commitment to a difficult project, as is indeed the effect of climate change on food security.

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1 Climate change and plant diseases caused by mycotoxigenic fungi: implications for food security

1.1 Introduction

The contribution of Working Group I to the International Panel on Climate Change (IPCC) 5th Assessment Report (AR5) reaffirmed that the warming of the climate system is unequivocal and the observed changes are unprecedented over decades to millennia. Compared to the 4th Assessment Report (AR4), improved climate models and longer and more detailed observations showed that human influence on the climate system is clearly indicated by increasing greenhouse gas concentrations in the atmosphere and observed global warming. The atmospheric concentration of carbon dioxide (CO_2) of 391 ppm in 2011 has increased by 40 % since pre-industrial times due to emissions from fossil fuel combustion and changes in land use. The total change in energy fluxes caused by natural and anthropogenic drivers for 2011 relative to 1750 (radiative forcing) is positive, leading to energy uptake by the climate system with the largest contribution by CO_2 [1].

Representative Concentration Pathways (RCP), a new set of climate change scenarios, were identified by their approximate total radiative forcing (watts (W) per m^2) in the year 2100 relative to 1750: mitigation scenario with very low radiative forcing level (RCP2.6), two stabilization scenarios (RCP 4.5 and 6), and very high greenhouse emission scenario (RCP8.5). Climate model simulations make high confidence projections that the global temperature changes will likely exceed 1.5 °C at the end of the 21st century, relative to 1850–1990 for all RCP scenarios except RCP2.6 with 1 °C mean change. The global mean surface temperature change from 2016–2035 relative to 1986–2005 will likely be in the range of 0.3–0.7 °C (medium confidence). As the mean global temperature increases, it is virtually certain (99–100 % probability) that more frequent hot and fewer cold extremes in temperature will occur and that heat waves will very likely (90–100 % probability) occur with higher frequency and duration [1].

Changes in the global water cycle in response to global warming in the 21st century will not be uniform. The contrast between wet/dry regions and seasons will increase except for some regions. Extreme precipitation over most of the mid-latitude land masses and wet tropical regions will very likely become more intense and frequent at the end of the 21st century. In many mid-latitude and subtropical dry regions, mean precipitation will likely (66–100 % probability) decrease. Due to the increase in atmospheric moisture, the variability in El-Niño-Southern Oscillation (ENSO)-related precipitation in regional scales and monsoon precipitation will likely intensify [1].

The contribution of Working Group II (WG II) to IPCC AR5 assessed a substantially larger knowledge base of relevant scientific, technical and socioeconomic literature compared to past reports. This facilitated a comprehensive assessment of impacts, adaptation, and vulnerability of climate change risks in human and natural systems. WG II AR5 found that a high likelihood that all aspects of food security will potentially be affected by climate change, from food production to food access, utilization, and price stability [2].

Climate change poses a considerable challenge to food security as the global demand for food will increase to feed 9.2 billion people in 2050 [3, 4]. Without adaptation a negative impact of climate change on food production is projected for ≥ 2 °C temperature increase above late 20th century levels for wheat, rice, and maize in tropical and temperate areas, but impacts will vary across crops, regions, and adaptation scenarios [2]. Expanded geographic ranges and altered dynamics of insect pests and diseases due to climate change can exacerbate the reductions in crop yields [5–7]. Plant disease is a major constraint in food production, as direct yield losses due to pathogens cause 16 % overall loss in agricultural productivity [8], but the indirect harmful effects on food quality and safety are very serious in many crops and environments worldwide [9].

This chapter aims to discuss the effects of climate change on mycotoxigenic fungi on the three major food crops vital to food security such as wheat, rice, and maize. Maize, wheat, and rice provide 30 % of the food calories for 4.5 billion people in 100 developing countries [10]. Mycotoxin contamination has become one of the most important and challenging problems facing plant pathologists today [11, 12]. For example, in Fusarium head blight of wheat, environmental conditions such as rainfall and temperature are the dominant factor associated with disease infection [13, 14]. Knowledge of population genetics and epidemiology are the keys to Fusarium head blight management [15, 16]. The effects of climate change variables on epidemics in major food crops caused by pre- and post-harvest mycotoxigenic fungi will be analyzed in terms of plant disease epidemiology and population genetics.

1.1.1 Mycotoxigenic fungi and food security

Significant crop losses in major food crops due to mycotoxigenic fungi remain a major hindrance in achieving food security. Fusarium head blight of wheat and barley is considered a re-emerging disease due to historical and recent epidemics worldwide [17, 18]. In the USA, a direct economic loss of US $ 2.491 billion was observed due to Fusarium head blight from 1993–2001 [19]. In 2003, another Fusarium head blight epidemic in southeastern USA caused a pre-milling economic loss of over US $ 13.6 million [20].

The production of mycotoxins by fungi in major food crops is another important factor which has a severe impact on food security. It has been estimated that 25 % of the world food crops are affected by mycotoxins [21]. The three most important genera of mycotoxigenic fungi are *Aspergillus*, *Fusarium*, and *Penicillium*, producing the following classes of mycotoxins: aflatoxin (*Aspergillus*), ochratoxin (*Aspergillus* and *Penicillium*), trichothecenes and fumonisins (*Fusarium*) [22]. The potential annual cost of food and feed contamination in the US with aflatoxins, fumonisins, and deoxynivalenol (DON) was estimated at US $ 946 million [23]. Annual average losses of US $ 163 million to aflatoxins and US $ 40 million to fumonisins were estimated for US maize [24]. In 2010, 10 % of the Kenyan maize harvest was contaminated with aflatoxins resulting in an economic loss of approximately US $ 100 million [25]. In 2012, Aspergillus and Fusarium ear rot caused yield losses of 94.7 and 80.8 million bushels in top corn producing US states and Ontario, Canada with 18 % loss from mycotoxin contamination [26].

Mycotoxin contamination of the food chain is a food safety risk globally, leading to human health threats because it can cause mycotoxicosis, resulting in acute or chronic disease episodes [22]. The mycotoxin hazard can be exacerbated by food insecurity because mycotoxin-contaminated food can be consumed rather than discarded and malnutrition enhances the susceptibility to lower mycotoxin levels [27]. A fitting example of the adverse effect of mycotoxin contamination on human health is the 2004 aflatoxin contamination in Kenya where 125 people died [28]. In Thailand, Indonesia, and the Philippines the total annual social cost of aflatoxins in maize was AUS $ 319 million in 1991 [29].

1.1.2 Climate change and food security

Food production is an important aspect of food security, and it needs to be increased by 60 % by 2050 under current food consumption trends, assuming no significant reduction in food waste [30]. Climate change is projected to negatively affect food production as local temperature increases by 2 °C or more above late 20th century levels, but some individual locations will have positive impact (medium confidence). Process-based models and regional statistical analysis showed negative impacts of temperature above 30–34 °C on crop yields depending on the crop and region [5]. Based on statistical crop models and climate projections for 2030 from 20 general circulation models, the production of wheat in South Asia, rice in Southeast Asia, and maize in Southern Africa will suffer negative impact in the absence of adaptation [31].

Climate change could slow down the progress towards food security. Climate change can have a range of direct and indirect effects on all four dimensions of food security: food availability, access, utilization, and stability [2, 32]. The direct impacts of climate change on food availability will occur throughout the food chain but will be greatest for agriculture considering its climate sensitivity and key role in food supply.

Indirect impacts of climate change on nutrition, health, livelihoods, and poverty will be more complex and highly differentiated. The impacts of climate change on food systems are expected to be widespread, complex, geographically and temporally variable, and greatly influenced by socio-economic conditions [33]. The overall impact of climate change on food security is considered more complex and potentially greater than the projected impact on agricultural productivity [5]. Food security is diminished when food systems are stressed. Climate change effects on the food system will vary between regions [34] and food inequalities will increase from local to global levels due to spatial variation in climate change effects [32].

The impacts of climate change on food security will be worst in countries already suffering high levels of hunger [32]. Sub-Saharan Africa had the highest proportion of food insecure people with an estimated regional average of 20 % of the population is undernourished in 2010–2012, while the largest number is in South Asia with 300 million undernourished [30]. The risks of food insecurity and breakdown of food systems are linked to global warming, drought, flooding, and variable and extreme precipitation particularly for poorer populations in urban and rural settings of Africa, Asia, and Central and South America. Based on IPCC WG II AR5, reduced crop productivity associated with heat and drought stress will have strong adverse effects on food security while increased pest and disease damage and flood impacts on food system are projected in Africa. Increased risk of drought-related water and food shortage causing malnutrition is projected for Asia whereas decreased food production and food quality are projected for Central America [2].

Climate change can destabilize the food system resulting in high and volatile food prices [4, 35]. Increased temperature and altered precipitation without CO_2 effects will contribute to increased global food prices by 2050 from 3–84 % (medium confidence). Any negative impact of climate change on global crop yields is expected to lead to increases in international food prices and the proportion of population which is food-insecure [5].

1.1.3 Climate change effects on plant diseases and food security

Food security is defined as the access to sufficient, safe, and nutritious food for dietary needs and food preferences [36]. One major factor contributing to low productivity is crop loss due to plant health problems, which is poorly recognized as an important driver of food security [37]. Nevertheless, plant diseases have enormous impacts on food security as exemplified by the Irish potato famine in 1845 due to the potato late blight epidemic caused by *Phytophthora infestans*, which resulted in the death of 1 million people and the emigration of 1.5 million to mainland US [38]. A further example is the great Bengal famine of 1943 due to the rice brown spot epidemic caused by *Helminthosporium oryzae* in India, resulting in the starvation of 2 million people [39]. During these two plant disease epidemics, the weather conditions were very con-